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MID-PARENT ADVANTAGE AND HETEROBELTIOSIS IN F_1 HYBRIDS FROM CROSSES OF WINTER AND SPRING WHEAT

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SUMMARY

The magnitude of heterosis over mid-parent and better-parent for yield and yield contributing characters were calculated in 7 x 7 diallel set of four winter (Druchamp, Fanjai 2, Wei 132 and Zhong 65) and three spring wheat (HD 2687, UP 2425 and PBW 373) for two years. For grain yield 19 crosses showed heterobeltiosis as well as mid-parent heterosis in both the years. HD 2687 among spring and Zhong65 among winter adjudged best parents on the basis of high heterotic values for grain yield and its attributes. Winter x spring and winter x winter wheat crosses were found to be the potential crosses for high heterosis for grain yield per plant. On the contrary spring x spring and spring x winter were found to be the potential crosses for high heterosis for biological weight per plant. On the basis of high heterosis and stable performance Zhong 65/ HD 2687 and Zhong 65/ UP 2425 were the best winter x spring crosses followed by Druchamp/ Wei 132 a winter x winter cross. Heterosis for biological yield per plant, thousand grain weight, grain weight per ear, effective tillers per plant were independently associated with grain yield per plant in spring x winter as well as in winter x spring wheat crosses, therefore, heterosis for yield was through component heterosis in these crosses. The present study suggests ample scope for exploitation of heterosis for commercial production of hybrid wheat by involving winter wheat gene pool for getting further break through in wheat yields.

Key words: Heterosis, heterobeltiosis, yield component, diallel, winter wheat

INTRODUCTION

Utilization of heterosis through hybrid wheat is an attractive approach than the conventional plant breeding methods, which in general show lower yield gain (approximately one percent per year). Many studies have shown that F_1 hybrid wheat can yield significantly more than the mean of its parents (Walton, 1971; Wilson and Driscoll, 1983). Pickett (1993) compiled the reports of heterosis in winter as well as in spring wheat. Maximum high parent heterosis ranged from 24.7 to 76.0 % in winter wheat and 3.9 to 88.0 % in spring wheat. Two main ways of expressing hybrid advantage have been used. First, it has been expressed as mid-parent advantage, the increase in yield or other character of the hybrid compared to the mean of the parents, and is an estimate of the mean directional dominance (potence) of the alleles for a given character. Second, it has been expressed as heterobeltiosis, the increase in yield or other character of the hybrid compared to that of the better-parent for the character. Heterobeltiosis implies that there is dispersion for dominant alleles between the parents which may increase or decrease the character.

In a self-pollinated crop like wheat, the utilization of heterosis depends mainly upon the direction and magnitude of heterosis. Further, the study of heterosis provides useful information about combining ability of parents and their usefulness in breeding programs (Sharma *et al.*, 1986). Estimation of heterosis over better-parent (heterobeltiosis) may be useful in identifying true heterotic cross combinations. Zhang *et al.* (1985) have shown that heterosis in wheat is positively correlated with the genetic diversity of the parents. The winter and spring wheat gene pools are also considered as genetically diverse due to geographical as well as agroecological isolation. The magnitude of the heterotic effect is influenced by the performance of both the parents and hybrids. Given that these relative performances will differ between environments, the magnitude of heterosis may also show similar variation. The comprehensive evaluation of heterosis, therefore, involves estimation of parent and hybrid differences in a range of environments. Demonstration of stability of hybrid superiority across environments together with a manageable hybrid seed production system is fundamental requirement for the establishment of a hybrid wheat breeding program.

The present study has therefore, been carried out to estimate the heterosis (%) over mid-parent (MP), and better-parent (BP) for quantitative characters present in Spring x Spring, Spring x Winter, Winter x Spring and Winter x Winter crosses under two environments, to determine the probable direction among these groups for getting high heterosis and to identify parental lines that could be used for commercial production of hybrid wheat as well as isolation of pure lines, among the progenies of heterotic F_1 for further amelioration of grain yield in bread wheat.

MATERIALS AND METHODS

Four winter wheats *viz.,* Druchamp, Fanjai 2, Wei 132 and Zhong 65 and three spring wheat *viz.,* HD 2687, UP 2425 and PBW 373 were crossed in all possible combinations including reciprocals. Among the four winter wheat 'Druchamp' was originated in France and 'Zhong 65' in China whereas, the origin of 'Fanjai 2' and 'Wei 132' could not be traced; however, all four were received from CIMMYT in form of nursery stock. These were selected based on their suitability/adaptability to Indian conditions. The three spring wheat cultivars ('HD 2687', 'UP 2425' and 'PBW 373') were the leading high yielding cultivars of India. The 7 parents and 42 F_1's were grown in a randomized block design with three replications under normal sown irrigated condition for two years (24th November 2000 and 20th November 2001) at Vivekananada Parvatiya Krishi Anusandhan Sansthan (Indian Council of Agricultural Research), Experimental Farm, Hawalbagh, Almora, India (29^{0}36'N and 79^{0}40'E and 1250 m amsl). No vernalization and photoperiod treatment was given to the winter wheats as they flower under natural conditions at Hawalbagh conditions. The plot consisted of 1 row of 1.5 long with 30 cm row spacing and 10 cm plant spacing within rows. Five individual competitive plants in parents and F_1's were selected randomly for recording observations on ten characters *viz.,* heading days, maturity days, plant height, effective tillers per plant, ear length, grain number per ear, grain weight per ear, 1000 grain weight, biological yield per plant and grain yield per plant under each year separately.

The mean of each selected plants 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 mid-parent heterosis (MP%) and heterobeltiosis (HB%) were estimated as deviation of F_1 value from the mid-parent and the better-parent values as suggested by Matzinger *et al.* (1962) and Fonsecca and Patterson (1968), respectively. The following formulae were used for the estimation of MP and HB in each environment for all the characters.

Heterosis over mid-parent (MP%)

$$= [(F_1\text{-}MP)/MP \times 100]$$

$$SE\ (F_1\text{-}MP) = \sqrt{(3\ Me/2r)}$$

Heterosis over better-parent (HB%)

$$= [(F_1\text{-}BP/BP \times 100]$$

$$SE (F1\text{-}BP) = \sqrt{(2 Me/r)}$$

where, Me = error mean squares for parents and F_1s data of individual environment; MP = mean mid-parent value = $(P_1+P_2)/2$; P_1 = mean performance of parent one; P_2 = mean performance of parent two; BP = mean better-parent value; r = number of replications; significance of MP & HB were tested by 't' test using SE values in all the characters under each environment, separately.

RESULTS

Highly significant differences were found among the seven parental lines for all the characters studied. Similarly, the significant differences were found among F_1 hybrids for all the traits. However genotype x year interaction for grain yield and yield components were non significant, consequently, to simplify the presentation of the results, the data from both years have been combined and the means are presented. The mean grain yield of the hybrids in 2002 was 10.8% greater than in 2001 (Table 1). The greater biological weight (+23.9%) appears to be the main reason for this increase, although effective tillers per plant (+9.4%) also contributed to it.

Table 1. Yield and yield components for F_1 wheat hybrids over two years involving winter and spring wheat crosses.

Characters	**2001**	**SE**	**2002**	**SE**
Heading days	123.9	±0.42	124.5	±0.38
Maturity days	161.4	±0.25	163.6	±0.21
Plant height (cm)	81.2	±1.08	79.7	±1.27
Effective tillers per plant	9.0	±0.30	9.9	±0.28
Ear length (cm)	11.0	±0.23	10.6	±0.20
Grain number per ear	66.3	±1.36	64.5	±1.14
Grain weight per ear	2.9	±0.06	2.8	±0.06
Grain yield per plant (g)	22.0	±0.77	24.4	±0.87
Biological yield per plant (g)	49.6	±1.76	61.5	±2.25
Thousand grain-weight (g)	44.5	±0.81	44.0	±0.67

The heterosis values have been grouped in spring and winter wheat parents and F_1 arising out of them averaged over the years. Among the spring wheat parents, HD 2687 showed highest heterosis (21.4%) for grain yield per plant, biological yield per plant (19.18%), thousand grain weight (14.73%), ear length (11.35%) and effective tillers per plant (8.22%), whereas, UP 2425 showed highest heterosis for grain number per ear (19.67%) (Table 2). Among the four winter wheat parents, Zhong 65 showed highest heterosis for grain yield per plant (43.20%), biological yield per plant (38.63%), effective tillers per plant (17.76%) and ear length (31.76%) whereas, for thousand grain weight (18.99%) and grain number per ear (7.11%), Wei 132 has shown highest heterosis (Table 2).

For the purpose of comparison the crosses has been grouped into four groups *viz.,* spring x spring, spring x winter, winter x spring and winter x winter. The range of heterosis and number of crosses showing significant desirable heterosis over mid-parent and better-parent for yield and other attributes have been depicted in Table 3. Maximum heterosis for grain yield per plant over mid-parent was observed 45.94% and 24.46% in 2001 and 2002, respectively in spring x spring crosses. Similarly, maximum heterosis over better-parent for grain yield per plant was observed 41.99% and 22.26% in 2001 and 2002, respectively in same group. In spring x winter group highest heterosis for grain yield per plant over mid-parent was observed as 65.29% and 56.66% in 2001 and 2002, respectively, however, better-parent heterosis was 46.67% and 37.81% in 2001 and 2002, respectively. In winter x spring group maximum mid-parent heterosis was 33.56% and 62.09% in 2001 and 2002, respectively, whereas, better-parent heterosis was 23.80% and 47.82% in 2001 and 2002, respectively. In the fourth group of winter x winter crosses maximum heterosis for grain yield per plant over mid-parent was 46.50% and 60.45% in 2001 and 2002, respectively, whereas, better-parent heterosis was 45.10% and 51.06% in 2001 and 2002, respectively.

In the spring x spring group maximum mid-parent (50.47%) and better-parent heterosis (46.76%) for biological weight per plant was observed in 2001. Similar was the case in spring x winter group where 69.36% mid-parent heterosis and 49.26% better-parent heterosis was observed for the same character. In case of winter x spring group maximum mid-parent heterosis (62.09%) and better-parent heterosis (47.82%) in 2002 for grain yield per plant has been observed. Interestingly in winter x winter group maximum heterosis (mid as well as better-parent) was exhibited in both the years for grain yield per plant ranging from 45.10 to 60.45 %.

In this study, both mid-parent and better-parent heterosis was highest for biological yield per plant among spring x spring and spring x winter crosses during the year 2001. However, both were highest for grain yield per plant in the year 2002 (Table 3). Amongst winter x spring crosses highest mid-parent and better-parent heterosis were exhibited by grain yield per plant during 2002. However, during 2001 highest mid-parent heterosis was shown for grain yield per plant whereas, highest better-parent heterosis has been recorded for effective tillers per plant. In this group biological yield per plant and grain number per ear also showed some consistency. The winter x winter crosses showed complete consistency particularly for grain yield per plant and biological yield per plant and showed high mid as well as better-parent heterosis in that order. Highest numbers of heterotic crosses have been recorded for grain weight per ear followed by grain yield per plant across the groups (Table 3).

In spring x spring crosses heterobeltiosis for grain yield per plant ranged from -8.05% (UP 2425/ PBW 373) to 41.99% (HD 2687/ UP 2425) and from –12.53% (UP 2425/ PBW 373) to 22.26% (PBW 373/ HD 2687) during 2001 and 2002, respectively. Out of six, three crosses showed significant positive heterosis for at least one year in this group. HD 2687 / UP 2425 is the most consistent having high heterobeltosis as well as high mid-parent heterosis. In spring x winter group heterobeltiosis for grain yield per plant ranged from –8.14% (PBW 373/ Zhong 65) to 46.67% (UP 2425/ Zhong 65) and from –11.72% (UP 2425/ Zhong 65) to 37.81% (PBW 373/ Druchamp) during 2001 and 2002, respectively. Six crosses out of 12 showed consistently significant positive mid as well as better-parent heterosis for grain yield per plant. HD 2687/ Druchamp and HD 2687/ Zhong 65 are the best crosses on the basis of high better-parent and mid-parent heterosis as well as consistent performance, respectively. In winter x spring group better-parent heterosis for grain yield per plant ranged from -11.34% (Wei 132/ PBW 373) to 23.80% (Druchamp/ HD 2687) and from –33.05% (Wei 132/ HD 2687) to 47.82% (Druchamp/ UP 2425) during 2001 and 2002, respectively. Seven out of 12 crosses showed significant positive mid as well as better-parent heterosis. On the basis of mid-parent and better-parent heterosis and consistency Zhong 65/ UP 2425 and Zhong 65/ HD 2687 were the desirable crosses, respectively. In winter x winter group better-parent heterosis for grain yield per plant ranged from –24.40% (Wei 132/ Fanjai 2) to 45.10% (Druchamp/ Zhong 65) and from –10.10% (Wei 132/ Fanjai 2) to 51.06% (Wei 132/ Zhong 65) during 2001 and 2002, respectively. Five out of twelve crosses showed significant positive mid as well as better-parent heterosis in this group. On the basis of mid-parent heterosis, better-parent heterosis and consistency Druchamp/ Wei 132 was the desirable cross.

Table 2. Yield and yield components of 4 winter and 3 spring parents, the mean of the F_1 hybrids derived from them and mean of females parents average of 2001 and 2002.

	Heading days	Maturity days	Plant height (cm)	Effective tillers per plant	Ear length (cm)	Grain number per ear	Grain weight per ear (g)	Grain yield per plant (g)	Biological yield per plant (g)	Thousand grain weight (g)
HD 2687	121.83	161.50	72.50	9.43	9.93	67.17	2.47	20.47	49.17	36.97
F_1	123.83	162.67	79.44	10.21	11.06	69.94	3.01	24.85	58.59	42.42
% Heterosis	1.64	0.72	9.58	8.22	11.35	4.14	22.21	21.40	19.18	14.73
UP 2425	124.17	163.17	81.67	8.97	12.63	53.67	2.76	21.35	52.67	51.27
F_1	123.94	163.06	82.83	9.58	11.79	64.22	3.10	24.91	58.79	48.18
% Heterosis	-0.18	-0.07	1.43	6.82	-6.66	19.67	12.41	16.69	11.63	-6.03
PBW 373	122.50	161.33	77.50	10.47	10.10	58.00	2.51	20.08	51.50	43.35
F_1	123.61	161.83	81.53	9.37	10.78	63.69	2.85	23.15	56.19	44.82
%	0.91	0.31	5.20	-10.46	6.71	9.82	13.28	15.30	9.12	3.38
Fanjai 2	124.17	161.00	68.33	9.43	8.73	59.00	2.58	20.26	51.58	43.73
F_1	123.28	161.36	76.39	9.24	10.27	62.08	2.88	22.22	54.16	46.58
%	-0.72	0.22	11.79	-2.00	17.62	5.23	11.69	9.65	5.00	6.52
Druchamp	126.17	163.67	90.83	10.07	13.63	63.50	2.42	19.40	52.72	38.18
F_1	124.72	162.83	88.89	10.16	11.96	63.86	2.77	24.50	59.98	43.62
%	-1.14	-0.51	-2.14	0.94	-12.29	0.57	14.55	26.32	13.77	14.25
Wei 132	125.17	162.00	75.00	8.47	8.53	62.50	2.30	17.60	40.10	36.18
F_1	124.28	162.53	78.61	8.38	9.92	66.94	2.88	20.59	48.51	43.05
%	-0.71	0.33	4.81	-1.05	16.21	7.11	24.89	16.98	20.98	18.99
Zhong65	128.00	164.33	62.50	7.90	7.43	64.33	2.51	15.35	38.05	39.11
F_1	125.64	163.11	75.42	9.30	9.79	67.17	2.75	21.97	52.75	41.01
%	-1.84	-0.74	20.67	17.76	31.76	4.40	9.62	43.20	38.63	4.87

Table 3. Range of heterosis, number of desirable crosses for yield and yield components in winter x spring wheat crosses in 2 years.

	Range				**No of significant heterosis crosses**			
Character	**Mid-parent heterosis**		**Better-parent heterosis**		Better-parent heterosis		Mid-parent heterosis	
	Spring x Spring		**Spring x Spring**					
	2001	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
HDD	-2.83-4.13	-1.49-1.89	-1.64-5.28	-0.54-2.17	1	-	-	-
MD	-1.04-1.24	-0.31-0.82	-0.42-1.66	0.20-1.44	-	-	-	-
PHT	1.05-8.51	0-6.67	4.35-10.87	4.44-17.07	-	-	-	-
ETPP	-18.35-47.74	-22.15-6.92	-22.14-41.37	-29.31-2.08	4	2	3	-
EL	-0.30-16.00	0.33-6.67	-10.16-16.00	-10.94-2.61	5	4	2	1
GNPE	5.71-26.15	0.27-12.68	-5.13-20.00	-9.62-11.05	4	3	2	1
GWPE	4.36-46.93	4.52-24.10	7.95-42.07	-1.26-15.57	6	6	6	5
GYPP	-5.40-45.94	-10.20-24.46	-8.05-41.99	-12.53-22.26	5	3	5	3
BYPPL	-7.94-50.47	-14.94-18.56	-10.21-46.76	-19.54-13.79	4	1	4	-
TGW	-14.27-13.39	0.50-10.25	-18.18-8.03	-10.28- -1.62	2	4	1	-
	Spring x Winter		**Spring x Winter**					
HDD	-2.14-1.21	-2.70-1.74	-1.88-4.44	-2.43-3.25	-	1	-	-
MD	-0.52-0.83	-0.61-1.02	-0.42-1.45	-0.21-1.64	-	-	-	-
PHT	2.17-14.29	3.37-16.88	2.17-25.64	4.55-29.27	-	-	-	-
ETPP	-16.03-36.55	-22.60-26.64	-21.43-33.86	-28.16-13.89	6	8	6	3
EL	-1.12-20.81	-3.80-24.62	-14.56-4.67	-23.44-9.46	11	9	6	4
GNPE	-8.56-29.28	-7.51-23.51	-13.64-23.08	-10.61-15.08	5	6	2	3
GWPE	0.38-48.45	-11.98-52.06	1.42-46.33	-20.59-18.54	11	11	12	9
GYPP	-2.45-65.29	0.88-56.66	-8.14-46.67	-11.72-37.81	9	10	8	10
BYPPL	-1.89-69.36	-12.57-47.14	-10.67-49.26	-19.54-28.75	8	8	6	3
TGW	-1.61-19.83	-8.92-23.05	-16.40-19.57	-17.03-16.62	7	9	3	4

	Winter x spring		**Winter x spring**					
HDD	-4.01-2.85	-2.43-2.83	-3.75-5.28	-1.08-3.25	2	2	1	-
MD	-1.14-1.14	-0.61-1.54	-0.42-1.66	-0.41-1.85	-	-	-	-
PHT	1.18-10.89	-1.18-15.29	0-17.07	2.44-36.11	-	-	-	-
ETPP	-22.51-32.93	-22.56-33.85	-24.46-30.31	-28.47-21.13	4	6	4	5
EL	1.12-18.77	-3.37-14.80	-16.04-5.33	-18.23-4.73	12	8	5	3
GNPE	-9.63-20.10	-4.35-20.22	-14.65-19.19	-10.10-16.30	3	4	3	1
GWPE	2.99-28.62	5.11-39.39	-1.50-26.47	1.03-34.65	12	12	11	12
GYPP	-9.12-33.56	-24.58-62.09	-11.34-23.80	-33.05-47.82	8	10	7	9
BYPPL	-9.55-31.68	-17.39-55.86	-13.04-25.48	-28.75-37.11	6	6	4	5
TGW	-3.46-15.69	0.64-15.70	-11.14-12.24	-15.27-12.11	9	10	3	7
	Winter x winter		**Winter x winter**					
HDD	-2.67-1.87	-2.37-0.80	-2.14-2.70	-2.37-8.26	-	-	-	-
MD	-1.04-0.72	-1.22-0.20	-0.21-1.24	-0.41-0.82	-	-	-	-
PHT	-1.18-12.09	1.18-12.24	2.56-30.77	4.88-36.11	-	-	-	-
ETPP	-27.07-22.35	-9.23-35.02	-27.61-17.29	-21.30-31.15	5	8	4	3
EL	-1.93-16.09	-4.13-16.10	-18.45-8.66	-25.62-10.48	11	9	2	2
GNPE	-0.56-14.57	-7.82-16.08	-6.81-10.14	-8.56-15.76	6	4	2	3
GWPE	0.80-31.83	-2.45-33.66	-5.85-29.46	-9.59-25.17	12	11	11	11
GYPP	-22.62-46.50	0.60-60.45	-24.40-45.10	-10.10-51.06	6	11	4	7
BYPPL	-22.41-38.77	-7.59-52.54	-25.54-30.83	-22.99-50.00	4	6	3	3
TGW	-5.95-20.32	-1.04-15.70	-13.33-17.94	-3.45-11.55	7	11	2	5

HDD=Heading days, MD=Maturity days, PHT=Plant height (cm), ETPP=Effective tillers per plant, EL=Ear length (cm), GNPE=Grain number per ear, GWPE=Grain weight per ear (g), GYPP=Grain yield per plant (g), BYPPL=Biological yield per plant (g), TGW=Thousand grain weight (g)

Table 4. Relationship of significant desirable heterosis (BP) for grain yield with other characters in winter x spring wheat crosses in two years.

Crosses	Year	GYPP		BYPPL		TGW		GWPE		GNPE		ETPP	
S X S		HB	MP	HB	MP	HB	MP	HB	MP	HB	MP	HB	MP
HD 2687/ UP 2425	2001	41.99**	45.94**	++	++	--	0	++	++	0	0	++	++
	2002	9.73**	11.31**	0	0	--	0	--	++	-	0	0	++
PBW 373/ HD2687	2001	5.13*	5.23*	0	0	0	++	++	++	0	++	--	++
	2002	22.26**	24.46**	0	+	0	++	++	++	0	+	-	++
PBW373/ UP 2425	2001	20.00**	23.46**	++	++	++	++	++	++	0	0	0	++
	2002	16.11**	19.86**	0	0	--	++	++	++	0	+	--	--
S X W													
HD2687/ Druchamp	2001	31.79**	43.64**	++	++	0	0	++	++	0	0	++	++
	2002	25.96**	29.24**	0	++	++	++	++	++	0	0	0	++
HD2687/ Wei132	2001	15.90**	18.91**	0	+	+	++	++	++	++	++	0	0
	2002	15.93**	30.61**	0	++	++	++	++	++	+	++	0	++
HD2687/ Zhong65	2001	22.74**	34.96**	++	++	++	++	++	++	0	0	+	++
	2002	31.94**	56.66**	++	++	++	++	++	++	++	++	++	++
UP2425/ Fanjai2	2001	8.11**	11.37**	0	+	++	++	++	++	0	0	0	0
	2002	30.45**	33.33**	+	+	0	++	++	++	0	++	0	++
UP2425/ Druchamp	2001	35.49**	51.40**	++	++	--	0	++	++	0	+	++	++
	2002	19.08**	20.46**	0	0	-	++	--	++	0	0	--	0
UP2425/ Wei132	2001	31.47**	38.53**	++	++	0	++	++	++	0	++	++	++
	2002	23.30**	40.65**	0	++	-	++	++	++	0	++	++	++
W X S													
Fanjai 2/ UP 2425	2001	10.21**	13.53**	+	++	+	++	++	++	0	0	++	++
	2002	17.74**	20.33**	+	+	0	++	++	++	0	0	0	+
Fanjai 2/ PBW	2001	7.36**	7.51**	0	0	++	++	++	++	0	0	--	--

373	2002	21.71**	22.96**	0	+	++	++	++	++	0	+	--	--
Druchamp/ HD 2687	2001	23.80**	34.94**	++	++	0	+	++	++	++	++	0	0
	2002	11.44**	4.08	0	0	+	++	++	++	-	0	--	--
Druchamp/ UP 2425	2001	19.45**	33.48**	++	++	-	++	++	++	0	0	++	++
	2002	47.82**	49.53**	++	++	-	++	++	++	0	0	++	++
Druchamp/ PBW 373	2001	6.35**	15.81**	0	+	0	++	--	++	--	-	0	0
	2002	8.93**	13.72**	0	0	++	++	++	++	0	0	--	--
Zhong 65 / HD 2687	2001	21.47**	33.56**	+	++	0	0	++	++	+	++	++	++
	2002	25.96**	49.55**	++	++	+	++	++	++	0	0	++	++
Zhong 65 / UP 2425	2001	8.92**	22.75**	0	++	--	0	++	++	-	0	++	++
	2002	34.95**	62.09**	++	++	--	++	++	++	0	+	++	++
W X W													
Fanjai2/ Druchamp	2001	9.53**	19.12**	--	-	0	++	++	++	0	0	++	++
	2002	25.24**	29.45**	0	+	++	++	++	++	0	0	0	++
Druchamp/ Wei132	2001	20.40**	28.12**	++	++	++	++	++	++	0	+	++	++
	2002	19.85**	38.07**	0	++	0	++	++	++	0	0	-	++
Zhong 65/ Druchamp	2001	25.61**	26.82**	++	++	0	0	--	++	0	0	0	++
	2002	19.22**	44.52**	0	0	0	0	++	++	+	++	--	--
Wei 132/ Druchamp	2001	4.94	11.67**	0	0	++	++	++	++	+	++	--	--
	2002	37.34**	58.22**	+	++	++	++	++	++	++	++	0	++

++ : Highly significant in positive direction, + : Significant in positive direction: --: Highly significant in negative direction, -: Significant in negative direction, * Significant at 5% level of significance, ** Significant at 1 % level of significance, 0: Non significant S X S-Spring X Spring, S X W-Spring X Winter, W X S-Winter X Spirng, W X W- Winter X Winter

ETPP=Effective tillers per plant, GNPE=Grain number per ear, GWPE=Grain weight per ear (g), GYPP=Grain yield per plant (g), BYPPL=Biological yield per plant (g), TGW=Thousand grain weight (g)

The crosses with good grain yield also showed heterobeltiosis for at least one or more yield contributing characters such as effective tillers per plant, 1000-grain weight, number of grains per ear and grain weight per ear (Table 4). In all the group of crosses grain weight per ear showed heterosis for maximum number of crosses followed by effective tillers per plant. However, for mid-parent heterosis in all the group of crosses grain weight per ear showed heterosis for maximum number of crosses followed by thousand grain weight and effective tillers per plant.

Three crosses (HD 2687/ UP 2425, PBW 373/ HD 2687 and PBW 373/ UP 2425) among spring x spring, 6 crosses (HD 2687/ Druchamp, HD 2687/ Wei 172, HD 2687/ Zhong 65, UP 2425/ Fanjai 2, UP 2425/ Druchamp, UP 2425/ Wei 132) among spring x winter and 6 crosses (Fanjai 2/ UP 2425, Fanjai 2/ PBW 373, Druchamp/ UP 2425, Druchamp/ PBW 373, Zhong 65/ HD 2687, Zhong 65/ UP 2425) among winter x spring and 3 (Fanjai 2/Druchamp, Druchamp/ Wei 132 and Zhong 65/ Druchamp) among winter x winter crosses showed significant mid-parent as well as better parent heterosis over the years.

DISCUSSION

The superiority of hybrids particularly over better-parent is more useful in determining the feasibility of commercial exploitation of heterosis and also indicating the potent parental combinations capable of producing the highest level of transgressive segregants. Heterosis over better-parent and over mid-parent is of high practical significance. Degree of heterosis is, however, important as it may be of value in deciding the directions of future breeding programme. The present study may also help to identify the cross combination, which are promising in breeding programme. Mackey (1976) described genetic principles of expression of heterosis superior to the better-parent, which may result from one or two of the following situations; (i) the accumulated action of favourable dominant or semi-dominant genes dispersed amongst two parents i.e. dominance; (ii) the complementing interaction of additive dominant on recessive genes at different loci i.e., non-allelic interactions or epistasis; (iii) favourable interaction between two alleles at the same locus i.e., intra-locus or inter-allelic interactions referred to as over dominance. It will be possible to recover homozygous lines as good as heterotic hybrids if either or both of the first two situations are cause of heterosis, although the case with which such lines can be recovered will depend on linkage relationship of the genes involved and the ability to identify the recombinants as and when they arise. This will be particularly difficult with close linkage and when heterosis is expressed by a slight improvement in each of main yield components. If heterosis is due to inter-allelic interactions of dominant types, it is not possible to fix such heterosis in homozygous conditions in subsequent generations.

Presence of highly significant differences among parents and hybrids indicated sufficient diversity among the materials. HD 2687 among spring and Zhong65 among winter were adjudged best parents on the basis of high heterotic values for grain yield and its attributes. Absence of genotype x year interaction for grain yield and yield components suggested consistency in the performance of heterosis over the years thereby indicating that heterosis is less affected by the environments and valid conclusion can be made from this set of materials. Previous studies have shown that wheat hybrids have stable performance across environments and seasons (Stroike, 1987). On comparing the four groups, winter x spring and winter x winter wheat crosses possess potential for high heterosis for grain yield per plant. Heterosis for grain yield has also been reported by several workers in the past in spring wheat (Sharma *et al.*, 1986; Larik *et al.*, 1995; Prasad *et al.*, 1998; Deshpande and Nayeem 1999; Singh *et al.*, 2004). On the contrary spring x spring and spring x winter may be desirable for high heterosis for biological weight per plant. It may be inferred that for getting high heterosis for grain yield winter x spring or winter x winter crosses may be exploited. However, these may also provide heterotic combinations for effective tillers per plant, biological yield per plant and grain weight per ear. On the basis of high heterosis and stable performance Zhong 65/ HD 2687 and Zhong 65/ UP 2425 are the best winter x spring crosses followed by Druchamp/ Wei 132 a winter x winter cross. Subsequently, spring x winter group can also provide heterotic combinations and HD 2687/ Zhong 65 is the potential cross in this group.

The results of present investigation for grain yield revealed that out of 42 F_1s, significant positive mid-parent heterosis and heterobeltiosis was recorded in 23 and 19 crosses, respectively in both years. This may be taken as an index that at least these 19 crosses which have shown heterobeltiosis for grain yield per plant as well as mid-parent heterosis are stable ones. In spring x spring group, cross HD 2687/ UP 2425 showed 41.99% and 45.94% heterobeltiosis and mid-parent heterosis for grain yield per plant, respectively during 2001. Among spring x winter crosses, UP 2425/ Druchamp had maximum heterobeltiosis for grain yield (35.49%) whereas, HD 2687/ Zhong 65 had 56.66% mid-parent heterosis for the same during 2001 and 2002, respectively. For grain yield per plant, Druchamp/ UP 2425 showed maximum heterobeltiosis (47.82%) and Zhong 65/ UP 2425 had 62.09% mid-parent heterosis among winter x spring crosses in 2002. Among winter x winter crosses maximum heterobeltiosis (25.61%) has been recorded in cross Zhong 65/ Druchamp whereas, Wei 132/ Druchamp recorded maximum mid-parent heterosis (58.22%) in 2001 and 2002, respectively (Table 4). From the analysis of heterobeltiosis and mid-parent heterosis it can be inferred that maximum heterobeltiosis has been expressed by winter x winter wheat crosses followed by spring x winter crosses. Whereas, maximum mid-parent heterosis has been expressed by spring x winter wheat crosses followed by winter x winter and winter x spring wheat crosses. Therefore, it would be desirable that for further enhancement in yield and adaptability breeders should resort to winter x spring wheat crosses or spring x winter wheat crosses which is nearer to the winter x winter group.

Several yield components appeared to be important in determining grain yields in high yielding hybrids (Mahajan *et al.*, 1999). The results of present study exhibited that the crosses showing heterosis for grain yield per plant were not heterotic for all the characters (Table 4). The results also supported the contentions of Grafius (1959), who had suggested that there could be no separate gene system for yield *per se* as yield is an end product of the multiplicative interactions between its various component characters. A close perusal of Table 4 showed that by and large, heterosis for grain weight per ear, biological yield per plant were independently associated with grain yield per plant in spring x spring wheat crosses. On the contrary, biological yield per plant, thousand grain weight, grain weight per ear, effective tillers per plant were independently associated with grain yield per plant in spring x winter wheat crosses as well as in winter x spring wheat crosses. However, grain weight per ear has been associated in winter x winter wheat crosses with grain yield per plant. On overall basis grain weight per ear produced heterotic effects in almost all the crosses. This implies that heterosis for a complex character like yield can be registered by single or several characters (Gautam and Jain, 1985).

Heterotic advantages up to 41% on large plot basis have been reported so far (Zehr *et al.*, 1997). The desired expression of economic heterosis in wheat can be achieved by matching yield and yield components from genetically diverse parents (Mahajan *et al.*, 1999). High magnitude of heterobeltiosis as well as mid-parent heterosis in the present investigation suggest the possibility of exploitation of hybrid vigour commercially particularly from winter x winter, spring x winter and winter x spring wheat crosses. Commercial hybrid production techniques are yet to be standardized in Indian subcontinent but can be possible by CMS methods. The most heterotic crosses can also be utilized for producing hybrids through double haploid breeding specially, via anther culture (Schaeffer *et al.*, 1984). It has advantages in achieving homozygosity after hybridization; it helps in quick fixation of genes and would not be necessity to under go repeated selfing to achieve homozygosity.

The present investigation thus suggest that heterosis for yield was high in parents of diverse background and level of heterosis was high in winter x winter, spring x winter and winter x spring wheat crosses as compared to spring x spring wheat crosses. The heterosis for yield was through component heterosis particularly in winter x spring and spring x winter wheat crosses. Hybrid vigour of even small magnitude for individual yield components may have additive effects on the end product. Evidently, manifestation of heterosis for yield and its attributes may be due to non additive gene effects in the parents particularly in cases where additive effects are lacking. HD 2687 and Zhong 65 have been identified as the best parents which can provide high heterosis. Zhong 65/ HD 2687 and Zhong 65/ UP 2425 are the potential crosses for developing high yielding genotypes. Thus, the present study suggests ample scope for exploitation of heterosis for commercial production as well as isolation of pure lines among the progenies of diverse crosses like winter x winter and spring x winter wheat crosses. This may be a possible approach for further break through in wheat yields.

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