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Winter x Spring Wheat Hybridization: A Potential Source for Yield Advancement

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ABSTRACT

Introgression of winter wheat gene pool in spring wheat is one of the potential approaches to break the yield barrier. However, little information is available on the combining ability of these two important groups. To assess the combining ability of yield and secondary traits, 42 F_1 hybrids developed by (7 × 7) diallel of four winter and three spring wheat parents were evaluated in replicated plots over 2 years. Additive gene effects were more important in determining yield. Reliable prediction of GCA (General Combining ability) effects from mean values was indicated for ear length, grain number per ear and 1000-grain weight. 'UP 2425' spring and 'Druchamp' winter wheat were good general combiners for maximum number of traits including yield. Cross 'HD 2687'/'Zhong 65' had significant Specific Combining ability (SCA) effects for seven traits. Although GCA effects of most winter wheats ranged from average to poor, their combination with spring wheat possessing high GCA can give improved genotypes. The chances of selecting improved genotypes were better in the case of winter × spring and winter × winter crosses as compared to spring × spring crosses.

Keywords: combining ability, *Triticum aestivum*, yield components

INTRODUCTION

Wheat contributes more than 25% of the global cereal output, and constitutes the main source of calories for more than 1.5 billion people (Reynolds *et al.* 1999). Developing countries are expected to increase their demand of cereals by 80% between 1999 and 2020 (Pinstrup-Anderson and Pandya-Lorch 1997). Rosegrant *et al.* (1997) reported that over the next two decades global demand for wheat and maize could rise by 40 and 47%, respectively, and by 2020, 67% of world's wheat is expected to be consumed in developing countries. With the current levels of food crop productivity, developing countries are expected to import 138 million tons of wheat every year by 2020. To ensure food security, breaking of yield stagnation through novel approaches like exploitation of gene pools of winter and spring wheats need to be considered.

Winter wheats possess enormous variability for tillering, leaf size, spike length, grain size, grain number, abiotic stress tolerance and better N and P efficiency (Nanda and Sohu 1998). However, they have poor adaptation to the subtropical climate due to specific vernalization and photoperiod requirements. Consequently, winter wheats do not flower in subtropical climate under natural conditions making their commercial cultivation impossible (Shoran *et al.* 1995; Kant *et al.* 2001; Kant and Gupta 2002). By introgressing genetic variability from winter wheats, plant breeders have considerably augmented the yield potential of spring wheats. The 'Veery' wheats, developed from crosses of CIMMYT spring wheats and Russian Winter Wheat, represented a quantum leap in spring wheat yield and wide adaptation during the 1970s and 1980s (Anonymous 1986). Recently, 'Attila', developed from crosses with western European and US winter wheats, has been rapidly adopted in the Indian subcontinent. Considerable progress can thus be made by exploiting winter wheat gene pool for improving spring wheats through the selection of optimal combinations of genes for a particular environment (Reeves *et al.* 1999). Further, yield is the product of component traits, therefore, selection for yield *per se* in any particular environment may not be effective unless its components are understood (Grafius 1964). It is important to understand the nature of gene action and the combining ability in winter and spring wheat for yield and yield attributes in the target geographic region. The present investigation was undertaken to determine general and specific combining abilities for yield and yield attributes among diverse winter and spring wheat crosses.

MATERIALS AND METHODS

Four winter wheats and 3 spring wheat were selected to produce 7 × 7 diallel crosses. Among the four winter wheat 'Druchamp' 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 the 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. F_1 hybrids were obtained by hand emasculation during the winter season 2000-2001 and 2001-2002. An experiment to evaluate 42 F_1 hybrids and the seven parental lines in a Randomized Complete Block design with three replicates was established on the 24th November 2000 and 20th November 2001 at the Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS) [Indian Council of Agricultural Research (ICAR)], Experimental Farm, Hawalbagh, Almora, India (29°36′N and 79°40′E and 1250 m asl). The plot consisted of 1.5 m row with a 10-cm plant spacing within rows and 30 cm row spacing. The crop received 60 kg/ha N, 60 Kg/ha P and 40 kg/ha K as a basal dose and 30 kg/ha N as a top dressing each after first irrigation and at the jointing stage. Three supplemental irrigations (50 mm each irrigation) were provided in addition to 176.1 and 254.4 mm rainfall during 2000-01 and 2001-02, respectively. The crop was not protected against leaf rust (*Puccinia recondita*), stripe rust (*Puccinia striiformis*), loose smut (*Ustilago nuda tritici*) and powdery mildew (*Erysphe tritici*) as these diseases were present at very low levels. Weeds were controlled fully and lodging prevented by planting taller wheat variety

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Table 1 Analysis of variance (Mean sum of squares) and correlation between GCA and *per se* value for yield and yield attributes in winter x spring wheat crosses.

Source	df	HDD	MD	PHT	ETPP	EL	GNPE	GWPE	GYPP	BYPP	TGW
GCA	6	28.1**	13.4**	742.4**	6.6**	29.5**	261.6**	0.2**	66.1**	485.2**	181.2**
SCA	21	4.3**	0.8**	25.9**	1.6**	0.6**	31.4**	0.2**	20.9**	102.0**	12.8**
REC	21	3.0**	0.5	5.4	1.1	0.1	11.4	0.1*	7.7	49.1	8.6**
Year	1	10.8**	123.6**	55.9**	17.7**	1.7**	62.1*	0.2*	112.4**	3463.9**	5.3
GCAX Year	6	6.1**	1.6**	34.4**	3.6**	0.5**	66.5**	0.1*	24.1**	153.6**	30.0**
SCAX Year	21	2.1**	0.2	3.9	1.2	0.2**	18.5	0.1*	7.8	52.1	4.9*
RECX Year	21	1.8**	0.7**	4.5	1.4*	0.2*	24.7**	0.1**	13.3**	85.6**	5.4*
ERROR	192	1.1	0.4	3.8	0.8	0.1	12.4	0.0	5.8	34.9	3.0
σ^2 GCA	-	2.65	1.40	79.61	0.55	3.21	25.58	0.00	5.02	42.57	18.71
σ^2 SCA	-	3.18	0.49	22.04	0.87	0.44	18.98	0.11	15.12	67.16	9.84
σ^2 GCA/ σ^2 SCA	-	0.83	2.85	3.61	0.63	7.29	1.35	0.04	0.33	0.63	1.90
r 00-01	-	0.52	-0.08	0.36	-0.33	0.98**	0.89**	0.32	0.40	0.50	0.96**
r 01-02	-	0.86*	0.84*	0.99**	0.80*	0.99**	0.78*	0.88**	0.50	0.82*	0.98**
r pooled	-	0.83*	0.89*	0.99**	0.52	0.99**	0.88*	0.55**	0.64	0.74	0.97**

HDD= Days to heading, MD= Maturity days, PHT= Plant height, ETPP= Effective tillers per plant, EL=Ear length, GNPE= Grain number per ear, GWPE=Grain weight per ear, GYPP=Grain yield per plant, BYPP= Biological weight per plant, TGW= Thousand grain weight. r 2000-01, r 2001-02, r pooled = Correlation between GCA and *per se* value during 2000-01,2001-02 and pooled respectively. *, **- significant at 5 % and 1 % level of significance, respectively, GCA= General combining ability, SCA= Specific combining ability, REC= Reciprocal.

Table 2 General combining ability (GCA) effects and *per se* performance for yield and yield attributes in winter and spring wheat parents.

Parents	HDD		MD		ETPPL		EL		GNPPE		GYPP		BYPP		TGW	
	GCA	Days	GCA	Days	GCA	No	GCA	cm	GCA	No.	GCA	g	GCA	g	GCA	G
HD 2687 F	-0.5	120	0.3*	161	0.8**	9.3	0.3**	10.0	4.6**	65.0	2.2**	19.8	4.5**	45.0	-1.8**	38.8
HD 2687 S	-0.3	124	-0.1	162	-0.3	9.6	0.0	9.9	3.7**	69.3	-0.8	21.1	-2.8	53.3	-2.3**	35.1
HD 2687 P	-0.4*	122	0.1	162	0.3	9.4	0.1**	9.9	4.2**	67.2	0.7	20.5	0.8	49.2	-2.1**	37.0
UP 2425 F	-0.2	125	0.5**	162	0.8**	8.5	1.1**	12.5	-4.2**	51.7	3.2**	21.0	7.8**	47.3	4.3**	50.2
UP 2425 S	-1.8**	123	0.2	164	-0.0	9.5	1.2**	12.8	-2.7**	55.7	1.4*	21.7	3.9*	58.0	5.5**	52.4
UP 2425 P	-1.0**	124	0.3**	163	0.4**	9.0	1.2**	12.6	-3.4**	53.7	2.3**	21.4	5.9**	52.7	4.9**	51.3
PBW 373 F	-0.9**	122	-0.9**	160	-0.4	9.3	-0.1	10.0	-3.0**	58.7	-0.9	19.8	-2.0	45.0	1.7**	45.6
PBW 373 S	-0.1	123	-0.4**	163	0.2	11.6	0.0	10.2	-0.4	57.3	-0.6	20.4	0.3	58.0	-0.5	41.1
PBW 373 P	-0.5**	123	-0.6**	161	-0.1	10.5	-0.1	10.1	-1.7**	58.0	-0.7	20.1	-0.9	51.5	0.6*	43.4
Fanjai 2 F	-0.9**	124	-1.4**	160	-0.5*	8.9	-0.9**	8.5	-5.7**	55.7	-1.6**	19.7	-3.4	45.2	2.5**	46.2
Fanjai 2 S	-0.7**	124	-1.0**	162	-0.2	9.9	-0.5**	9.0	-1.0	62.3	-0.4	20.8	-1.3	58.0	0.2	41.3
Fanjai 2 P	-0.8**	124	-1.2**	161	-0.3*	9.4	-0.7**	8.7	-3.4**	59.0	-1.0*	20.3	-2.3*	51.6	1.4**	43.7
Druchamp F	0.5	126	0.6**	162	0.4*	8.9	1.7**	13.7	0.6	66.0	0.4	16.6	1.5	40.8	-2.7**	35.1
Druchamp S	0.6*	127	0.5**	165	1.1**	11.3	1.3**	13.5	-2.0*	61.0	2.8**	22.2	8.5**	64.7	0.8*	41.3
Druchamp P	0.5**	126	0.6**	164	0.7**	10.1	1.5**	13.6	-0.7	63.5	1.6**	19.4	5.0**	52.7	-0.9**	38.2
Wei 132 F	-0.2	124	-0.3	161	-1.0**	8.8	-1.0**	8.8	3.0**	63.7	-2.2**	18.8	-5.8**	41.5	-1.3**	36.6
Wei 132 S	0.9**	127	0.3	163	-0.4	8.1	-0.8**	8.3	1.6	61.3	-1.0	16.4	-4.3**	38.7	-2.0**	35.8
Wei 132 P	0.3	125	0.0	162	-0.7**	8.5	-0.9**	8.5	2.3**	62.5	-1.6**	17.6	-5.1**	40.1	-1.6**	36.2
Zhong 65 F	2.3*	128	1.1**	163	-0.2	8.1	-1.2**	7.4	4.7**	69.0	-1.1*	16.3	-2.7*	36.1	-2.8*	39.0
Zhong 65 S	1.5**	128	0.5**	165	-0.4*	7.7	-1.2**	7.5	0.7	59.7	-1.6*	14.5	-4.2**	40.0	-1.7**	39.3
Zhong 65 P	1.9**	128	0.8**	164	-0.3*	7.9	-1.2**	7.4	2.7**	64.3	-1.3**	15.4	-3.5**	38.1	-2.2**	39.1
SE_F	0.27	0.7	0.15	0.4	0.21	0.3	0.09	0.5	0.82	1.6	0.51	0.6	1.30	1.4	0.48	1.3
SE_S	0.23	0.5	0.14	0.3	0.22	0.4	0.09	0.5	0.92	1.2	0.66	0.9	1.61	2.6	0.36	1.2
SE_P	0.18	0.4	0.10	0.3	0.15	0.3	0.06	0.3	0.62	1.0	0.42	0.5	1.03	1.6	0.30	0.9

F- year 2000-01, S- year 2001-02, P- pooled *, **- significant at 5 % and 1 % level of significance, respectively.

around the experiment site to prevent wind flow. The crop was harvested on the 17th May 2001 and 13th May 2002.

Five individual competitive plants were selected randomly in each plot of three replications for recording observations. Data on days to heading and days to maturity were taken on a plot basis. Plant height was recorded at physiological maturity. The sampled plants were uprooted and data on effective tillers per plant were recorded. Data on ear length, grain number per ear and grain weight per ear were recorded on the main tiller of each sampled plants. Grain yield per plant, biological yield and 1000-grain weight were recorded after hand threshing of individual plants.

Means of cross combinations and parents (means of five plants per replicate) for various desirable characters were used for statistical analysis. The diallel analysis was conducted according to Griffing (1956) method model I. Statistical software package SPAR1 of Indian Agricultural Statistical Research Institute (IASRI), New Delhi was used for the analysis.

RESULTS

Highly significant differences were found among the seven parental lines for days to heading, days to maturity, plant height, effective tillers per plant, ear length, grain number per ear, grain weight per ear, grain yield per plant, biological weight per plant and 1000-grain weight. Significant GCA effects were observed between years for all traits, except 1000-grain weight. The general combining ability (GCA) mean squares for the diallel analysis were highly significant for all traits measured (**Table 1**). When data were analyzed separately for each year, GCA effects were highly significant for all traits in both years, except for grain weight per ear. In addition, specific combining ability (SCA) mean squares were consistently smaller than GCA mean squares and were highly significant for all traits. The GCA x Year interactions were significant for all traits (**Table 1**). The SCA x Year interactions were significant for heading days, 1000-grain weight, grain weight per ear and ear length.

Grain as well as biological yield was lower in 2000-01 than in 2001-02 (**Fig. 1**; **Table 2**). On an overall basis ear length, grain number per ear and thousand-grain weight had a significant correlation between *per se* value and GCA for both years (**Table 1**). Very high correlations between *per se* value and GCA were observed for ear length. The estimates of GCA effects from the diallel analysis were negative for 'Fanjai 2', 'Wei 132', 'Zhong 65' winter wheat and 'PBW

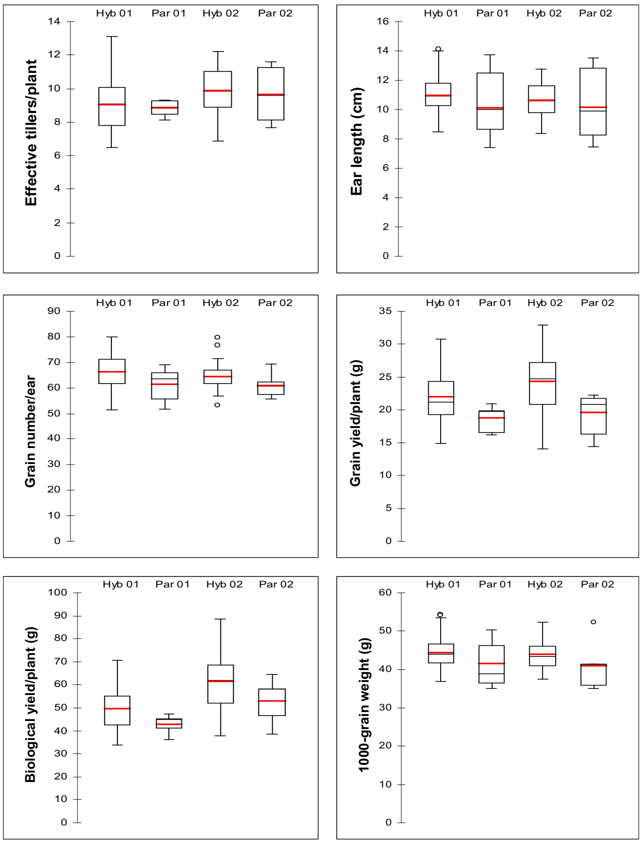

Fig. 1 Box plot presentation of six characters measured 2 years on seven parental lines and 42 corresponding hybrids. The mean is indicated by a solid line (—). When the best hybrid is significantly higher than the best line, the best hybrid & the best line are represented by a circle.

373' spring wheat parents for yield in both years (**Table 2**). In contrast, 'UP 2425' spring wheat and 'Druchamp' winter wheat parents had positive GCA effects for yield in both years. The parent 'UP 2425' had positive GCA effects for both yield and seed weight.

Winter wheats, 'Druchamp' and 'Fanjai 2' had desirable GCA effects for effective tillers/plant, ear length, grain yield per plant and biological yield per plant and plant height, maturity days, heading days and 1000-grain weight, respectively. Among spring wheats 'UP 2425' had desirable GCA effects for heading days, effective tillers per plant, ear length, grain weight per ear, grain yield per plant, biological yield per plant and 1000-grain weight, whereas parents 'HD 2687' had desirable GCA effects for plant height, heading days, ear length and grain number per ear and 'PBW 373' for heading days, maturity days and 1000-grain weight (**Table 2**).

For grain yield per plant, crosses 'HD 2687'/'Zhong 65', 'UP 2425'/'Fanjai 2' and 'Druchamp'/'Wei 132' had positive significant SCA effects, whereas 'Fanjai 2'/'Wei 132' was significantly negative (**Table 3**). For biological yield per plant, crosses 'HD 2687'/'Zhong 65', 'UP 2425'/'Wei 132' and 'UP 2425'/'Zhong 65' had positive significant SCA effects and 'UP 2425'/'PBW 373' was significantly undesirable. For 1000-grain weight 'HD 2687'/'Zhong 65', 'UP 2425'/'Fanjai 2', 'PBW 373'/'Druchamp', 'Fanjai 2'/'Druchamp', 'UP 2425'/'Wei 132' and 'Druchamp'/'Wei 132' had positive significant SCA effects (**Table 3**). Crosses 'HD 2687'/'Zhong 65', 'HD 2687'/'PBW 373', 'UP 2425'/'Wei 132' and 'Druchamp'/'Wei 132' had positive significant SCA effects for grain weight per ear whereas only two crosses *viz*., 'UP 2425'/'PBW 373', 'HD 2687'/ 'PBW 373' had positive significant effects for grain number per ear. In contrast, 'PBW 373'/'Druchamp' was significantly negative. Only two crosses 'UP 2425'/'Zhong 65' and 'HD 2687'/ 'Zhong 65' had significant positive SCA effects for effective tillers per plant whereas crosses 'UP 2425'/'PBW 373' and 'HD 2687'/'PBW 373' had significant negative SCA effects. 'UP 2425'/'Fanjai 2' was the cross having highest significant negative SCA effects for heading days while 'Fanjai 2'/'Druchamp' for maturity days (**Table 3**).

DISCUSSION

Diallel analysis is frequently used in plant breeding to assess general and specific combining abilities for traits (Parodi *et al.* 1983; Du *et al.* 1999). It also helps plant breeders in making decisions regarding the type of breeding system to use and in selecting breeding materials of greatest promise (Gardner and Eberhart 1966). Highly significant differences among seven parental lines for all attributes demonstrated that sufficient variability existed in this set of material. Significant effects between years for all traits, except 1000-grain weight, indicated that results were variable over the years. Though both additive and non-additive gene effects are involved in expression of yield and its components, additive gene action predominates for maturity days, plant height, ear length, grain number per ear and 1000-grain weight. As this is a component which can be fixed in subsequent generations, selection is expected to bring substantial improvement in these characters. Prevalence of additive gene effects in winter × spring wheat crosses were also suggested by Sharma *et al.* (1995) for plant height and Kant *et al.* (2001) for days to heading, plant height and spikelets per ear, Kant and Gupta (2002) for days to heading, plant height and grain yield per plant, Shoran *et al.* (2003) for days to heading and days to maturity, Nazeer *et al.* (2004) for plant height and days to maturity, Dere and Yildirim (2006) for plant height and 1000-grain weight and Chowdhary *et al.* (2007) for plant height, ear length and grain number per ear. In contrast, non-additive gene effects

Table 3 Crosses having significant Specific combining ability (SCA) effects for maximum number of characters in winter x spring wheat crosses.

	Year	HDD	MD	PHT	ETPPL	EL	GNPPE	GWPE	GYPP	BYPP	TGW
HD2687/Zhong65	2000-01	0	0	0	0	+	0	0	0	0	+
HD2687/Zhong65	2001-02	0	0	+	+	+	+	+	+	+	+
HD2687/Zhong65	Pooled	0	0	+	+	+	0	+	+	+	+
UP2425/Wei132	2000-01	0	0	+	0	0	0	+	0	0	+
UP2425/Wei132	2001-02	0	0	0	0	0	0	0	+	+	0
UP2425/Wei132	Pooled	-	0	+	0	0	0	+	+	+	+
UP2425/Fanjai2	2000-01	-	0	0	0	0	0	0	0	0	+
UP2425/Fanjai2	2001-02	-	0	+	0	+	0	+	0	0	+
UP2425/Fanjai2	Pooled	-	0	+	0	0	0	0	0	0	+
Fanjai2/Druchamp	2000-01	-	-	+	0	0	0	0	0	0	0
Fanjai2/Druchamp	2001-02	-	0	+	0	0	0	0	0	0	+
Fanjai2/Druchamp	Pooled	-	-	+	0	0	0	0	0	0	+
Druchamp/Wei132	2000-01	0	0	0	0	0	0	+	0	0	+
Druchamp/Wei132	2001-02	-	0	+	0	0	0	0	0	0	0
Druchamp/Wei132	Pooled	0	0	+	0	0	0	+	+	0	+

\+ Significant in positive direction; 0 Non Significant; - Significant in negative direction

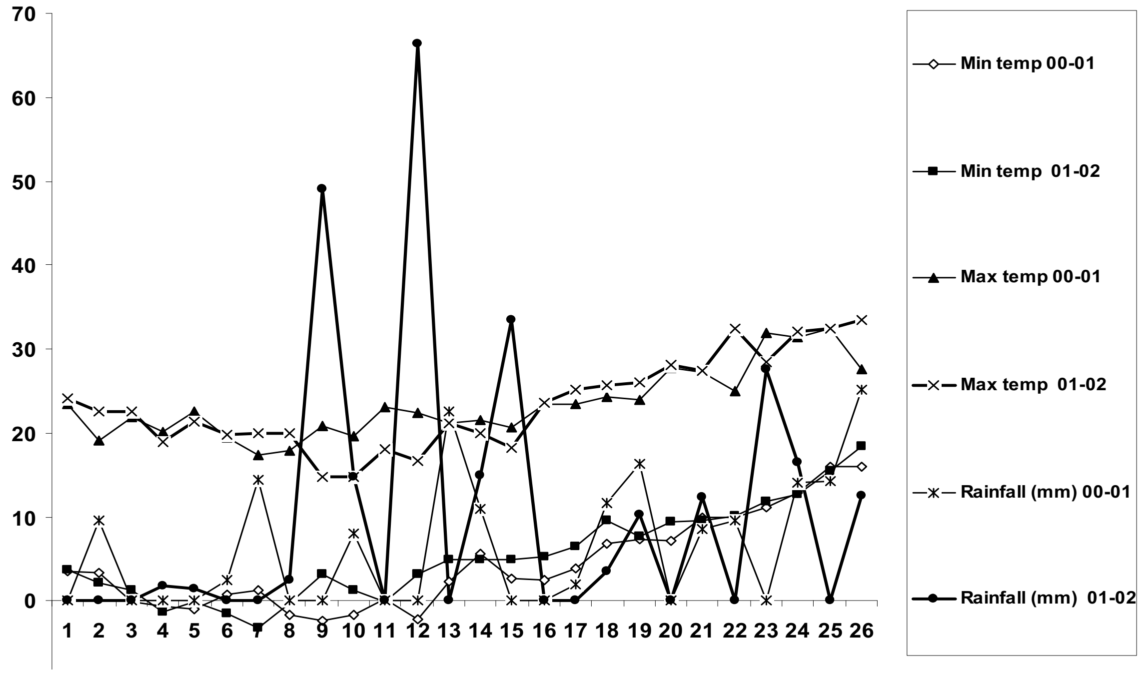

Fig. 2 Meteorological data during two years at the experimental site.

were predominant for heading days, effective tillers/plant, grain weight per ear, grain yield per plant and biological yield/plant. Non-additive genetic effects predominantly control expression of tillers/plant, grains per ear, 1000-grain weight, biological yield, spikelets/spike, grain weight/ear and grain yield per plant in winter × spring crosses (Salgotra *et al.* 1997; Kant *et al.* 2001; Kant and Gupta 2002; Shoran *et al.* 2003; Nazeer *et al.* 2004). Therefore, it would be imperative to evaluate not only the GCA of parents, but also the SCA of the cross combinations. Studies conducted in replicated plot trials have shown that GCA effects were larger than SCA effects in wheat (Perenzin *et al.* 1998; Oury *et al.* 2000; Gouis *et al.* 2002; Nazeer *et al.* 2004; Chowdhary *et al.* 2007).

Significant GCA × Year interactions for all traits indicate that the GCA effects associated with parents were inconsistent over years (**Table 1**). The larger magnitude of GCA compared to GCA × Year mean squares, further suggested that interaction effects may be of relatively minor importance for all the traits studied. However, a close perusal of individual year's data indicated that GCA effects for heading days, plant height, ear length, grain weight per ear, biological weight per ear and 1000-grain weight were least affected by the environment. Therefore, parents identified as having favourable GCA effects for these traits during 2000-01 would also have favourable GCA effects during 2001-02. Reciprocal × Year interactions were significant for all characters but for plant height indicating deviations in the performance of reciprocal combinations over the years.

Lower grain and biological yield in 2000-01 than in 2001-02 (**Figs. 1, 2**) may be attributed to the better moisture regime during tillering, late jointing and flowering due to good rains, better temperature particularly during initial growth period and during late jointing to flowering during 2001-02. This has led to better establishment of the crop at early stages, proper filling of grains and longer duration for grain filling.

Since GCA effects were largely superior to SCA effects, the correlation between *per se* value and GCA will give an indication about the possibility to use means of the two parents to predict the value of hybrid. Significant correlations in both years for three characters *viz.*, ear length, grain number per ear and 1000-grain weight (**Table 1**) indicated that GCA effects for these traits can be reliably predicted from their respective means. Sharma and Chaudhary (2007) suggested that selection for grain number per ear may improve grain yield. GCA effects for other traits were correlated with mean in 2001-02 but not in 2000-01, which indicated that predictability of these traits is environment dependent.

The diallel analysis revealed that GCA effects were negative for three winter wheat *viz.*, 'Fanjai 2', 'Wei 132', 'Zhong 65' and one-spring wheat *viz.*, 'PBW 373' parents for yield in both years (**Table 2**). On the contrary, GCA effects for yield of 'UP 2425' spring and 'Druchamp' winter wheat were positive in both years and should therefore contribute positive additive effects to their progeny. Out of seven, only 'UP 2425' had positive GCA effects for both yield and seed weight. Thus progeny of crosses involving 'UP 2425' would deserve increased attention for selection of high yielding, large seeded lines.

The SCA resulting from non-additive genetic effects are important for the breeding potential of cross combinations. Diallel analysis of combining ability demonstrated that GCA of 'Zhong 65' was greater than that of 'Wei 132' for the potential quantum yield (**Table 2**). When 'Zhong 65' was used as male parent and 'HD 2687' as female parent, their progeny had high and significant effects for plant height, effective tillers per plant, ear length, grain weight per ear, grain yield per plant, biological weight, 1000-grain weight (**Table 3**). These parents had either average or poor GCA for these traits, except for plant height, grains per ear and ear length. 'Fanjai 2', a winter wheat having good GCA for 1000-grain weight, plant height, heading and maturity days combined with 'Druchamp' having poor GCA for these traits to produce F_1 having high significant SCA. These results indicated that yield and yield attributes were affected by genes from both female and male parents and additive gene action was important in parents having high GCA, which complement with the genes of a low GCA parent. In such situation desirable transgressive segregants can be obtained by crossing high x low GCA combiner and selecting in F_2 generation (Langham 1961). These results were in general consistent over two years. As expected spring wheat parent 'UP 2425' would be the best genotype to use as a parent for developing progenies having high grain weight per ear, grain yield per plant, 1000-grain weight and biological yield per plant. Moreover, it also contributed, early heading, more effective tillers per plant and ear length. The winter wheat variety 'Wei 132' combined with 'UP 2425' to produce progeny with tall plant height, higher grain weight per ear, 1000-grain weight, biological yield and grain yield per plant, although GCA effects were poor/average for these traits. When two winter wheat parents such as 'Druchamp' and 'Wei 132' with poor or average GCA effects for 1000-grain weight, grain weight per ear, plant height and grain yield per plant were crossed, the F_1 showed a greater SCA for these traits. It may be inferred that diverse gene constellations for these traits would have caused this effect (Langhum 1961). Parent 'UP 2425' combined well with winter wheat variety 'Fanjai 2' for early heading, 1000-grain weight and plant height. However, both parents were good for thousand-grain weight, heading days and plant height. This cross is valuable because of the presence of an additive gene action and may respond to conventional selection methods.

Based on these results, it may be inferred that both *per se* performance as well as GCA are important in the selection of parents. These results indicated that breeders have been able to manipulate such yield attributes as tiller per plant, plant height, spikelets per ear, grains per ear, grain yield per plant and 1000-grain weight in the pursuit of obtaining higher yielding genotypes both in spring as well as in winter wheat. 'UP 2425' is a released variety, has an early heading, higher ear length, grain weight per ear, grain yield per plant, biological yield per plant and 1000-grain weight. 'Fanjai 2' had early heading and maturity, shorter plant height, higher 1000-grain weight. However, 'Druchamp' had higher effective tillers per plant, ear length, grain yield per plant and biological yield per plant. Whereas, 'Wei 132' is poor for effective tillers per plant, ear length, grain yield per plant, biological yield per plant and 1000-grain weight. 'Zhong 65' had later heading and maturity, lower effective tillers per plant, ear length, grain yield per plant, biological weight per plant and 1000-grain weight.

On an overall basis 'UP 2425' among spring wheat and 'Druchamp' among winter wheat were the best parents as revealed by GCA effects. Combining ability estimates of the parents revealed the importance of both additive as well as non-additive gene effects. 'HD 2687'/'Zhong 65' was the best cross combination having significant SCA effects for plant height, effective tillers per plant, ear length, grain weight per ear, grain yield per plant, biological yield per plant and 1000-grain weight (**Table 3**). However, both the parents were either poor or average general combiners for these traits, except plant height for which both were good. Spring × winter cross combinations of 'HD 2687'/'Zhong 65', 'UP 2425'/'Wei 132', 'UP 2425'/'Fanjai 2' showed significant SCA effects for most of the yield contributing characters. The performance of winter × winter crosses 'Fanjai 2'/ 'Druchamp' and 'Druchamp'/ 'Wei 132' indicated that though these parents were good and poor, and average and poor for most of the yield attributes their progenies may give desirable segregants. These results however restricted to these set of parents indicated that although GCA of most of the parents ranged from average or good or poor nevertheless possibilities exist to develop desirable genotypes by crossing appropriate parents. Further, probabilities of developing desirable genotypes are high in spring × winter and winter × winter crosses than spring × spring crosses. These results suggest that multiple crossing followed by conventional selection may improve yield attributes and consequently yield.

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