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Combing ability and heterosis analysis for yield and its related traits in bread wheat (*Triticum Aestivum* L.)

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Abstract
In order to estimate the magnitude of combining ability and heterosis of wheat, 15 hybrids were synthesised in a 6 × 6 diallel fashion excluding reciprocals. The experiment was conducted in 2014–15 and 2015–16 at Crop Research Farm of CSAUA&T, Kanpur, UP. Analysis of combining ability and heterosis over better parent (BP) was undertaken for yield and its component traits. The inspection of data exhibited that the variance due to *gca* was higher than variance due to *sca* for all traits except for number of spikelets per spike and 1000-grain weight which indicated the predominance of additive gene action. Parental genotypes K9107, PBW343 and K1006 were found as good general combiners based on their *gca* effects as well as *per se* performance for grain yield. Based on *sca* effects, crosses K1006×K9107 and K9107×K607 were exhibited good specific combinations in F_1 generation for grain yield per plant. All the desirable specific combiners for different traits involved either high x high or high x low or low x low general combiners. Significant and desirable heterosis over better parent identified for three cross combinations K1006×K424, K9107×K424, and K607×K424 for grain yield.

Keywords: Combining ability, diallel, heterosis, wheat, yield

Introduction
The predetermination of suitable parents for evolving high yielding progenies is a matter of concern to the plant breeders. The combining ability is one of the efficient way to differentiate between good and poor combiners for choosing appropriate parents and crosses for yield and its associated components in the breeding programme (Singh *et al.*, 2013) [3, 14-16]. Performances per se do not reveal alone which parents are good or poor combiners. To overcome this problem, it is necessary to gather information on the nature of gene actions. General combining ability is associated with additive type of gene action while specific combining ability is associated with non-additive type of gene actions. Non-additive gene type of actions is not fixable considering that additive type of gene actions or complementary type epistatic gene interactions are reliably fixable (Raiyani *et al*., 2015) [12].
Heterosis breeding offers promises to break the yield stagnation in global wheat productivity (Adhikari *et al.*, 2020) [2]. Exploitation of heterosis is considered to be one of the outstanding achievements of plant breeding. In a self-pollinated crop like wheat the scope of utilization of heterosis depends mainly on the direction and magnitude of heterosis. Estimation of heterosis over better parent (heterobeltiosis) may be useful in identifying true heterotic cross combinations. The aim of heterosis is to exploit increased vigour in self-pollinated crops like wheat in order to getting increased yield (Singh *et al.*, 2012) [3, 14-16]. Keeping in view of all above, in the present study, an attempt has been made to examine the combing ability as well as heterosis of some wheat varieties and their crosses on yield related traits.

Materials and Methods
The experimental material comprising six wheat genotypes (PBW 343, K 1006, K9107, K607, K424 and K9423) was sown at Crop Research Farm, Nawabganj of CSAUA&T, Kanpur (26 °46'N and 80 °33'E and 126msl), Uttar Pradesh, India during *rabi* 2014-2015 for attempting of crossing programme in a diallel fashion (6 × 6) excluding reciprocals. Following season (*rabi* 2015-2016) experimental material comprising total 15 genotypes (6 parental line and 15 F_1's) was planted in a Randomized Block Design (RBD) having three replications. Each of the parental lines and crosses were sown by hand dibbling method in three rows plot (3 m length keeping 23 cm spacing between row and 10 cm between plants). The recommended package of practices and cultural operations were followed to raise good crop and for proper

expression of material.

Observations were collected from 5 randomly selected competitive plants in each of three replications for nine traits namely: days to 75% flowering, days to maturity, plant height (cm), number of productive tillers per plant, spike length (cm), number of spikeletes per spike, number of grain per main spike, 1000-grain weight (g) and grain yield per plant (g). Statistical analysis was done on the mean values of 5 competitive plants per treatment in each of three replications for nine traits. Combining ability analysis was done by using Griffing's (1956b) [5, 6] Method 2 Model 1 for F_1's and and magnitude of heterosis in F_1 over better parent was done according to this formula: Heterosis (%) over BP = $[\overline{F}1 - \overline{B}P / \overline{B}P] \times 100$ where, BP = the value of the better parent. Significance of heterosis over better parent was tested by the method suggested by Panse and Sukhatme (1961) [11].

Results and Discussion

The Combining ability analysis provides useful information regarding nature and magnitude of gene action as well as selection of parents and cross combinations to utilize them in further breeding programme. General and specific combining ability variances and effects were evaluated for the assessment of the genetic architecture of the characters under investigation. Combining ability describes the breeding value of parental lines to produce hybrids (Kumar and Kerkhi, 2015) [9, 10]. The general combining ability has been equated with additive gene action and specific combining ability with non-additive gene action (Griffing 1956a) [5, 6].

The analysis of variance for combining ability (Table 1) indicted that general combining ability (*gca*) and specific combining ability (*sca*) were observed highly significant for all the traits except number of productive tillers per plant, spike length and grain yield per plant. Almost similar trend of involvement of both additive and non-additive gene actions has been earlier reported by Kumar and Maloo (2012) [9, 10], Adel and Ali (2013) [1], Desale *et al*., (2014) [3], Kumar and Kerkhi, (2015) [9, 10] and Sharma *et al*., (2019) [8, 13, 14]. The estimated value of σ^2 g was higher than its σ^2 s for all traits except for number of spikelets per spike and 1000-grain weight which indicated the predominance of additive gene action. Similar findings were also reported by Adhikari *et al*., (2020) [2]. However, the ratio of $\sigma^2 g / \sigma^2 s$ was less than unity for number of spikelets per spike showed preponderance of non-ad ditive gene action. The value of average degree of dominance $(\sigma^2 s / \sigma^2 g)^{0.5}$ for number of spikelets per spike indicated partial dominance while rest of the traits showed over dominance. Such types of findings were also reported by Gami *et al*., (2011) [4].

Table 1: Analysis of variance (ANOVA) for combining ability for nine traits in diallel crosses in bread wheat

Source of variation	d. f.	Days to 75% flowering	Days to maturity	Plant height	Number of productive tillers per plant	Spike length	Number of spikelets per spike	Number of grains per main spike	1000-grain weight	Grain yield per plant
Gca	5	44.60**	386.37**	111.58**	7.21**	8.31**	4.66**	53.41**	18.11**	8.90**
Sca	15	4.04**	14.83**	13.90**	0.27	0.50	0.90**	3.34**	3.21**	0.68
Error	40	0.27	0.28	0.16	0.77	0.70	0.14	0.45	0.64	0.93
$\delta^2 g$	-	5.54	48.26	13.93	0.81	0.95	0.56	6.62	2.18	1.00
$\delta^2 s$	-	3.77	14.55	13.74	-0.5	-0.2	0.76	2.89	2.57	-0.25
$\delta^2 g / \delta^2 s$	-	1.47	3.31	1.01	-1.62	-4.75	0.74	2.30	0.85	-4.00
$(\delta^2 s / \delta^2 g)^{0.5}$		1.21	1.82	1.00	-1.27	-2.17	0.86	1.52	0.92	-2.00

*Significant at 5% level; ** Significant at 1% level, *GCA* = General combining ability; *SCA* = Specific combining ability; Degree of dominance. $\delta^2 g / \delta s^2$ = Ratio of *GCA* variance to *SCA* variance; $(\delta^2 s / \delta^2 g)^{0.5}$ = Degree of dominance

Selection of suitable parental genotypes and their crosses for the effective hybridization is a prerequisite in order to formulate a systematic breeding programme resulting rapid and sustained improvement. The combining ability effects contribute the information on these aspects. The comparison of mean values and general combining ability effects of parents indicated that there was close relationship between parental *per se* performance and *gca* effects for almost all the characters. The estimate of *gca* effects and *per se* performance of six parents for all the nine traits have been presented in Table 2 and Table 3. On the basis of general combining ability effect the best general combiners was PBW343. Negative significant parent K424 and K9423 were the best general combiners for days to maturity. Parent K9107 positive significant found best combiner for spike length. For 1000-grain weight, K9107 found best positive significant combiner and K424 and K9423 were negative significant combiners.

Table 2: Estimates of *GCA* effects and *Per se* performance of the parents for nine traits in diallel crosses of bread wheat

Source of variation	Days to 75% flowering		Days to maturity		Plant height		Number of productive tillers per plant		Spike length		Number of spikelets per spike		Number of grains per main spike		1000-grain weight		Grain yield per plant	
	GCA	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se	*GCA*	Per se
PBW343	-0.01**	81.67	4.39*	120.67	0.45	81.37	1.12	9.22	0.55	11.37	0.13	17.37	2.55	49.44	1.14	40.23	0.89	10.59
K1006	1.99	85.22	5.14*	124.33	-0.05	82.67	0.45	7.14	-1.01	9.16	-0.24	16.79	0.27	46.04	1.09	40.75	0.04	9.02
K9107	3.03	84.33	5.81**	125.33	2.45	93.27	0.36	6.73	1.79*	14.13	1.39	20.96	3.27	49.31	1.68*	44.28	1.50	12.63
K607	0.40	80.33	2.35	119.67	5.63	92.95	0.38	7.21	-0.67	9.11	-0.40	16.40	-0.48	41.76	-0.53	38.60	-0.28	8.44
K424	-2.72	74.33	-8.44**	93.67	-3.89	74.70	-0.89	4.88	-0.30	10.57	-0.87	16.43	-2.57	39.14	-1.72*	38.08	-0.82	7.60
K9423	-2.68	74.67	-9.24**	94.67	-4.59	74.20	-1.41	3.63	-0.36	10.28	-0.01	17.97	-3.05	39.26	-1.66*	37.48	-1.33	7.65
SE(gi)5%	1.30		1.41		3.29		0.73		0.68		0.97		1.73		0.63		0.77	

*Significant at 5% level, ** Significant at 1% level

Table 3: Ranking top three desirable parents based on *GCA* effect and *per se* performance for nine traits in bread wheat

Traits	Good specific combiners based on *GCA* effect	Superior crosses on the basis of *per se* performance	Traits	Good specific combiners based on *GCA* effect	Superior crosses on the basis of *per se* performance	Traits	Good specific combiners based on *GCA* effect	Superior crosses on the basis of *per se* performance
Days to 75% flowering	PBW343	K424	Number of productive tillers per plant	PBW343	PBW343	Number of grains per main spike	K9107	PBW343
	K424	K9423		K1006	K607		PBW343	K9107
	K9423	K607		K9107	K1006		K1006	K1006
Days to maturity	K9423	K424	Spike length	K9107	K9107	1000-grain weight	K9107	K9107
	K424	K9423		PBW343	PBW343		PBW343	K1006
	K607	K607		K424	K424		K1006	PBW343
Plant height	K9423	K9423	Number of spikelet per spike	K9107	K9107	Grain yield per plant	K9107	K9107
	K424	K424		PBW343	PBW343		PBW343	PBW343
	K1006	PBW343		K424	K9423		K1006	K1006

Generally, specific combining ability effects do not make any significant contribution in the improvement of self-pollinated crops except those crops where commercial exploitation of heterosis is possible. Several workers emphasized that superiority of hybrids might indicate their ability to produce transgressive sergeants due to interaction of genes and non-additive gene effects. A perusal of the result indicated that none of these cross combinations was found good for all traits. The estimates of specific combining ability (*sca*) and their effects in F_{1s} for nine yield and its attributes are presented in Table 4 and Table 5. The cross combinations PBW343×K424, PBW343×K9423, K1006×K607 and K1006×K424 were found superior in F_1 generation for days to 75% flowering. The cross combinations K1006×K607, PBW343×K424 and K9107×K424 were found superior for days to maturity, PBW343×K607, PBW343×K424 and K424×K9423 for plant height, PBW343×K1006 for number of productive tillers per plants, K9107×K607 for spike length, K1006×K9107, PBW343×K9107 and K424×K9423 for number of spikelets per spike, PBW343×K1006, PBW343×K607 and K9107×K607 for number of grains per main spike and PBW343×K9107, K1006×K607 andK1006×K9107 for 1000-grain weight in F_1 generation. None cross combination was obtained good for grain yield per plant.

Table 4: Estimates of *SCA* effects and *per se* performance of 15 F_1s for nine traits in diallel crosses of bread wheat

Traits / Crosses	Days to 75% flowering		Days to maturity		Plant height		Number of productive tillers/plant		Spike length		Number of spikelets/spike		Number of grains/main spike		1000-grain weight		Grain yield per plant	
	Sca	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*	*SCA*	*Per se*
PBW343×K1006	0.92**	82.67	1.06**	121.00	0.35*	82.66	0.77**	8.70	0.64	10.66	-0.31	17.17	1.90**	49.20	-0.02	41.16	-0.54	9.46
PBW343×K9107	1.54**	84.33	-0.61**	120.00	-7.48**	77.33	0.09	7.93	0.46	13.28	1.07**	20.19	-1.38**	48.92	2.36**	44.13	0.48	11.94
PBW343×K607	-0.17	80.00	2.52**	119.67	6.68**	94.67	-0.76*	7.10	-0.43	9.93	-0.14	17.19	1.53**	48.07	-0.36**	39.21	0.50	10.18
PBW343×K424	-3.38**	73.67	-1.02**	105.33	4.17**	82.63	-1.06**	5.53	-0.75*	9.97	-0.80**	16.06	1.08**	45.54	0.22	38.59	0.04	9.19
PBW343×K9423	-2.27**	74.33	-4.90**	100.67	-0.86**	76.90	-0.27	5.80	0.49	11.16	0.09	17.81	-2.86**	41.12	-0.19	38.24	0.05	8.69
K1006×K9107	0.87**	85.67	-1.69**	119.67	-0.98**	83.33	0.10	7.27	-0.83*	10.44	1.13**	19.87	0.46	48.48	0.52**	42.24	0.75	11.36
K1006×K607	-1.50**	80.67	-7.23**	110.67	-2.12**	85.37	-0.12	7.07	0.08	8.99	-0.14	16.82	0.76*	45.03	0.69**	40.20	-0.68	8.15
K1006×K424	-1.38**	77.67	1.56**	108.67	0.55**	78.52	-0.12	5.80	-0.56	8.62	0.47*	16.96	-2.59**	39.59	-0.51**	37.81	0.49	8.78
K1006×K9423	2.08**	77.00	-0.98**	105.33	0.50**	77.77	-0.37	5.03	-0.72	8.40	-0.52**	16.83	-2.55**	39.15	0.09	38.47	0.24	8.02
K9107×K607	1.12**	84.33	1.77**	120.33	1.18**	91.17	0.45	7.53	1.27**	12.88	0.41*	19.00	1.70**	48.97	0.10	40.20	0.69	10.99
K9107×K424	-0.42	79.67	-3.44**	104.33	-4.14**	76.33	0.44	6.27	-0.15	11.82	-1.80**	16.32	0.43	45.61	-3.67**	35.15	-1.18*	8.57
K9107×K9423	-0.13	80.00	-2.65**	104.33	-1.49**	78.28	-0.37	4.93	-0.88*	11.03	-1.99**	16.99	2.22**	46.92	-3.14**	35.83	-1.88**	7.36
K607×K424	0.87**	78.33	-3.32**	101.00	-2.98**	80.67	-0.22	5.63	-0.42	9.09	0.01	16.34	-0.21	41.22	-1.22**	35.48	0.43	8.40
K607×K9423	0.17	77.67	-2.86**	100.67	-2.34**	80.67	0.47	5.80	-0.43	9.03	0.65**	17.84	-0.26	40.69	-1.60**	36.48	-0.78	6.68
K424×K9423	4.29**	78.67	5.93**	98.67	1.24**	74.67	0.37	4.43	0.50	10.32	1.00**	17.72	1.70**	40.57	0.13	35.70	-0.11	6.81
SE(Sij) ± 5%	0.21		0.22		0.16		0.35		0.35		0.16		0.28		0.11		0.41	

*Significant at 5% level, ** Significant at 1% level

Table 5: Ranking top three desirable parents based on *SCA* effect and *per se* performance for nine traits in bread wheat

Traits	Good specific combiners based on *SCA* effect	Superior crosses on the basis of *per se* performance	Traits	Good specific combiners based on *SCA* effect	Superior crosses on the basis of *per se* performance	Traits	Good specific combiners based on *SCA* effect	Superior crosses on the basis of *per se* performance
Days to 75% flowering	PBW343×K424	PBW343×K424	Number of productive tillers per plant	PBW343×K1006	PBW343×K1006	Number of grains per main spike	PBW343×K1006	PBW343×K1006
	PBW343×K9423	PBW343×K9423		K607×K9423	PBW343×K9107		PBW343×K607	K9107×K607
	K1006×K607	K1006×K9423		K9107×K607	K9107×K607		K9107×K607	PBW343×K9107
Days to maturity	K1006×K607	K424×K9423	Spike length	K9107×K607	PBW343×K9107	1000-grain weight	PBW343×K9107	PBW343×K9107
	PBW343×K424	K607×K9423		PBW343×K1006	K9107×K607		K1006×K607	K1006×K9107
	K9107×K424	PBW343×K424		K424×K1006	K9107×424		K1006×K9107	PBW343×K1006
Plant height	PBW343×K607	K424×K9423	Number of spikelet per spike	K1006×K9107	PBW343×K9107	Grain yield per plant	K1006×K9107	PBW343×K9107
	PBW343×K424	K9107×K424		PBW343×K9107	K1006×K9107		K9107×K607	K1006×K9107
	K424×K9423	PBW343×K9423		K424×K9423	K9107×K607		PBW343×K607	K9107×K607

Singh *et al*. (2004) [3, 14-16] stated that the superiority of hybrids particularly over high parent is more useful for commercial exploitation of heterosis and also indicated the parental combinations capable of producing the highest level of transgressive segregants (Singh *et al*., 2012) [3, 14-16]. Heterosis at better parent (Table 6) reflected the idea of gene action *i.e.* dominance, over dominance or recessive. The positive and significant values always indicated over dominance effect of the parents.

Table 6: Percent heterosis over better parents for nine traits in bread wheat

Crosses	Days to 75% flowering	Days to maturity	Plant height	Number of productive tillers per plant	Spike length	Number of spikelets per spike	Number of grains per main spike	1000 grain weight	Grain yield per plant
PBW343×K1006	-3.12**	-2.68*	0.00	21.79*	16.34	2.24	6.86	1.01	4.84
PBW343×K9107	0.00	-4.26**	-17.08**	17.88	-6.01	-3.70	-0.79	-0.34**	-5.51**
PBW343×K607	-0.41	0.00	1.85**	-1.57**	9.04	4.80	15.12*	1.58	20.66
PBW343×K424	-0.90	12.46*	10.62*	13.39**	-5.68*	-2.25**	16.35	1.33	20.88
PBW343×K9423	-0.45**	6.34*	3.64	59.93*	8.53	-0.89	4.73**	2.02	13.60
K1006×K9107	1.58**	-4.52**	-10.65*	7.97	-26.13**	-5.22	-1.68	-4.61	-10.11
K1006×K607	0.41**	-7.52*	-8.16	-2.03	-2.42	2.54	7.85	4.16	-3.40
K1006×K424	4.48**	16.01	5.12	18.85**	-18.48**	3.25	1.16**	-0.71	15.57**
K1006×K9423	3.12**	11.27**	4.81	38.79	-18.29**	-6.35	-0.28**	2.63	4.84
K9107×K607	4.98**	0.56**	-1.92	4.44	41.40**	15.83	17.27**	4.16	30.17
K9107×K424	7.17	11.39**	2.19**	28.42	11.83	-0.67**	16.54**	-7.69	12.81**
K9107×K9423	7.14	10.21**	5.50**	36.03	7.30**	-5.45**	19.51	-4.41	-3.75**
K607×K424	5.38	7.83	7.99	15.44	-14.03	-0.53	5.31**	-6.84	10.57**
K607×K9423	4.02	6.34	8.63	59.93	-12.19	-0.71	3.63	-3.51	-12.60**
K424×K9423	5.36**	4.23	0.63	22.24	0.39	-1.39	3.32	-4.75	-10.99**
SE±	0.67	0.69	1.85	0.44	0.41	0.62	0.97	0.43	0.48
+(sig)	(6)	2(4)	1(3)	2(2)	(2)	-	1(5)	-	(3)
-(sig)	(2)	2(2)	1(1)	(1)	1(5)	(3)	(1)	(1)	(4)

*Significant at 5% level, ** Significant at 1% level

Heterosis over better parent varied from -12.60 to 20.88 percent for grain yield per plant. For days to 75% flowering, crosses PBW343×K1006 and PBW343×K9423 exhibited negative highly significant heterosis for desirable earliness obtained by Jaiswal *et al*. (2010) [7] while six crosses showed positive highly significant heterosis for late flowered genotype. K1006×K9107, PBW343×K9107, K1006×K607 and PBW343×K1006 showed negative significant heterosis for early maturity while six crosses exhibited positive and significant heterosis for late maturity. The crosses PBW343×K9107 and PBW343×K424 were best for short plant type exhibited negative significant heterosis whereas, four crosses were responsible for positive significant heterosis for tallness. For number of productive tillers per plant, four crosses *viz* K1006×K424, PBW343×K9423, PBW343×K9423 and PBW343×K1006 had positive significant heterosis. K9107×K607 and K9107×K9423 showed desirable positive significant heterosis for spike length. For number of spikelets per spike, three cross combinations showed negative significant heterosis value while none cross combination revealed positive significant heterosis for this trait. K9107×K607, K9107×K424, K607×K424, PBW343×K9423, K1006×K424 and PBW343×K607 crosses showed positive significant heterosis while one cross combination had negative significant heterosis for number of grains per main spike. For 1000-grain weight, none cross combination had positive significant value for better parent while one cross PBW343×K9107 showed negative significant better parent heterosis. K1006×K424, K9107×K424, and K607×K424 identified with positive significant better parent heterosis whereas four crosses showed negative significant heterosis over better parent for grain yield per plant.

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