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Research Article

Heterosis and combining ability analysis for grain yield and quality traits in bread wheat(*Triticum aestivum* L.)

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Abstract
Heterosis and combining ability analysis were studied in a 10 × 10 diallel set of bread wheat. Significant heterobeltiosis and standard heterosis was observed in HW-5018 x HI-1544for grain yield per plant, harvest index, total soluble sugar and non-reducing sugar. Cross RAJ-4136 x UAS-281 showed significant heterobeltiosis for grain yield per plant, total soluble sugar, reducing sugar and non-reducing sugar as well as significant standard heterosis for grain yield per plant, harvest index, chlorophyll content, total soluble sugar and non-reducing sugar. Analysis of variance for combining ability revealed that the mean squares due to both general combining ability(GCA) and specific combining ability(SCA) were significant for all traits indicating both additive and non-additive genetic variances played a vital role in inheritance of all these traits. The ratio between GCA and SCA variatnce was less than unity for all the traits which indicated that non-additive component play relatively greater role in inheritance of all eight traits. On the basis of GCA, SCA effects and *per se* performance, parents HI-1544 for all the traits except biological yield per plant and reducing sugar and HW-5018 for all the traits except biological yield per plant and chlorophyll content and two crosses namely HW-5018 x HI-1544 andRAJ-4136 x UAS-281 for four traits were found as good general and specific combiners, respectively.

Key words
Bread wheat, Heterobeltiosis, Standard heterosis, grain yield.

Introduction

Wheat is the second most important staple food crop next to rice, consumed by nearly 35% of the world population and providing 20% of the total food calories. Choice of suitable parents for evolving better varieties/hybrids is a matter of concern to the plant breeders. In systemic breeding programme, selection of parents with desirable characteristics having good general combining ability effects for grain yield and its components, high heterosis and high estimates of specific combining ability effects are essential. These estimates will help in formulating efficient and effective breeding procedure to bring about rapid and suitable improvement in this crop. The present investigation was, therefore, attempt to obtain information on the extent of heterosis and combining ability for grain yield and its related traits in bread wheat.

Material and methods

The initial experimental material consisted of ten genotypes /varieties of bread wheat (*Triticum aestivum* L. Em. Thell) *viz.*, GW-496, GW-322, LOK-1, GW-173, KYZ-300, RAJ-4136, HW-5018, K-604, UAS-281, HI-1544, along with GW-366 as a standard check. These genotypes were crossed in all possible combinations using diallel mating design excluding reciprocal during *Rabi* 2010-11 at Wheat Research Station, Junagadh Agricultural University, Junagadh. A set of 56 entries, including 10 parents, their 45 crosses and one standard check (GW-366) were sown in randomized block design with three replications during *Rabi* 2011-12. Each entry was sown in a single row plot of 2.5 m long keeping row-to-row and plant-to-plant distance of 22.5 cm, and 10 cm, respectively. Five competitive plants per genotype in each replication were selected randomly for the purpose of recording observations for eight traits *viz.*, grain yield per plant, biological yield per plant, harvest index, total soluble sugar (Dubosis *et al.*,1956), protein content (Lowery*et al.*, 1951), chlorophyll content (Arnon, 1949), reducing sugar (Nelson,1944) and non reducing sugar (calculated by the difference between total soluble sugar and reducing sugar). Heterobeltiosis and standard heterosis respectively were calculated by using formulae of Fonseca and Patterson (1968). The analysis of variance for general (GCA) and specific (SCA) combining abilities were carried out according to Model I, Method 2 (half-diallel set) of Griffing (1956).

Results and Discussion

Mean square due to genotypes was significant for all the traits, indicating that experimental material had sufficient genetic variability for all the traits studied. Mean square due to parents *Vs* hybrids comparison was significant for all the traits except harvest index indicating that the performance of hybrids as a group was different than that of parents for most of the traits. This revealed the presence of substantial amount of heterosis in various cross combinations.

Heterobeltiosis and standard heterosis (with GW 366 as check) were estimated and results are presented in Table1 and 2. Seven crosses showed heterobeltiosis and three crosses for standard heterosis estimates in desirable direction for grain yield per plant. The crosses which exhibited significant heterobeltiosis for grain yield per plant (Table 1) were RAJ-4136 x UAS-281, HW-5018 x K-604, KYZ-300 x HW-5018, HW-5018 × UAS-281, KYZ-300 × RAJ-4136, GW-173 × RAJ-4136, and HW-5018 x HI-1544and the crosses which exhibited significant standard heterosis for grain yield per plant were HW-5018 x K-604, RAJ-4136 x UAS-281, and HW-5018 x HI-1544. Similar finding were reported by Chakraborty and Tewari (1995); Sharma and Menon (1996); Nehvi *et al*. (2000), Vanparia *et al*. (2006a) and Singh *et al*. (2007).

For biological yield per plant, nineteen and two crosses showed significant and positive heterotic effects over better parent and standard check, respectively (Table 1).The two hybrids namely Lok-1 x HI-1544 and KYZ-300 x RAJ-4136 exhibited the desirable heterobeltiosis (80.48 % and 67.85%) and standard heterosis (14.27% and 13.87%)for biological yield per plant. Nine and twenty-seven crosses had significant and positive heterobeltosis and standard heterosis, respectively for harvest index. The two crosses GW-496 x K-604 and HW-5018 x HI-1544 exhibited the desirable heterobeltiosis (83.76 % and 36.02%) and standard heterosis (153% and 144.74%) for harvest index. Eighteen and seventeen hybrids over better parent and standard check, respectively exhibited significant and positive heterosis for total soluble sugar. The hybrid GW-173 x K-604 exhibited the highest desirable heterobeltiosis (48.53%) and standard heterosis (43.36%) followed by RAJ-4136 x HI-1544 (43.57%& 40.56%), HW-5018 x K-604 (42.11%& 34.27%), respectively for total soluble sugar.

Twelve and one hybrid expressed significant and positive heterobeltiosis and standard heterosis respectively (Table 2) for protein content. GW-496 x RAJ-4136 cross exhibited maximum heterobeltosis (14.00%) for protein content followed by KYZ-300 x HI-1544 (12.24%), GW-322 x HW-5018 (11.44%) and GW-322 x RAJ-4136 (9.79%) and hybrid GW-322 x UAS-281 ranked first by expressing the highest standard heterosis (2.88%) in desirable direction. Six hybrids over standard check exhibited significant and positive heterosis for chlorophyll content. The cross RAJ-4136 x UAS-281 exhibited the highest magnitude of standard heterosis (33.33%) followed by Lok-1 x HI-1544 (12.99%), and RAJ-4136 x K-604 (10.73%) for chlorophyll content. Seven and one hybrids expressed significant and positive heterobeltiosis and standard heterosis respectively for reducing sugar. The cross combination GW-322xKYZ-300 (34.78%) had maximum heterobeltiosis for reducing sugar followed by RAJ-4136 xUAS-281 (21.84%) and K-604xUAS-281 (20.69%) and only one hybrid GW-322 xRAJ-4136 ranked first by expressing the highest standard heterosis (14.85%) in desirable direction. Twenty-four and thirty-two hybrids expressed significant and positive heterobeltiosis and standard heterosis respectively for non-reducing sugar.GW-173xUAS-281cross had maximum heterobeltiosis (1574.67%) for non-reducing sugar followed by GW-173xK-604 (604.85%) and HW-5018xK-604 (537.78%). GW-496 x RAJ-4136 (405.25%) had maximum standard heterosis followed by GW-496 x Lok-1 (379.47%) and GW-173xK-604 (367.69%).

Analysis of variance for combining ability revealed that the variances due to GCA and SCA were significant for all the traits (Table 3). This indicated existence of genetic variability in the parental lines and involvement of both additive and non-additive gene effects in the inheritance of these traits. Magnitude of GCA and SCA variances revealed that the SCA variances were higher than their respective GCA variances for all the traits. Ratio between GCA and SCA variance was less than unity for all the traits indicating that non-additive component plays relatively greater role in the inheritance of most of these traits.

The GCA effects of the genotypes (Table 4) indicated that there was close relationship between parental mean performance and GCA effects for all the traits except grain yield per plant. Thus, the perfect relationship could be established between *per se* performance and GCA effects of the parents.Two parental lines *viz.*, HW-5018 (0.92) and HI-1544 (0.92) were found to be good general combiners for grain yield per plant as they had significant and positive GCA effects for this trait. The GCA value of parents revealed that five genotypes *viz.*, RAJ-4136 (3.47), GW-173 (2.72), UAS-281 (2.70), KYZ-300 (2.34) and Lok-1 (1.42) manifested significant and positive GCA effects and were good general combiners for biological yield per plant. Four genotypes *viz.*, HW-5018 (5.89), K-604 (3.71), HI-1544 (3.60) and UAS-281 (2.98) exhibited significant and positive GCA effects and hence, they were depicted as good general combiners for harvest index. Significant and positive GCA effects were observed in seven genotypes viz., HI-1544 (39.10), RAJ-4136 (29.15), GW-496 (27.44), UAS-281 (20.23), GW-173 (14.06), HW-5018 (5.83) and K-604 (4.46). Thus, they were considered as good general combiners for total soluble sugar. Six genotypes *viz.*, UAS-281 (0.41), KYZ-300 (-0.27), HI-1544 (0.24), HW-5018 (0.23), GW-322 (0.13) and GW-173 (0.10) exhibited significant and positive GCA effects and were considered as good general combiners for protein content. Significant and positive GCA effects were observed in four genotypes namely HI-1544 (0.024), K-604 (0.021), UAS-281 (0.018) and RAJ-4136 (0.013) and are considered as good general combiners for chlorophyll content.

On the basis of overall performance (Table 4), genotypes HI-1544 and HW-5018 was found to be good general combiner for grain yield per plant, harvest index, total soluble sugar, and protein content. Besides, genotype HI-1544 also showed to be a good general combiner for chlorophyll content, reducing and non-reducing sugar traits. Similar findings were reported by Sharma and Garg (2005), Vanpariya *et al*. (2006) and Zahid *et al*. (2011).

As regard to specific combining ability effect (Table 5), nine crosses exhibited significant and positive SCA effects for grain yield per plant. The cross combination HW-5018 x K-604 (good x poor) recorded the highest SCA effect followed by RAJ-4136 x UAS-281 (average x average), KYZ-300 x RAJ-4136 (average x average), KYZ-300 x HW-5018 (average x good) and GW-173 x RAJ-4136 (average x average) and were rated as good specific cross combinations for grain yield per plant. Similar results were also reported by Singh *et al*. (1990) and Mavi *et al*. (2003).Nineteen cross combinations showed significant and positive SCA effects for higher biological yield per plant with the highest SCA effect in Lok-1 x HI-1544 followed by KYZ-300 x RAJ-4136 and K-604 x HI-1544. Twelve hybrids were identified as the best specific cross combinations by exhibiting significant and positive SCA effects for harvest index. The cross combination GW-496 x K-604 recorded the highest SCA effect followed by HW-5018 x HI-1544, KYZ-300 x HI-1544 and GW-173 x K-604 and were classified as best specific cross combinations for harvest index. Eighteen crosses showed significant and positive SCA effect for total soluble sugar and the cross GW-173 x K-604 ranked first for SCA effect followed by HW-5018 x K-604, RAJ-4136 x HI-1544 and Lok-1 x HI-1544 and were rated as the best specific cross combinations.

Sixteen hybrids exhibited significant and positive SCA effects (Table 6) for protein content; out of which hybrid GW-496 x RAJ-4136 showed maximum SCA effect followed by GW-322 x HW-5018 and GW-322 x UAS-281.Likewise, twelve crosses producing significant SCA effect for chlorophyll content, among which the cross RAJ-4136 x UAS-281 ranked first for SCA effect followed by Lok-1 x HI-1544, GW-173 x KYZ-300 and GW-173 x RAJ-4136 and were rated as the best specific cross combinations. Sixteen crosses showed significant and positive SCA effect for reducing sugar and the cross GW-322xKYZ-300 ranked first for SCA effect followed by GW-496 x K-604, UAS-281 x HI-1544 and RAJ-4136 x HI-1544 and were rated as the good specific cross combinations. Similarly, seventeen hybrids were identified as good specific cross combinations by exhibiting significant and positive SCA effects for non-reducing sugar. The cross combination GW-173 x K-604 recorded the highest SCA effect followed by GW-496xLok-1, GW-496x RAJ-4136,Lok-1xHI-1544 and KYZ-300 x RAJ-4136 and were classified as best specific cross combinations for non-reducing sugar.

General Combining Ability effects of genotypes and SCA effects of their crosses indicated that the crosses between two high general combiners were not best specific combiners. The best specific combinations for different traits were either good x poor, average x average, average × good general combiners.

Cross HW-5018 x HI-1544 and RAJ-4136 x UAS-281 possessed significant heterobeltiosis and SCA effect. Both additive and non-additive gene action played important roles in expression of these traits, although non-additive genetic variance was predominant. Therefore, recurrent selection which may allow inter-mating of the selects in different cycles and utilize both additive and non-additive gene effect could be effective in developing wheat cultivar having high grain yield and its component. Dominance genetic effect shall be valuable in wheat breeding programmes when hybrid seed production is made economically feasible through an efficient cytoplasmic male sterility system.

References

Arnon, D. I. 1949.Copper enzymes in isolated chloroplasts poly phenolodidase in *Beta* vulgaris. *Plant Physiol.*, **24:** 1-15.

Chakraborty, S.K. and Tewari, V. 1995.Heterosis in bread wheat. *J. Res Birsa Agric Univ*., **7:**109-111.

Dubosis, M., Gillies, R. A., Hemilton, J. K., Rebers, P. A. and Smith, F. 1956.Colourimetric method for determination of sugar and related substances. *Anal. Chem.,* **23:** 250-360.

Fonseca, S. and Patterson, E.L. 1968. Hybrid vigour in seven parent diallelcross in common winter wheat (*Triticum aestivum L.*). *Crop Sci*., **8**: 85-95.

Griffing, B. 1956.Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. J. Biol. Sci*., **9**: 463-493.

Lowery, O. W., Rosebrough, N. I., Farr, A. C. and Randall, R. J. 1951. Protein measurements with folin-phenol reagent. *J. Biol. Chem.,***193:** 255-257.

Mavi, G.S.; Nanda, G.S.; Sahu, V.S.; Sharma, S. and Kaur, S. 2003.Combining ability analysis for yield and its components in bread wheat in two nitrogen regimes. *Crop Improv.,***30:** 50-57.

Nehvi, F. A. Shafiq, Wani, A., Zargar, G. H. 2000. Heterosis in bread wheat (*Triticum aestivum L*.). *Applied Biolo. Res*. **2(1/2):** 69-74.

Nelson, N. 1944. A Photometric adaptation of the somogyi method for the determination of glucose. *J. Biol. Chem.*,**153:** 375.

Sharma, A.K. and Garg, D.K. 2005.Combining ability over environments in bread wheat *(T. aesivum* L.).*J. Maharashtra Agric. Univ.,* **30:** 153-156.

Sharma, S.N. and Menon, U. 1996. Heterosis over environments in bread wheat. *Crop Improv.*,**23**: 225-228.

Singh, S. K., Singh. A., Singh, S., Singh, B. N., Kaushik, R., Singh, R. 2007.Line x tester analysis of combining ability in wheat (*Triticum aestivum L*.).*Flora and Fauna, Jhansi*; **13 (2):** 261-271.

Singh, S. P.; Singh, R. M.; Singh, J. and Agarwal, R. K. 1990.Combining ability for yield and some of its important components in induced mutants of bread wheat. *Indian J. Genet.,* **50:** 167-170.

Vanpariya, L. G., Chovatia, V. P. and Mehta, D. R. 2006a. Heterosis for grain yield and its attributes in bread wheat*(Triticum aestivum L.). National J. Pl. Improv.* **8**: 100-102.

Vanpariya, L. G., Chovatia, V. P. and Mehta, D. R. 2006b. Combining ability studies in bread wheat*(Triticum aestivum L.).National J. Pl. Improv.* **8**: 132-137.

Zahid, A., Saif, U.A., Khalid, S.K., Rahmatullah and Muhammad, 2011. Combining ability estimates of some yield and quality related traits in spring wheat (*Triticum aestivum* L.). *Pakistan J. Bot.*,**43**(1):221-231.

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Table 1. Estimates of heterobeltiosis (H) and standard heterosis (SH) for grain yield per plant, biological yield per plant, harvest index and total soluble sugar in bread wheat

Hybrids	Grain yield per Plant (g)		Biological yield per plant (g)		Harvest index (%)		Total soluble Sugar (mg/g)	
	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)
GW-496 X GW-322	-2.71	-2.41	-34.55**	-35.28**	35.67**	49.81**	7.80**	6.29**
GW-496 X Lok-1	-7.55	0.98	7.68*	-4.22	-39.04**	4.79	16.36**	14.69**
GW-496 X GW-173	-8.90	-8.62	-22.37**	-30.95**	12.68	32.94**	2.17	0.70
GW-496 X KYZ-300	-15.08*	-14.82*	6.29*	-5.46*	-34.48**	-10.20	-6.38**	-7.69**
GW-496 X RAJ-4136	-12.54	-12.27	-27.12**	-35.18**	-18.60**	34.63**	29.84**	27.97**
GW-496 X HW-5018	-9.93	-9.65	29.27**	-37.09**	26.32**	44.54**	-2.09	-3.50
GW-496 X K-604	-0.40	-0.10	-55.82**	-60.70**	83.76**	153.00**	-4.21*	-5.59**
GW-496 X UAS-281	-6.96	-6.67	-44.63**	-50.75**	8.00	88.64**	10.69**	9.09**
GW-496 X HI-1544	2.76	3.08	-10.17**	-20.10**	-28.38**	28.87**	2.17	0.70
GW-322 X Lok-1	-20.82**	-13.51	-28.48**	-28.84**	-29.25**	21.62	-19.11**	-20.28**
GW-322 X GW-173	-0.53	-0.22	-27.88**	-28.24**	17.20	38.27**	2.17	0.70
GW-322 X KYZ-300	-11.74	-11.47	-23.74**	-24.12**	-15.31	16.09	4.26*	2.80
GW-322 X RAJ-4136	-19.38**	-19.13**	-28.48**	-28.84**	-31.18**	13.82	0.04	-1.40
GW-322 x HW-5018	-10.22	-9.95	-46.77**	-47.04**	48.13**	69.49**	-4.21*	-5.59**
GW-322 x K-604	-12.44	-12.18	-31.92**	-32.26**	-6.18	29.18*	-14.86**	-16.08**
GW-322 x UAS-281	-7.56	-7.27	-23.54**	-23.92**	-30.36**	21.64	-10.60**	-11.89**
GW-322 x HI-1544	-7.83	-7.55	-32.53**	-32.86**	-23.74**	37.21**	-0.67	-2.10
Lok-1x GW-173	-29.99**	-23.92**	-26.11**	-41.71**	-24.09**	29.93**	-15.22**	-18.18**
Lok-1x KYZ-300	-29.77**	-23.68**	-27.39**	-13.07**	-48.89**	-12.51	-48.94**	-49.65**
Lok-1x RAJ-4136	-10.06	-2.27	41.90**	-10.15**	-36.74**	8.27	-30.43**	-32.87**
Lok-1x HW-5018	-9.79	-1.98	-35.32**	-48.64**	11.62	91.06**	-24.50**	-28.67**
Lok-1x K-604	-9.32	-1.46	7.78	-31.76**	-15.97*	43.83**	-51.89**	-54.55**
Lok-1x UAS-281	-1.91	6.59	21.90**	-22.81**	-21.43**	37.24**	-6.52**	-9.79**
Lok-1x HI-1544	-3.79	4.54	80.48**	14.27**	-49.42**	-9.00	22.86**	20.28**
GW-173 x KYZ-300	3.40	-3.06	23.72**	-3.02	-27.39**	-0.48	-9.22**	-10.99**
GW-173 x RAJ-4136	16.42*	7.05	-1.15	-22.51**	-16.89*	37.45**	-10.88**	-13.99**
GW-173 x HW-5018	6.20	-2.35	24.94**	-0.80	-17.27	-1.79	0.71	-2.80
GW-173 x K-604	12.08	3.05	-37.18**	-50.75**	51.17**	108.13**	48.53**	43.36**
GW-173 x UAS-281	7.95	-0.74	22.44**	-4.02	-41.11**	2.85	13.02**	9.09**
GW-173 x HI-1544	-9.54	-10.62	11.79**	-12.36**	-43.57**	1.54	13.57**	11.19**
KYZ-300 x RAJ-4136	19.53*	9.91	67.85**	13.87**	-41.70**	-3.59	8.56**	6.99**
KYZ-300 x HW-5018	22.32**	12.47	-27.85**	-42.71**	41.65**	95.52**	-19.11**	-20.28**
KYZ-300 x K-604	11.00	2.06	-4.59	-35.28**	13.64	56.86**	-2.09	-3.50
KYZ-300 x UAS-281	10.73	1.81	21.93**	-17.29**	-29.77**	22.67*	0.04	-1.40
KYZ-300 x HI-1544	6.09	4.83	-30.52**	-52.86**	23.46**	122.15**	-6.34**	-7.69**
RAJ-4136 x HW-5018	7.62	-1.63	28.61**	2.11	-42.08**	-4.07	4.33*	0.70
RAJ-4136 x K-604	9.80	-4.96	8.99*	-31.76**	-16.20*	38.81**	17.37**	13.29**
RAJ-4136 x UAS-281	39.60**	16.69*	73.53**	-11.06**	-24.89**	31.19**	13.02**	9.09**
RAJ-4136 x HI-1544	13.70	12.36	78.35**	-2.31	-36.20**	14.79	43.57**	40.56**
HW-5018 x K-604	30.56**	20.05**	2.01	-18.49**	6.62	46.79**	42.11**	34.27**
HW-5018 x UAS-281	19.76**	10.11	-34.97**	-48.04**	20.95**	111.25**	26.09**	21.68**
HW-5018 x HI-1544	16.18*	14.81*	-41.51**	-53.27**	36.02**	144.74**	13.57**	11.19**
K-604 x UAS-281	5.03	-7.82	33.65**	-15.38**	-37.85**	8.56	13.04**	9.09**
K-604 x HI-1544	-6.19	-7.30	55.56**	-1.51	-47.90**	-6.26	-1.43	-3.50
UAS-281 x HI-1544	4.36	3.12	19.82**	-34.37**	-12.92*	56.68**	-0.71	-2.80
SE±	1.66	1.66	1.76	1.76	4.12	4.12	11.70	11.70

*,** Significant at 5% and 1% levels, respectively

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Table 2. Estimates of heterobeltiosis (H) and standard heterosis (SH) for protein content, chlorophyll content, reducing sugar and Non-reducing sugar in bread wheat

Hybrids	Protein content		Chlorophyll content		Reducing sugar		Non-reducing sugar	
	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)
GW-496 X GW-322	-6.83**	-20.85**	-51.00	-16.95**	19.08**	-7.41*	-34.40**	82.72**
GW-496 X Lok-1	-14.10**	-21.65**	-47.67**	-11.30**	-31.82**	-44.44**	116.98**	379.47**
GW-496 X GW-173	-6.91**	-15.39**	-43.67**	-4.52	-17.24**	-11.11**	-25.03*	65.66**
GW-496 X KYZ-300	-7.85**	-15.63**	-44.33**	-5.65	-36.23**	-45.68**	46.97**	224.76**
GW-496 X RAJ-4136	14.00**	-8.95**	-46.67**	-9.60*	-21.74**	-33.33**	128.65**	405.25**
GW-496 X HW-5018	-7.30**	-15.42**	-49.33**	14.12**	-11.54**	-14.81**	-28.15**	58.76*
GW-496 X K-604	-12.05**	-20.13**	-43.33**	-3.95	15.07**	3.70	-88.40**	-74.38**
GW-496 X UAS-281	-14.94**	-15.28**	-45.33**	-7.34	-24.14**	-18.52**	23.90*	173.78**
GW-496 X HI-1544	1.39	-8.73**	52.67**	-19.77**	9.09*	-11.11**	-25.03*	65.66**
GW-322 X Lok-1	-6.98**	-15.15**	-47.67**	-11.30**	-13.64**	-29.63**	-43.14**	65.66**
GW-322 X GW-173	5.86**	-3.78**	-56.33**	-25.99**	-27.59**	-22.22**	-54.98**	31.15
GW-322 X KYZ-300	-0.35	-8.76**	-54.67**	-23.16**	34.78**	14.81**	-18.86*	136.39**
GW-322 X RAJ-4136	9.79**	-3.54**	-65.67**	-41.81**	-39.13**	-48.15**	-94.56**	-84.15**
GW-322 x HW-5018	11.44**	1.68	-46.00**	-8.47*	-17.95**	-20.99**	32.56**	286.20**
GW-322 x K-604	-0.35	-9.50**	-41.67**	-1.13	-4.11	-13.58**	-37.25**	82.81**
GW-322 x UAS-281	3.29**	2.88*	-50.00**	-15.25**	-10.34**	-3.70	-79.59**	-40.55**
GW-322 x HI-1544	1.33	-8.79**	-37.67**	5.65	3.03	-16.05**	-90.71**	-72.94**
Lok-1x GW-173	-0.53	-9.58**	-46.00**	-8.47*	-17.24**	-16.05**	-82.90**	-71.50**
Lok-1x KYZ-300	5.09**	-3.78**	-46.67**	-9.60*	-44.94**	-11.11**	-61.38**	-32.81**
Lok-1x RAJ-4136	2.39	-10.04**	-51.00**	-16.95**	-24.64**	-53.10**	-52.60**	-21.00
Lok-1x HW-5018	-1.34	-9.98**	-53.33**	-20.90**	-30.77**	-35.80**	-43.74**	-6.24
Lok-1x K-604	-12.28**	-20.34**	-47.00**	-10.17*	-50.68**	-33.33**	-71.64**	-52.74*
Lok-1x UAS-281	-8.39**	-8.76**	-47.00**	-10.17*	-31.03**	-55.56**	10.27	83.77**
Lok-1x HI-1544	0.98	-9.11**	-33.33**	12.99**	-9.09*	-25.93**	120.59**	302.21**
GW-173 x KYZ-300	-1.19	-9.53**	-37.67**	5.65	-13.81**	-25.93**	-65.06**	-39.21**
GW-173 x RAJ-4136	-4.03**	-15.68**	-35.00**	10.17*	12.66**	-7.41*	-82.65**	-72.46**
GW-173 x HW-5018	5.49**	-3.75**	-54.33**	-22.60**	-14.96**	-6.17	71.11*	24.54
GW-173 x K-604	0.44	-8.79**	-43.67**	-4.52	-16.11**	-8.64*	604.85**	367.69**
GW-173 x UAS-281	-9.73**	-10.09**	-63.00**	-37.29**	-26.45**	-9.88**	1574.67**	189.49**
GW-173 x HI-1544	6.48**	-4.15**	-40.67**	0.56	-37.94**	-20.99**	110.23**	283.33**
KYZ-300 x RAJ-4136	2.09	-10.30**	-7.53	-1.72	-30.43**	-33.33**	129.81**	300.00**
KYZ-300 x HW-5018	-1.11	-9.77**	-5.91	0.00	-43.59**	-40.74**	34.04*	133.32**
KYZ-300 x K-604	5.75**	-3.97**	-22.04**	-17.24**	-21.92**	-45.68**	45.39**	153.07**
KYZ-300 x UAS-281	-3.88**	-4.26**	1.08	8.62*	-21.14**	-29.63**	13.51	97.57**
KYZ-300 x HI-1544	12.24**	1.04	-32.80**	-25.99**	-8.63*	-18.52**	-3.79	75.43**
RAJ-4136 x HW-5018	4.00**	-5.11**	-57.00**	-27.12**	-30.77**	-22.22**	92.86**	207.13**
RAJ-4136 x K-604	0.41	-8.81**	-34.67**	10.73*	-21.92**	-33.33**	135.48**	274.99*
RAJ-4136 x UAS-281	-9.28**	-9.64**	-21.33**	33.33**	21.84**	-16.05**	62.05**	158.06**
RAJ-4136 x HI-1544	-5.29**	-14.75**	-35.33**	9.60*	5.87	-9.88**	145.35**	347.36**
HW-5018 x K-604	-5.69**	-14.35**	-41.67**	-1.13	-16.73**	-19.75**	537.78**	364.52**
HW-5018 x UAS-281	-8.39**	-8.76**	-38.00**	5.08	-3.45	3.70	207.20**	123.75**
HW-5018 x HI-1544	7.54**	-3.19**	-43.00**	-3.39	-15.45**	-18.52**	58.51**	189.02**
K-604 x UAS-281	-9.41**	-9.77**	-42.00**	-1.69	20.69**	-14.81**	275.33**	150.20**
K-604 x HI-1544	-3.49*	-13.13**	-41.67**	-1.13	-34.28**	-40.74**	77.59**	223.80**
UAS-281 x HI-1544	-0.17	-4.31**	-42.00**	-1.69	-42.54**	-38.27**	71.75**	213.16**
SE±	0.15	0.15	0.024	0.024	17.16	17.16	18.63	18.63

*,** Significant at 5% and 1% levels, respectively

Table 3. Analysis of variance for combining ability for various traits in bread wheat

Source	Df	Grain yield per plant	Biological yield per plant	Harvest index	Total soluble sugar	Protein content	Chlorophyll content	Reducing sugar	Non reducing sugar
GCA	9	4.46**	74.99**	175.21**	17086.45**	1.47**	0.0000044**	10610.01**	8819.65**
SCA	45	5.69**	162.42**	211.23**	9747.18**	0.34**	0.0000062**	5840.21	13185.19**
Error	108	1.37	1.55	8.47	68.46	0.011	0.0000029	147.22	173.50
σ^2GCA		0.26	6.12	13.89	1418.17	0.12	0.000000034	871.90	720.51
σ^2SCA		4.31	160.86	202.76	9678.72	0.33	0.00000059	5692.98	13011.70
σ^2GCA/ σ^2SCA		0.06	0.038	0.069	0.15	0.37	0.0000058	0.15	0.055

*,** Significant at 5%and 1 % levels respectively GCA and SCA denote general and specific combining ability, respectively

Table 4. Estimates of general combining ability effects for different traits in bread wheat

Parents	Grain yield per plant	Biological yield per plant	Harvest index	Total soluble sugar	Protein content	Chlorophyll content	Reducing sugar	Non-reducing sugar
GW-496	-0.42	-0.93**	0.55	27.44**	-0.78**	-0.0030	0.74	26.98**
GW-322	-1.10**	0.12	-4.09**	-16.80**	0.13**	-0.0035	6.58	-23.85**
LOK-1	-0.10	1.42**	-2.18**	-85.39**	-0.19**	-0.0030	-52.85**	-29.93**
GW-173	-0.43	2.72**	-4.42**	14.06**	0.10**	-0.0020	48.49**	-41.25**
KYZ-300	-0.06	2.34**	-2.13**	-38.07**	0.27**	-0.0180**	-21.01*	-1.87
RAJ-4136	0.15	3.47**	-3.90**	29.15**	-0.20**	0.0130**	-23.13**	-27.57**
HW-5018	0.92**	-2.73**	5.89**	5.83*	0.23**	-0.0150**	12.95**	6.90
K-604	-0.08	-3.70**	3.71**	4.46*	-0.20**	0.0210**	-0.32	13.39**
UAS-281	0.20	2.70**	2.98**	20.23**	0.41**	0.0180**	-38.94**	-16.24**
HI-1544	0.92**	-0.004	3.60**	39.10**	0.24**	0.0240**	-10.40**	38.30**
SE(gi) ±	0.32	0.34	0.80	2.27	0.03	0.0023	3.32	3.60

*,** Significant at 5% and 1% levels, respectively

Table 5. Estimates of specific combining ability effects for grain yield per plant, biological yield per plant, harvest index and total soluble sugar in bread wheat in bread wheat

Hybrids	Grain yield per plant	Biological yield per plant	Harvest index	Total soluble sugar
GW-496 X GW-322	1.63	-5.35**	7.38**	35.01**
GW-496 X Lok-1	1.44	13.95**	-10.84**	152.98**
GW-496 X GW-173	-0.53	-5.09**	1.60	-28.78**
GW-496 X KYZ-300	-2.38*	12.21**	-16.31**	-26.03**
GW-496 X RAJ-4136	-1.98	-8.64**	1.69	116.63**
GW-496 X HW-5018	-2.12*	-3.70**	-4.51	-45.24**
GW-496 X K-604	1.17	-18.40**	36.96**	-56.21**
GW-496 X UAS-281	-0.69	-12.80**	14.38**	14.44
GW-496 X HI-1544	0.92	4.84**	-7.90**	-53.81**
GW-322 X Lok-1	-1.36	-3.44**	-0.10	-8.54
GW-322 X GW-173	2.16*	-4.34**	8.17**	15.46*
GW-322 X KYZ-300	-0.90	-1.23	-2.15	79.93**
GW-322 X RAJ-4136	-2.95**	-5.49**	-1.21	-11.97
GW-322 x HW-5018	-1.52	-11.35**	9.17**	-13.34
GW-322 x K-604	-1.05	-0.59	-3.26	-73.70**
GW-322 x UAS-281	-0.16	3.95**	-5.26*	-64.79**
GW-322 x HI-1544	-0.95	-4.68**	-0.23	-26.03**
Lok-1x GW-173	-4.51**	-14.57**	3.25	-27.06**
Lok-1x KYZ-300	-4.83**	4.81**	-14.42**	-160.12**
Lok-1x RAJ-4136	0.09	5.61**	-5.12	-128.57**
Lok-1x HW-5018	-0.61	-13.72**	15.08**	-80.56**
Lok-1 x K-604	0.51	-1.55	0.14	-231.45**
Lok-1x UAS-281	2.16*	3.38**	-1.51	16.15*
Lok-1x HI-1544	0.94	25.29**	-18.88**	174.24**
GW-173 x KYZ-300	0.44	10.18**	-7.82**	-29.12**
GW-173 x RAJ-4136	2.65**	-3.89**	7.69**	-116.91**
GW-173 x HW-5018	-0.37	16.71**	-16.32**	-27.75**
GW-173 x K-604	1.93	-15.45**	25.68**	245.23**
GW-173 x UAS-281	0.74	14.55**	-11.73**	27.81**
GW-173 x HI-1544	-2.35*	6.32**	-12.82**	21.29**
KYZ-300 x RAJ-4136	2.97**	20.62**	-9.47**	58.67**
KYZ-300 x HW-5018	2.81**	-10.71**	16.64**	-78.50**
KYZ-300 x K-604	1.32	-4.81**	4.82	21.64**
KYZ-300 x UAS-281	0.98	6.13**	-6.84**	18.21*
KYZ-300 x HI-1544	0.98	-20.17**	28.58**	-37.69**
RAJ-4136 x HW-5018	-0.77	-17.89**	-17.66**	-22.26**
RAJ-4136 x K-604	-0.57	-3.61**	0.04	53.19**
RAJ-4136 x UAS-281	4.33**	9.12**	-1.99	12.72
RAJ-4136 x HI-1544	2.57*	12.23**	-8.55**	179.04**
HW-5018 x K-604	4.64**	11.40**	-6.85**	199.96**
HW-5018 x UAS-281	1.99	-9.20**	17.23**	110.11**
HW-5018 x HI-1544	2.38*	-15.37**	28.74**	29.53**
K-604(8) x UAS-281	-1.30	13.43**	-17.80**	37.41**
K-604 x HI-1544	-1.91	19.94**	-23.78**	-55.52**
UAS-281x HI-1544	0.31	-2.87*	-0.25	-67.19**
SE(Sij) ±	1.08	1.15	2.68	7.62

*,** Significant at 5% and 1% levels, respectively

Table 6. Estimates of specific combining ability effects for grain yield per plant, biological yield per plant, harvest index and total soluble sugar in bread wheat in bread wheat

Hybrids	Protein content	Chlorophyll content	Reducing sugar	Non-reducing sugar
GW-496 X GW-322	-0.73**	-0.021	61.78**	-26.29*
GW-496 X Lok-1	-0.51**	-0.019	-69.79**	220.18**
GW-496 X GW-173	-0.01	0.019	0.77	-22.70
GW-496 X KYZ-300	-0.22*	0.029	-107.99**	-66.80**
GW-496 X RAJ-4136	1.10**	-0.025	-42.20**	183.57**
GW-496 X HW-5018	-0.15	-0.024	17.22	-76.44**
GW-496 X K-604	-0.31**	0.000	125.98**	-190.78**
GW-496 X UAS-281	-0.31**	-0.017	-27.88**	39.87**
GW-496 X HI-1544	0.68**	-0.097**	59.66**	-102.25**
GW-322 X Lok-1	-0.61**	0.012	0.78	16.80
GW-322 X GW-173	0.54**	-0.076**	-62.36**	0.17
GW-322 X KYZ-300	-0.27**	-0.043**	198.14**	46.05**
GW-322 X RAJ-4136	0.86**	-0.183**	-124.44**	-162.05**
GW-322 x HW-5018	1.09**	-0.041**	-20.45*	-158.63**
GW-322 x K-604	0.11	0.048**	31.01**	-12.62
GW-322 x UAS-281	1.05**	-0.032*	42.68**	-82.92**
GW-322 x HI-1544	-0.24**	0.085**	28.36**	-163.70**
Lok-1x GW-173	0.12	-0.005	54.36**	-76.91**
Lok-1x KYZ-300	0.67**	0.005	-92.66**	-84.93**
Lok-1x RAJ-4136	0.36**	-0.069**	-1.35	-104.81**
Lok-1x HW-5018	-0.06	-0.065**	-24.69*	-72.19**
Lok-1 x K-604	-0.93**	-0.037*	-126.03**	-116.34**
Lok-1x UAS-281	-0.09	-0.034*	-12.49	23.86
Lok-1x HI-1544	0.04	0.096**	36.85**	146.27**
GW-173 x KYZ-300	-0.33**	0.093**	41.63**	-78.79**
GW-173 x RAJ-4136	-0.62**	0.090**	50.11**	135.18**
GW-173 x HW-5018	0.44**	-0.076**	1.30	-35.93**
GW-173 x K-604	0.23*	-0.005	8.20	235.55**
GW-173 x UAS-281	-0.54**	-0.195**	-88.36**	120.83**
GW-173 x HI-1544	0.38**	0.021	-102.68**	142.30**
KYZ-300 x RAJ-4136	-0.13	0.029	-58.65**	127.17**
KYZ-300 x HW-5018	-0.50**	0.067**	-120.19**	12.81
KYZ-300 x K-604	0.66**	-0.069**	-24.16**	22.32
KYZ-300 x UAS-281	0.01	0.077**	-6.12	6.99
KYZ-300 x HI-1544	0.85**	-0.139**	24.12*	-65.48**
RAJ-4136 x HW-5018	0.57**	-0.117**	-54.41**	43.16**
RAJ-4136 x K-604	0.53**	0.070**	-22.04*	91.64**
RAJ-4136 x UAS-281	-0.18	0.207**	8.73	26.54*
RAJ-4136 x HI-1544	-0.65**	0.060**	89.90**	125.36**
HW-5018 x K-604	-0.60**	0.028	-7.19	-184.83**
HW-5018 x UAS-281	-0.50**	0.068**	74.52**	19.42
HW-5018 x HI-1544	0.36**	0.011	9.26	17.75
K-604(8) x UAS-281	-0.20*	-0.008	-7.72	34.35**
K-604 x HI-1544	-0.45**	-0.011	-92.08**	39.44**
UAS-281x HI-1544	0.04	-0.011	118.60**	60.45**
SE(Sij) ±	0.10	0.016	10.02	12.13

*,** Significant at 5% and 1% levels, respectively