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Full Length Research Paper

Heterosis and combining ability analysis in bread wheat (*Triticum aestivum* L.)

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Heterosis and combining ability analysis were studied in a 7 × 7 diallel set of bread wheat. Analysis of variance (ANOVA) revealed the presence of significant variance due to general combining ability (GCA) among the parents for all the traits, and due to specific combining ability (SCA) among the crosses for the all the traits except for number of tillers per plant, plant height and number of spikelets per spike. Combining ability analysis revealed the involvement of both additive and non additive gene action in the inheritance of most of the traits. On the basis of GCA, SCA effects and per se performance, parents K 9107 for 6 traits, K 9162 for 4 traits and GW 373 for 3 traits and crosses K 9107 × K 7903 for 2 traits, K 68 × K 7903 for 2 traits were found good general and specific combiners, respectively. Significant heterosis over economic parent and mid parent was observed for almost all the traits studied. The magnitude of heterosis was highest (21.74%) for number of spikelets per spike over economic parent and for number of tillers per plant (13.73%) over mid parent.

Key words: Wheat, heterosis, combining ability, diallel.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely cultivated crop among the cereals and is the principal food crop in most areas of the world. It is the leading grain crop of the temperate climates of the world, and is grown on 215.27 million hectares in the world (FAO, 1999). Global demand for wheat is growing at approximately 2% per year, twice the current rate of gain in genetic yield potential (Skovmand and Reynolds, 2000). Heterosis breeding provides the way to overcome the yield barriers. Wheat production can be enhanced through the development of new cultivars having wider genetic base and better performance under various agro-climatic conditions. Researchers (Griffing, 1956; Hayman, 1954; Mather and Jinks, 1982) developed techniques to analyze genotypes for all possible crosses. The scope for utilization of heterosis largely depends on the direction and magnitude of heterosis. Knowledge about combining ability is important in selecting suitable parents for hybridization, understanding of inheritance of quantitative traits and also in identifying the promising crosses for further use in breeding programmes. The present investigation was undertaken to study the combining ability of varieties/ lines and to quantify the magnitude and direction of heterosis in hybrid for yield and its contributing traits. The combining ability in wheat refers to experiments carried out with a limited number of hybrids grown in small plots at a few sites (Johnson and Schmidt, 1968; Virmani and Edwards, 1983; Lucken 1986). The significance of the effects for general combining ability (GCA) and specific combining ability (SCA) were tested according to Ross et al. (1983), for the quality measurements. The second order interaction location × male × female was used as experimental error to test the main sources of variation and the first-order interactions. The statistically non-significant first-order interactions were pooled with the second-order interaction in order to have a better estimation of variance error.

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Abbreviations: ANOVA, Analysis of variance; **GCA,** general combining ability; **SCA,** specific combining ability; **RBD,** randomized block design; **M.S,** mean sum of squares; **GPR,** general predictability ratio.

Table 1. ANOVA for combining ability.

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	'F' test
GCA	(n-1)	S_g	M_g	$M_g/M_{e'}$ for (n-1) and error d.f.
SCA	n (n-1)/2	S_s	M_s	$M_g/M_{e'}$ for n(n-1)/2 and error d.f.
Error	(r-1) $(n+f_1-1)$	S_e	$M_{e'}$	

GCA, General combining ability; SCA, specific combining ability; n, number of parents; r, number of replications; f_1, number of F_1 hybrids; S_g, sum of squares due to gca; S_g, 1/(n+2).

MATERIALS AND METHODS

Production of F_1 seed

During the Rabi season 2007 to 2008, all possible straight crosses in diallel fashion excluding reciprocals were made among 7 parents so as to have 21 crosses with sufficient seed (40 to 45 seeds).

Conduct of experiment

Experimental material consisting of 7 parents and their 21 F_1 progenies were grown during cross made and F1 rose in same season in randomized block design (RBD) with 3 replications at Crop research farm, Nawabganj of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. Each treatment consisted of 3 rows of 3 m length spaced at 25 and 15 cm for inter and intra row spacing, respectively. Recommended doses of fertilizers at 120 kg N + 60 kg P_2O_5 + 40 kg K_2O per hectare were applied in the experimental field along with five irrigations at all critical stage to raise a healthy crop.

Recording of experimental data

Data were recorded on 5 randomly selected plants from parents as well as in F_1 progenies for various quantitative traits with the help of appropriate biometrical approaches.

Days to 75% flowering

Flowering days were recorded from date of sowing to date of 75% flowering stage in each treatment.

Number of tillers per plant

Before harvesting total number of ear bearing tillers per plant were counted.

Plant height

Plant height was measured in cm from ground level to tip of ear avoiding awns of the panicle of the main shoot.

Number of spikelets per spike

The spikelets bearing the grains in each spike of selected plants were counted and averaged.

Number of grains per spike

Number of grains of main ear from each selected plant were counted and averaged.

1000 - Grains weight

The weight of 1000 grains of each treatment were taken with the help of electronic balance.

Seed hardness

Seed hardness was determined by OSK 201 grain hardness type E. It is expressed in kg per seed. Randomly 10 grains were taken from each selected 5 plants of each replication of each treatment and each grain was placed one by one on the machine plate and pressure column handle till the grain was crushed. The hardness was recorded from the scale attached with the instrument. The average mean was taken as the final press weight in kg of each sample.

Grain yield per plant

Total grains obtained from each plant were weighed in gm with the help of electronic balance.

The combining ability analysis was worked out by the procedure suggested by Griffing's (1956) Method 2, Model 1. The mathematical model for the combining ability analysis is assumed to be:

$Y_{ijkl} = \mu + g_i + g_j + s_{ij} + 1/bc\ \Sigma i\ \Sigma e_{ijkl}$

(ij = 1,2,3,……….n;

k = 1, 2, 3,………b;

l = 1,2,3,……….c)

Where $\mathbf{Y_{ijkl}}$, Mean of i x j^{th} genotype in k^{th} replication; $\boldsymbol{\mu}$, the population mean; $\mathbf{g_i}$, the GCA effect of i^{th} parent; $\mathbf{g_j}$, the GCA effect of j^{th} parent; $\mathbf{s_{ij}}$, the specific combining ability (sca) effect for the cross between i^{th}, j^{th} parent such that $s_{ij} = s_{ji}$; $\mathbf{\Sigma i\ \Sigma e_{ijkl}}$, the environmental effect associated with the $ijkl^{th}$ individual observation on i^{th} individual in the k^{th} block with i^{th} as female parent and j^{th} as male parent.

The usual restrictions such as $\Sigma g_i = 0$ and $\Sigma s_{ij} = s_{ii} = 0$ (for each i) were imposed. The analysis of variance (ANOVA) table for combining ability with expectation of mean sum of squares (M.S.) is shown in Table 1.

$[\Sigma (Y_i + Y_{ii})^2 - (4/n) Y^2]$,$S_s$ = Sum of squares due to sca,

$S_s = \Sigma < \Sigma\ Y_{ij}^2 - 1/(n+2)\ [\Sigma (Y_i + Y_{ii})^2 + 2/(n+1)(n+2) Y^2]$, $M_{e'}$ =

Me1/r

Where Y_i, Total of the array involving i^{th} as a female parent; Y_{ii}, the value of the i^{th} of the array; Y.., the grand total; Y_{ij}, the value of i x j^{th} cross; M_{el}, the error M.S. obtained from main ANOVA.

The components of variances were estimated as suggested by Singh et al. (1990) in the following ways:

GCA expected M.S. = σ_e^2 + (n + 2)/(n – 2) σ_{gi}^2

SCA expected M.S. = σ_e^2 + 2/(n – 1) σ_{sij}^2

General predictability ratio (GPR) was computed according to the procedure given by Baker (1968).

$$GPR = 2\sigma^2_{gca} / 2\sigma^2_{gca} + \delta\sigma^2_{sca}$$

Estimates of various effects

The various effects were estimated as follows:

GCA effect of i^{th} parent = g_i = 1/(n+2) [($Y_{i.}$ + Y_{ii}) – 2/nY..]

SCA effect of ij^{th} cross = S_{ij} = Y_{ij} – 1/(n + 2) [$Y_{i.}$ + $Y_{.j}$ + Y_{ij}) + 2Y/ (n + 1)(n +2)Y..]

Where g_i and s_{ij}, The estimates of the GCA and SCA effects, respectively; n, $Y_{i,}$ Y_{ii}, Y.. and Y_{ij}, the same as explained earlier; $Y_{.j}$, total of the arrays involving j^{th} parent as a male; Y_{jj}, the value of the j^{th} parent in the array.

Estimation of standard errors

SE (g_i) = $[(n-1)\ \sigma_e^2 / n\ (n+2)]^{0.5}$

SE (g_i-g_j) = $[2\ \sigma^2 / (n+2)]^{0.5}$

SE (s_{ij}) = $[(n\ (n+1)\ \sigma_e^2 / (n+1)\ (n+2)]^{0.5}$

SE (s_{ij}-s_{ik}) = $[2(n+1)\ \sigma_e^2 / (n+2)]^{0.5}$

Where σ_e^2, $M_{e'}$ [taken as error M.S. from the combining ability analysis] = Mel/r

Estimation of heterosis

Heterosis

The heterosis was calculated (in per cent) as increase or decrease in relation to mid parent and economic parent. The formulae used are given below:

a. Heterosis over economic parent (%) = $[\overline{F_1} - \overline{EP} / \overline{EP}]$ × 100

b. Heterosis over mid parent (%) = $[\overline{F_1} - \overline{MP} / \overline{MP}]$ × 100

Where $\overline{F_1}$, $\overline{EP}$, and $\overline{MP}$ are the mean of F_1, economic parent and mid parent, respectively.

Test of significance

Significance of heterosis over economic parent was tested as:

SE_{EP} = $(2Me'/r)^{0.5}$

Where Me', Error variance obtained from parents and F_1 combination; r, number of replications; CD, SE x't' ('t' value at 5% and 1%).

Seven genotype namely, K-65 (P_1), K-9351 (P_2), K-9162 (P_3), GW-373 (P_4), K 9107 (P_5), K 68 (P_6) and K 7903 (P_7) and their 21 direct were evaluated for yield and yield related traits. Observation were recorded on days to 75% flowering, number of tillers/plants, plant height(cm), number of spikelets/ spike, number of grains/spike, 1000 - grains weight or test weight (g), seed hardness and grains yield per plant(g) on five randomly selected plants in each plot. The combining ability analysis was worked out by the procedure suggested by Griffing's (1956) Method 2, Model 1. The F_1 hybrid performance was computed as the estimate of heterosis over economic parents and mid parents and their significant was examined with "F" test. The GPR was computed according to the procedure given by Baker (1968).

RESULTS AND DISCUSSION

ANOVA for combining ability revealed that the variance due to GCA were significant for all the traits and due to SCA were significant for all the characters except for number of tillers per plant, plant height and number of spikelets per spike (Table 2). The extent of M.S due to GCA was higher than SCA for all the characters. This indicates existence of genetic variability in the parental lines included in the present study and involvement of both additive and non-additive gene effects in the inheritance of these traits. The GCA effects of the parents along with the mean value of the parents (Table 3) indicated that there was close relationship between parental mean performance and GCA effects for almost all the characters. On the basis of over all performance, parent K 7903 was found to be desirable combiner for early flowering and shorter plant height. The parent K 9107 was responsible for early flowering, number of tillers/plant, plant height, number of spikelets per spike, grain number, 1000 grain weight, seed rigidity and grain yield per plant. Similarly, the parent GW 373 was responsible for early flowering and more tillers per plant, and parents K 9162 were responsible for more tillers per plant, more spikelets per spike, grain number, more seed hardness, and grain yield per plant. K 9351 resulted in shorter plant height and enhanced grain yield. Thus, the perfect relationship could be established between per se performance and GCA effects of the parents. Similar finding was reported by Yadav and Singh, (2004).

The magnitude of SCA effects is of vital importance in selecting cross combinations with higher probability of

Table 2. ANOVA for combining ability (GCA and SCA) for 8 characters in 7 × 7 diallel cross of wheat.

Source of variation	Degree of freedom	Day to 75% flowering	Number of tiller per plant	Plant height (cm)	Number of spikelet per spike	Number of grain per spike	1000-grain weight (g)	Seed hardness (kg/seed)	Grain yield per plant (g)
GCA	6	22.43**	5.79**	286.01**	7.29**	34.90**	6.53**	0.72**	2.71**
SCA	21	0.66**	0.20	0.50	0.34	0.68*	0.64**	0.12*	0.19**
Error	54	0.27	0.21	0.38	0.29	0.35	0.29	0.07	0.08

*,Significant at 5% level of significance; **, significant at 1% level of significance; GCA, general combining ability; SCA, specific combining ability.

Table 3. Estimation of GCA effects of 7 parents along with their mean performance for 8 characters in F_1 generation of wheat.

Parent	Day to 75% flowering		Number of tiller per plant		Plant height (cm)		Number of spikelet per spike		Number of grain per spike		1000-grain weight (g)		Seed hardness (kg/seed)		Grain yield per plant (g)	
	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean	GCA effect	Parent mean
K 65	1.09**	75.00	-0.62**	7.00	3.66**	102.17	0.51**	26.00	-3.08**	55.00	0.01	39.00	0.14**	11.30	-0.08**	14.67
K 9351	1.24**	76.00	-0.18**	7.33	-3.99**	87.10	-0.60**	25.00	1.96**	65.00	-0.32**	37.67	-0.15**	10.80	0.28**	15.47
K 9162	2.39**	78.67	0.12**	8.67	1.76**	96.00	1.03**	28.00	-0.04	62.00	-0.12	38.00	0.50**	11.90	0.59**	16.13
GW 373	-0.69**	72.00	0.67**	10.00	-6.49**	81.83	-1.34**	23.00	-1.41**	59.00	-1.23**	36.40	-0.31**	10.17	-0.05**	14.57
K 9107	-0.69**	72.00	1.41**	11.00	3.82**	102.20	1.03**	28.00	2.77**	67.00	1.65**	42.00	-0.09**	10.70	0.41**	15.67
K 68	-1.58**	70.33	-0.74**	6.00	7.72**	109.83	-0.08**	26.33	-0.45**	60.00	0.07	37.73	0.15**	11.00	-0.06**	15.07
K 7903	-1.76**	70.00	-0.66**	6.33	-6.48**	80.60	-0.56**	24.00	0.25**	61.67	-0.06	38.17	-0.24**	10.40	-1.09**	12.00
SE (gi)	0.03		0.01		0.02		0.02		0.06		0.05		0.01		0.01	
SE (gi-gj)	0.13		0.02		0.03		0.02		0.09		0.09		0.01		0.01	

*, Significant at 5% level of significance; **, Significant at 1% level of significance.

generating transgressive segregates. Significant yield performance in the specific crosses was due to the involvement of best general combiners in our study. The desirable SCA effects are presented in Table 4. Out of 21 crosses 11, 11, 7, 7, 11 and 12 were observed to be desirable with positive significant value of SCA effects for number of tillers per plant, number of spikelets per spike, number of grains per spike, 1000-grain weight, seed hardness and grains yield per plant, respectively. The ranking of specific cross combinations on the basis of their per se performance and SCA effects were computed in Table 5. In the present study four crosses namely, K 9162 × GW 373, K 9162 × K 7903, K 65 × K 7903 and GW 373 × K 9107 represent significant positive SCA effects for grain yield. However, the common good crosses on the basis of per se performance and SCA effects were K 9107 × K 7903 and K 68 × K 7903 for days to 75% flowering; K 9107 × K 68 and K 9162 × K 7903 for number of tillers per plant; K 9351 × K 7903 for shorter plant height; K 65 × K 7903 for number of spikelets per spike; K 9107 × K 7903 for number of grains per spike; K 68 × K 7903 for 1000-grain weight; K 9351 × K 68 and K 9162 × K 68 for seed hardness and K 9162 × GW 373 and GW 373 × K 9107 for grain yield per plant. Some crosses showed desirable SCA effects for more than one characters. Cross combination K 65 × K 9351 showed significant and desirable SCA effects for 4 traits viz.; days to 75% flowering, number of tillers per plant, plant height and grain yield per plant.

Table 4. Estimation of SCA effects and corresponding mean performance of 8 characters in 7 × 7 diallel cross of wheat.

Cross	Day to 75% flowering		Number of tiller per plant		Plant height (cm)		Number of spikelet per spike	
	SCA effect	Mean	SCA effect	Mean	SCA effect	Mean	SCA effect	Mean
K 65 × K 9351	-0.35**	76.00	0.52**	8.00	-0.41**	93.77	-0.05	26.00
K 65 × K 9162	-0.50**	77.00	-0.11*	7.67	0.56**	100.50	0.32**	28.00
K 65 × GW 373	0.57**	75.00	-0.67**	7.67	-0.58**	91.10	0.69**	26.00
K 65 × K 9107	0.57**	75.00	-0.07	9.00	-0.49**	101.50	0.32*	28.00
K 65 × K 68	0.46**	74.00	0.41**	7.33	-0.06	105.83	0.10*	26.67
K 65 × K 7903	1.65**	75.00	0.00	7.00	0.31**	92.00	0.92**	27.00
K 9351 × K 9162	0.35**	78.00	0.11*	8.33	0.71**	93.00	0.10*	26.67
K 9351 × GW 373	0.09	74.67	0.22**	9.00	-0.37**	83.67	-0.19**	24.00
K 9351 × K 9107	1.43**	76.00	0.15**	9.67	-0.31**	94.03	-0.23**	26.33
K 9351 × K 68	-0.69**	73.00	-0.04	7.33	-0.38**	97.87	-0.79**	24.67
K 9351 × K 7903	0.17*	73.67	0.22**	7.67	-0.38**	83.67	1.03**	26.00
K 9162 × GW 373	-0.72**	75.00	-0.41**	8.67	0.21**	90.00	-0.16**	25.67
K 9162 × K 9107	0.28**	76.00	-0.48**	9.33	0.73**	100.83	-0.19**	28.00
K 9162 × K 68	0.50**	75.33	0.00	7.67	0.67**	104.67	-0.08	27.00
K 9162 × K 7903	0.35**	75.00	0.59**	8.33	1.20**	91.00	0.40**	27.00
GW 373 × K 9107	-0.31**	72.33	-0.37**	10.00	-0.02	91.83	0.18**	26.00
GW 373 × K 68	1.24**	73.00	0.44**	8.67	-0.18**	95.57	0.62**	25.33
GW 373 × K 7903	0.43**	72.00	0.04	8.33	0.35**	81.90	-0.23**	24.00
K 9107 × K 68	0.24**	72.00	0.70**	9.67	-0.12*	105.93	-0.08	27.00
K 9107 × K 7903	-0.91**	70.67	0.30**	9.33	0.14*	92.00	0.40**	27.00
K 68 × K 7903	-0.69**	70.00	0.11*	7.00	0.31**	96.07	-0.49**	25.00
SE (S_{ij})	0.08		0.04		0.05		0.04	
SE (S_{ij} - S_{ik})	0.11		0.06		0.08		0.07	

Cross	Number of grains per spike		1000-grain weight (g)		Seed hardness (kg/seed)		Grain yield per plant (g)	
	SCA effect	Mean	SCA effect	Mean	SCA effect	Mean	SCA effect	Mean
K 65 × K 9351	0.24	61.00	0.02	38.40	-0.29**	10.83	0.26**	15.60
K 65 × K 9162	1.24**	60.00	0.92**	39.50	0.13**	11.90	-0.29**	15.37
K 65 × GW 373	0.61**	58.00	-1.31**	36.17	0.44**	11.40	-0.44**	14.57
K 65 × K 9107	-0.57**	61.00	0.68**	41.03	-0.28**	10.90	0.03	15.50
K 65 × K 68	-0.35	58.00	-0.58**	38.20	0.32**	11.73	0.50**	15.50
K 65 × K 7903	0.28	59.33	-0.31	38.33	-0.10**	10.93	0.56**	14.53

Table 4. Continued.

K 9351 × K 9162	0.20	64.00	-0.25	38.00	-0.05*	11.43	0.02	16.03
K 9351 × GW 373	-0.09	62.33	0.62**	37.77	-0.20**	10.47	0.14**	15.50
K 9351 × K 9107	0.39*	67.00	0.15	40.17	0.11**	11.00	0.30**	16.13
K 9351 × K 68	0.61**	64.00	-0.61**	37.81	0.48**	11.60	-0.33**	15.03
K 9351 × K 7903	0.24	64.33	0.85**	39.17	0.00	10.73	0.07**	14.40
K 9162 × GW 373	-0.43*	60.00	-0.01	37.33	0.05*	11.37	0.59**	16.27
K 9162 × K 9107	-0.61**	64.00	0.12	40.33	0.16**	11.70	-0.15**	16.00
K 9162 × K 68	0.28	61.67	0.62**	39.27	0.42**	12.20	-0.34**	15.33
K 9162 × K 7903	-1.09**	61.00	-0.51**	38.00	-0.23**	11.17	0.56**	15.20
GW 373 × K 9107	-0.24	63.00	-1.11**	38.00	0.01	10.73	0.50**	16.00
GW 373 × K 68	0.98**	61.00	1.86**	39.40	-0.46**	10.50	0.14**	15.17
GW 373 × K 7903	-0.72**	60.00	-0.41**	37.00	0.83**	11.40	0.01	14.00
K 9107 × K 68	-0.20	64.00	-0.08	40.33	0.28**	11.47	-0.43**	15.07
K 9107 × K 7903	2.09**	67.00	0.22	40.50	0.20**	11.00	0.34**	14.80
K 68 × K 7903	0.65**	62.33	0.99**	39.70	-0.20**	10.83	0.38**	14.37
SE (S_{ij})	0.17		0.17		0.02		0.02	
SE (S_{ij} - S_{ik})	0.24		0.25		0.03		0.03	

*, Significant at 5% level of significance; **, significant at 1% level of significance.

Table 5. Estimation of heterosis in percent for 8 characters over economic parent and average parent in 7 × 7 diallel cross of wheat.

Cross	Day to 75% flowering		Number of tiller per plant		Plant height (cm)		Number of spikelet per spike		Number of grain per spike		1000 grain weight (g)		Seed hardness (kg/ seed)		Grain yield per plant	
	EP	MP	EP	MP	EP	MP	EP	MP	EP	MP	EP	MP	EP	MP	EP	MP
K 65 × K 9351	5.55**	0.66**	-20**	11.63**	14.59**	-0.92**	13.04**	1.96**	3.39*	1.67	5.49*	0.17*	6.49	-1.96*	7.07**	3.54
K 65 × K 9162	6.94**	0.22**	-23.3**	-2.13**	22.81**	1.43**	21.74**	3.70**	1.69	2.56	8.52**	2.60**	17.01**	2.59**	5.49*	-0.22*
K 65 × GW 373	4.17**	2.04*	-23.3**	-9.80*	11.33**	-0.98**	13.04**	6.12	-1.69	1.75*	-0.63	-4.07	12.09**	6.21	0.00	-0.34
K 65 × K 9107	4.17**	2.04*	-10.0	0.00	24.04**	-0.67**	21.74**	3.70**	3.39*	0.00	12.72**	1.32**	7.18	-0.91*	6.38*	2.20
K 65 x K 68	2.78**	1.83	-26.7**	12.82**	29.33**	-0.16**	15.96**	1.91**	-1.69	0.87	4.94*	-0.43*	15.34**	5.23*	6.38*	4.26
K 65 x K 7903	4.17**	3.45	-30.0**	5.00**	12.43**	0.67**	17.39**	8.00*	0.56	1.71	5.30*	-0.65**	7.47*	0.77	-0.27	9.00
K 9351 × K 9162	8.33**	0.86**	-16.7*	4.17**	13.65**	1.58**	15.96**	0.63**	8.47**	0.79**	4.39*	0.44	12.39**	0.73**	3.51**	1.48**
K 9351× GW 373	3.71**	0.90**	-10.0	3.85*	2.25**	-0.95**	4.35	0.00	5.64**	0.54**	3.76	1.98	2.95	-0.16	6.38*	3.22
K 9351 × K 9107	5.55**	2.70**	-3.3	5.45	14.91**	-0.65**	14.48**	-0.63**	13.56**	1.52**	10.36**	0.84**	8.16*	2.33	10.71**	3.64*
K 9351× K 68	1.39	-0.23	-26.7**	10.00**	19.60**	-0.61**	7.26**	-3.90**	8.47**	2.40**	3.93	0.35	14.06**	6.42	3.16	1.53
K 9351 × K 7903	2.32	0.91	-23.3**	12.20**	2.25**	-0.22**	13.04**	6.12	9.03**	1.38**	7.61**	3.30*	5.51	1.26	-1.17	4.85
K 9162× GW 373	4.17**	-0.44**	-13.3*	-7.14	9.98**	1.22**	11.61**	0.65**	1.69	-0.83	2.55	0.36	11.80**	3.02*	11.67**	5.97*

Table 5. Continued.

K 9162 × K 9107	5.55**	0.88**	-6.7	-5.08	23.22**	1.75**	21.74**	0.00**	8.47**	0.78**	10.80**	0.83**	15.04**	3.54**	9.81**	0.63**
K 9162 × K 68	4.62**	1.12**	-23.3**	4.55*	27.91**	1.70**	17.39**	-0.61**	4.52**	1.09*	7.88**	3.70	19.96**	6.55**	5.22	-1.71**
K 9162 x K 7903	4.17**	0.90**	-16.7*	11.11**	11.21**	3.06**	17.39**	3.85**	3.39*	-1.35**	4.39*	0.22*	9.83*	0.15*	4.32	8.06
GW 373 × K 9107	3.24	0.46	0.00	-4.76	12.22**	-0.20**	13.04**	1.96**	6.78**	0.00**	4.39*	-3.06**	5.51	2.88	9.81**	5.84
GW 373 ×K 68	1.39	2.58	-13.3*	8.33**	16.79**	-0.28**	10.13**	2.70*	3.39*	2.52	8.24**	6.29	3.24	-0.79	4.12	2.36
GW 373 ×K 7903	0.00	1.41	-16.7*	2.04**	0.08	0.84	4.35	2.13	1.69	-0.55	1.65	-0.76	12.09**	10.86	--3.91	5.40
K 9107 × K 68	0.00	1.17	-3.3	13.73**	29.45**	-0.08**	17.39**	-0.61**	8.47**	0.79**	10.80**	1.17**	12.78**	5.68	3.43	-1.95*
K 9107 × K 7903	-1.85	-0.47	-6.7	7.69*	12.43**	0.66**	17.39**	3.85**	13.56**	4.15**	11.26**	1.04**	8.16*	4.27	1.58	6.99
K 68 × K 7903	-2.78**	-0.24	-30.0*	13.51**	17.40**	0.89**	8.69**	-0.66**	5.64**	2.47*	9.06**	4.61*	6.49	1.25	-1.37	6.16

*, Significant at 5% level of significance; **, significant at 1% level of significance.

plant. Similarly K 65 × K 9162 recorded significant and desirable SCA effects for days to 75% flowering, number of spikelets per spike, number of grains per spike, 1000 grain weight, and seed hardness.

Heterosis was estimated over the mid or economic parent. The heterosis was estimated over wide adopted and high yield variety GW 373 and results are presented in Table 6. The significant economic heterosis and average heterosis in desirable direction were observed in K 68 × K 7903 and K 9162 × GW 373 for early flowering and grain yield per plant, respectively. Economic heterosis for number of tillers per plant was not observed in desirable direction, but in average heterosis, out of 21 crosses, 14 crosses were observed in desirable direction. The average heterosis for plant height was observed in 11 crosses; 19 crosses in economic heterosis and 12 crosses in average heterosis for number of spikelets per spike were observed in desirable direction, 15 crosses in economic heterosis and 11 crosses in mid heterosis were observed in desirable direction for number of grains per spike, 16 crosses in economic heterosis and 10 crosses in average heterosis were observed in desirable direction for 1000 grain weight, 14 crosses in economic heterosis and 7 crosses in average heterosis were observed in desirable direction for seed hardness, and 10 and 4 crosses showed economic heterosis and average heterosis estimates in desirable direction for grain yield. Enhancement of grain yield is possible through hybridization. The crosses which exhibited significant economic heterosis for grain yield per plant were K 9162 × GW 373, K 9351 × K 9107, K 9162 × K 9107, GW 373 × K 9107, K 65 × K 9351, K 65 × K 9107, K 65 × K 68, K 9351 × GW 373, K 65 × K 9162, and K 9351 × K 9162 and the crosses which exhibited significant average heterosis for grain yield per plant were K 9162 × GW 373, K 9351 × K 9107, K 9351 × K 9162 and K 9162 × K 9107. It indicated that high yielding varieties involved in the crosses were predominantly responsible for enhancing the yield. Similar finding were reported by Sharma et al. (1991).

Conclusion

The GCA and SCA variances were significant for almost all the characters whereas non significant SCA variance was observed for number of tillers per plant, plant height and number spikelets per spike, indicating the importance of both additive and non-additive gene effects. On the basis of GCA effects it was observed that K 9107 was best general combiner for almost all the characters, and K 9162 for number of tillers per plant, number of spikelets per spike, seed hardness and grain yield per plant. GW 373 was most important parent for the expression of early flowering, more tillers per plant and shorter plant height. The best specific combiners K 9107 × K 7903 was considerable for days to 75% flowering and number of grains per spike, the cross K 68 × K 7903 were considerable for days to 75% flowering and 1000-grain weight. Economic heterosis was estimated over widely adopted and high yielding variety GW 373. Out of 21 crosses only 10 crosses exhibited significant heterosis over economic parents. These include K 9162 x GW 373, K 9351 × K 9107, K 9162 × K 9107, GW 373 × K 9107, K 65 × K 9351, K 65 × K 9107, K 65 × K 68, K 9351 × GW 373, K 65 × K 9162 and K 9351 × K 9162. Three crosses namely K 9351 × K 9107, K 9162 × K 9107 and K 9351 × K 9162 had the both parents with significant GCA effects, indicating additive x additive gene action played an important role for the expression of the traits.

Table 6. Ranking of good cross combination on the basis of per se performance and their SCA effect in a 7 × 7 diallel cross of wheat.

Character	Parent with higher per se performance	Good cross combination	Superior common cross combination
Days to 75% flowering	(1) K 68 × K 7903 (2) K 9107 × K 7903 (3) K 9107 × K 68 (4) GW 373 × K 7903 (5) GW 373 × K 9107	K 9107 × K 7903 K 68 × K 7903 K 9351 × K68 K 65 × K9162	K 9107 × K 7903 K 68 × K 7903
Number of tillers per plant	(1) GW 373 × K 9107 (2) K 9351 × K 9107 (3) K 9107 × K 68 (4) K 9162 × K 9107 (5) K 9162 × K 7903	K 9107 × K 68 K 9162 × K 7903 K 65 × K 9351 GW 373 × K 68	K 9107 × K 68 K 9162 × K 7903
Plant height (cm)	(1) GW 373 × K 7903 (2) K 9351 × GW 373 (3) K 9351 × K 7903 (4) K 9162 × GW 373 (5) K 9162 × K 7903	K 65 × GW 373 K 65 × K 9107 K 65 × K- 9351 K 9351 × K 7903	K 9351 × K 7903
Number of spikelets per spike	(1) K 65 × K 9162 (2) K 65 × K 9107 (3) K 9162 × K 9107 (4) K 65 × K 7903 (5) K 9162 × K 68	K- 9351 × K 7903 K- 65 × K 7903 K- 65 × GW 373 GW 373 × K 68	K 65 × K 7903
Number of grains per spike	(1) K 9351 × K 9107 (2) K 9107 × K 7903 (3) K 9351 × K 7903 (4) K 9351 × K 9162 (5) K 9351 × K 68	K 9107 × K 7903 K 65 × K 9162 GW 373 × K 68 K 68 × K 7903	K 9107 × K 7903
1000 grain weight (g)	(1) K 65 × K 9107 (2) K 9107 × K 7903 (3) K 9162 × K 9107 (4) K 9107 × K 68 (5) K 68 × K 7903	GW 373 × K 68 K 68 × K 7903 K 65 × K 9162 K 9351 × K 7903	K 68 × K 7903

Table 5. Continued.

Seed hardness (kg/ seed)	(1) K 9162 × K 68 (2) K 65 × K 9162 (3) K 65 × K 68 (4) K 9162 × K 9107 (5) K 9351 × K 68	GW 373 × K 7903 K 9351 × K 68 K 9162 × K 68 K 65 × GW 373	K 9351 × K 68 K 9162 × K 68
Grains yield per plant (g)	(1) K 9162 × GW 373 (2) K 9351 × K 9107 (3) K 9351 × K 9162 (4) K 9162 × K7 (5) GW 373 × K 9107	K 9162 × GW 373 K 9162 × K 7903 K- 65 × K 7903 GW 373 × K 9107	K 9162 × GW373 GW 373 × K 9107

High heritability (broad sense) was observed for all the characters. High heritability with moderate genetic advance per cent of mean were noticed for number of tillers per plant (in F_1s), plant height, number of spikelets per spike (in parent), number of grain per spike (in parents), and grain yield per plant (in parents).

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