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COMBINING ABILITY STUDIES ON YIELD RELATED TRAITS IN WHEAT UNDER NORMAL AND WATER STRESS CONDITIONS

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Six diverse wheat cultivars/lines viz; Baviacore, Nesser, 9247, 9252, 9258 and 9267 were crossed in a complete diallel fashion to develop 30 F_1 crosses, which were tested alongwith their parents under normal and water stress conditions. Numerical analysis was made for spike density, number of grains per spike, 100-grain weight, biological yield, grain yield and harvest index. Significant differences among genotypic mean were observed in all of the traits under both conditions. GCA and SCA differences were significant for all the traits under study except spike density and 100-grain weight in both conditions. Wheat variety Nesser showed maximum general combining ability value for spike density under water stress conditions and maximum GCA value for biological yield and grain yield under irrigated condition. The variety Baviacore proved best general combiner for number of grains per spike and harvest index under both conditions while biological yield and grain yield under water stress condition. Variety 9252 found best general combiner for 100-grain weight under both condition. The cross 9252 x Nesser showed maximum specific combining ability value for spike density and biological yield under irrigated while for 100-grain weight under water stress condition. 9258 x 9252 exhibited maximum SCA for number of grains per spike under irrigated while 9258 x Nesser under water stress condition. 9267 x Nesser showed maximum SCA for 100-grain weight under irrigated condition while spike density under water stress condition. 9258 x 9247 was proved best combiner for grain yield and harvest index irrigated while 9267 x 9258 for biological yield, grain yield and harvest index under water stress condition.

Keywords: *Triticun aestivum* L., genotypes, combining ability, diallel cross, water stress, variances, yield related traits

INTRODUCTION

Wheat (*Triticun aestivum* L.) is the most important food crop and is the staple food for a large part of the world population including Pakistan. It has a significant role in food security and economic stability of Pakistan. In Pakistan, wheat is grown on 9.061 million hectares with an average yield of 2.57 tones per hectare (Anonymous, 2009) which is far below than that of most of the leading wheat producers in the world like Germany (7.9 t ha^{-1}), France (6.6 t ha^{-1}) and Egypt (6.4 t ha^{-1}). Increased population exerts pressure on wheat consumption and some time Government has to arrange its import to meet the national demand. Increase in per unit production is always needed but yield is a complex character, improvement of which relies mainly upon identification of genetically superior and suitable genotypes and their exploitation through either heterosis breeding or pedigree breeding. About 14 % of the wheat area in Pakistan is sown as rainfed (Anonymous, 2009) and the area under canal system also observe periodic water stress due to canal closure in result of even distribution of water among users. Genetic improvement in wheat having better tolerance against water stress has a good promise for the improvement in national average and total production of wheat. Selection of parents and their crosses is based on the knowledge of magnitude and nature of the genetic variances available in the base population. To explore the gene pool regarding the presence of variability and its genetic basis, combining ability analysis provides very useful information.

Significant estimates of general and specific combining ability variances for yield and yield related traits have been reported in the literature. The effects of general combining ability (GCA) were highly significant for number of grains per spike, 500 kernel weight and grain yield while specific combining ability (SCA) effects were highly significant for all the studied traits (Ahmadi *et al.*, 2003). The GCA mean squares were larger than those of SCA mean squares for all the characters studied except grain yield and relative magnitude of those variances indicated preponderance of additive gene action for most of the characters (Ajmal *et al.*, 2000). The number of crosses exhibiting significant positive GCA effects was higher under moisture stress condition than non moisture stress condition for almost all the traits except 1000-grain weight and harvest index (Budak, 2001). Plainaman was declared as the best combiner and Plainaman × Kobomugi as the best specific combination for improving drought tolerance (Farshadfar *et al.*, 2000). Role of additive genetic component was proved in the inheritance of harvest index. Among the parents, WH 542, UP2338, RAJ 3765 and PBW 343 were found to be good general combiners. The cross UP 2338 × RAJ 3765 and WH 147 × PBW 373 in the normal environment and WH 542 × PBW 343 in the stress environment were adjudged to be the best cross combinations for both grain yield per plant and harvest index (Sameena and Singh, 2000). Significant variation among the genotypes for the characters like, spikes per plant, plant height, spike length, grains per spike and grain yield per plant was observed. General combining ability (GCA), Specific combining ability and reciprocal variances were significant for all the characters (Hakim *et al.,* 2007). The GCA component of variance was predominant indicating the predominance of additive gene effects for the traits studied. Among the parents, Durgapura 65, HD 2285, Lok-1, Raj 1972 and HD 2329 were the best general combiners for tillers per plant, grain yield per spike and 1000-grain weight. The best specific crosses for grain yield were Sonalika × WH 157, HD 2428 × Durgapura 65, Durgapura 65 × Sonalika, HD 2428 × Lok-1 and CPAN 3004 × Raj 1972. The parent Raj 1972, Lok-1 and HD 2285 were the best general combiner for grain yield (Joshi *et al.,* 2004). Crosses displaying high SCA effects for seed weight and yield were observed to be derived from parents having various types of GCA effects (high × high, high × low, low × low and medium × low) (Kamaluddin *et al.,* 2007). Significant differences for specific combining ability were observed in morphological and technological traits (Krystkowiak *et al.*, 2009). High significant differences among cultivars in their GCA value were present for all traits. The high ratio of GCA to SCA mean squares implied the importance of additive gene effects in the appearance of grain yield per plant. For grain number per main spike, the contribution of additive gene effect was higher (Mohammadi *et al.*, 2007). Significant specific combining ability for studied traits was reported and suggested that these crosses have possibility for commercial exploitation of heterosis as well as selection of potential homozygous lines from transgressive segregants for improvement of yield levels of bread wheat (Seboka *et al.*, 2009). Significant differences due to general combining ability and specific combining ability were observed for the studied traits (Pang *et al.*, 2010).

In wheat breeding programmes, higher yield is the ultimate objective. It is a polygenic character and is greatly influenced by the varying environment. The objective of the present investigations was to create variability, expose general combiners and mark crosses with better specific combining ability for yield related traits by employing diallel cross technique. The information obtained from this study would be utilized in wheat breeding program for the evolution of new wheat cultivars with wider adaptability and higher yield potential.

MATERIALS AND METHODS

These studies were conducted at experimental area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. The wheat cultivars/lines viz; Baviacore, Nesser, 9247, 9252, 9258 and 9267 were used to develop thirty F_1 hybrids following 6 X 6 diallel fashion. Necessary precautions were adopted during the crossing operations to avoid contamination of the genetic material.

The seeds of the thirty F_1 hybrids including reciprocals and their six parents were planted under field capacity condition and four irrigations were provided at the development stages of tillering, booting, heading and grain filling. Lay out of the experiment was done according to the randomized complete block design with three replications, during crop season 2005-06. Single row of 5 meter length was kept as an experimental unit. The parents and their crosses were assigned at random to the experimental units in each replication. Inter-plant and inter-row distances were maintained 15 and 30 cm, respectively. Two seeds per hole were sown with the help of dibbler and later on thinned to one seedling per site after germination. Uniform cultural practices were applied in all replications. Ten guarded plants for each parent and cross were tagged at random from each replication and data were recorded on spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index at maturity.

The recorded data were subjected to the analysis of variance technique following Steel *et al.* (1997) to determine the significant differences among hybrids and parents. For genetic analysis, diallel cross technique Method I, Model I developed by Griffing (1956) was used where genotypic differences were found significant.

The variance resulting from the cross was partitioned into the variance due to general combining ability effects, specific combining ability effects and reciprocal effects by the following formula (Griffing, 1956) method I modal I.

RESULTS

Spike density: Irrigated conditions**:** The analysis of variance showed significant differences among genotypes under both the conditions (Table 1). The estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were non-significant under both conditions for this trait (Table 2). The values of GCA and SCA variances were found equivalent to zero for this trait (Table 3) which indicated that both additive and non-additive variations were present for this trait.

The highest positive GCA effects for spike density (Table 4) were found for Nesser (0.123), whereas, the lowest GCA effects were observed for 9247 (-0.056). Positive GCA effects in descending order were closely followed by the genotype 9258. Negative GCA effects, however, in ascending order were exhibited by Baviacore and 9252, respectively. The cross, 9252 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9252 × Baviacore. For spike density, five crosses showed positive SCA effects and ten crosses negative SCA effects. The cross Baviacore × 9252 showed maximum reciprocal effect followed by Baviacore × Nesser (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while seven of them showed positive reciprocal effects.

Spike density: water stress**:** Similar trends were observed under water stress as it was observed under normal conditions. Highest positive GCA effects for spike density under water stress conditions (Table 4) were found for Nesser (0.133), whereas, the lowest GCA effects were observed for Baviacore (-0.094). Positive GCA effects in descending order were exhibited by the genotype 9258 and 9267, respectively. Negative GCA effects however, in ascending order were exhibited by 9247 and 9252, respectively. The cross, 9267 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). For spike density, seven crosses showed positive SCA effects and eight crosses negative SCA effects. The cross Baviacore x Nesser showed maximum reciprocal effect followed by Baviacore × 9252 (Table 6). More than half of the crosses exhibited positive reciprocal effects for this trait, while seven of them showed negative reciprocal effects.

Number of grains per spike: Irrigated conditions**:** Significant differences were observed among genotypes tested in this study under irrigated conditions (Table 1).The estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were highly significant for number of grains per spike (Table 2). High specific combining ability variance was found for this trait (Table 3). This indicated a high percentage of non-additive variation was present for this trait.

The highest positive GCA effects for number of grains per spike under irrigated condition (Table 4) were found for Baviacore (4.745), whereas, the lowest GCA effects were observed for 9258 (-5.799). Positive GCA effects in descending order were exhibited by the genotypes, 9252 and 9247, respectively. Negative GCA effects, however, in ascending order were exhibited by 9267 and Nesser, respectively. The cross, 9258 × 9252, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9252 × Nesser. For number of grains per spike, nine crosses showed positive SCA effects and six crosses negative SCA effects. The cross Baviacore × 9247 showed maximum reciprocal effect followed by Baviacore × 9258 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while five of them showed positive reciprocal effects.

Number of grains per spike: Water stress conditions**:** Analysis of variance results indicated highly significant differences among genotypes (Table 1). The estimates of mean squares due to general combining ability, Specific combining ability and reciprocal effects revealed that results were highly significant for number of grains per spike under water stress conditions (Table 2). High GCA and SCA variances were found for this trait (Table 3). This indicated that both additive and non-additive variation was present for this trait.

The highest positive GCA effects for number of grains per spike under water stress conditions (Table 4) were found for Baviacore (3.409), whereas, the lowest GCA effects were observed for 9258 (-3.615). Positive GCA effects in descending order were exhibited by the genotypes Nesser and 9267, respectively. Negative GCA effects however, in ascending order were closely followed by the genotype 9252. The cross, 9258 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9252 × Baviacore. For number of grains per spike, six crosses showed positive SCA effects and nine crosses negative SCA effects. The cross Baviacore x 9247 showed maximum reciprocal effect followed by 9258 × 9267 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while three of them showed positive reciprocal effects.

100-grain weight: Irrigated conditions**:** The analysis of variance showed significant differences among genotypes under irrigated conditions (Table 1). The estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were non-significant for 100-grain weight under both conditions (Table 2). The values of GCA and SCA variances were found equivalent to zero for this trait (Table 3) which indicated that both additive and non-additive variations were present for this trait under both conditions.

The highest positive GCA effects for 100-grain weight under irrigated condition (Table 4) were found for 9252 (0.236), whereas, the lowest GCA effects were observed for Nesser (-0.272). Positive GCA effects in descending order were exhibited by the genotypes 9267 and 9247, respectively. Negative GCA effects, however, in ascending order were exhibited by 9258 and Baviacore, respectively. The cross, 9267 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9258 × Baviacore. For 100-grain weight, eight crosses showed positive SCA effects and seven crosses negative SCA effects. The cross 9247 x 9267 showed maximum reciprocal effect followed by Nesser × 9258 (Table 6). More than half of the crosses exhibited positive reciprocal effects for this trait, while seven of them showed negative reciprocal effects.

100-grain weight: Water stress conditions**:** Positive GCA effects in descending order were exhibited by the genotype 9258 and 9247, respectively. Negative GCA effects however, in ascending order were exhibited by Baviacore and 9267, respectively. The cross, 9252 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9258 × 9247. For 100-grain weight, ten crosses showed positive SCA effects and five crosses negative SCA effects. The cross 9247×9258 showed maximum reciprocal effect followed by 9258 × 9267 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while four of them showed positive reciprocal effects.

Biological yield per plant: Irrigated conditions**:** Significant differences were observed among genotypes tested in this study under irrigated conditions under both conditions (Table 1). Similarly estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were highly significant for biological yield per plant for both environments (Table 2). High GCA and SCA variance was found for this trait (Table 3). This indicated both additive and non-additive variations were contributing for the control of this trait.

The highest positive GCA effects for biological yield per plant under irrigated condition (Table 4) were found for Nesser (7.683), whereas, the lowest GCA effects were observed for 9258 (-4.770). Positive GCA effects in descending order were exhibited by the genotypes, 9247 and 9252, respectively. Negative GCA effects, however, in ascending order were exhibited by 9267 and Baviacore, respectively. The cross, 9252 × Nesser, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9247 × Baviacore. For biological yield per plant, nine crosses showed positive SCA effects and six crosses negative SCA effects. The cross 9252 × 9267 showed maximum reciprocal effect followed by 9247 × 9267 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while five of them showed positive reciprocal effects.

Biological yield per plant: Water stress conditions**:** The highest positive GCA effects for biological yield per plant under water stress conditions (Table 4) were found for Baviacore (8.119), whereas, the lowest GCA effects were observed for 9267 (-4.369). Positive GCA effects in descending order were closely followed by the genotypes Nesser. Negative GCA effects however, in ascending order were exhibited by the genotype 9252 and 9258, respectively. The cross, 9267 × 9247, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross Nesser × Baviacore. For biological yield per plant, nine crosses showed positive SCA effects and six crosses negative SCA effects. The cross 9252 × 9267 showed maximum reciprocal effect followed by 9247 × 9267 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while four of them showed positive reciprocal effects. The results of the study are in good agreement with the

Table 1. Mean squares for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Source	df	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
		Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
Genotypes	35	0.03^{**}	0.04^{**}	159.97^{**}	162.44^{**}	0.46^{**}	0.52^{**}	289.58^{**}	239.58^{**}	72.29^{**}	39.10^{**}	34.65^{**}	30.56^{**}
Replications	2	0.01^{NS}	0.02^{NS}	314.26^{**}	7.47^{NS}	0.16^{**}	0.24^{**}	1.00^{NS}	7.61^{NS}	0.03^{NS}	0.10^{NS}	0.13^{NS}	3.01^{NS}
Error	70	0.01	0.01	43.09	10.00	0.02	0.01	3.62	2.65	1.29	0.56	1.31	1.23

**Significant at P?0.01; *Significant at P?0.05, ^{NS}Non significant at P>0.05

Table 2. Combining ability analysis for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Source	df	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
		Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
GCA	5	0.05^{NS}	0.08^{NS}	144.05^{**}	76.42^{**}	0.36^{NS}	0.53^{NS}	243.10^{**}	245.55^{**}	33.74^{**}	43.86^{**}	27.02^{**}	16.43^{**}
SCA	15	0.00^{NS}	0.00^{NS}	42.19^{**}	34.04^{**}	0.13^{NS}	0.08^{NS}	72.26^{**}	71.08^{**}	23.39^{**}	10.72^{**}	10.97^{**}	7.52^{**}
Reciprocals	15	0.00^{NS}	0.00^{NS}	34.19^{**}	66.83^{**}	0.10^{NS}	0.15^{NS}	71.93^{**}	33.40^{**}	21.59^{**}	5.07^{**}	6.98^{**}	10.78^{**}
Error	70	0.34	0.34	14.70	3,67	0.34	0.34	1.54	1.22	0.76	0.52	0.77	0.74

**Significant at P?0.01; *Significant at P?0.05, ^{NS}Non significant at P>0.05

Table 3. Estimates of variance components, relative to general and specific combining ability for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Source	Df	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
		Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
σ^2_g	5	-0.02	-0.02	10.78	6.06	0.00	0.02	20.13	20.36	2.75	3.61	2.18	1.31
σ^2_s	15	-0.33	-0.33	27.49	30.37	-0.21	-0.26	70.72	69.87	22.62	10.19	10.19	6.78
σ^2_r	15	-0.17	-0.16	9.76	31.58	-0.11	-0.09	35.19	16.09	10.41	2.27	3.11	5.02
σ^2_e	70	0.34	0.34	14.70	3.67	0.34	0.34	1.54	1.22	0.76	0.52	0.77	0.74

Negative estimates for which the most reasonable value is zero (Allard, 1960)

Table 4. Estimates of general combining ability effects f or six parental lines for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Parents	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
9267	-0.008	0.009	-0.845	0.631	0.115	-0.012	-3.803	-4.369	-0.855	-1.456	1.526	-0.078
9258	0.004	0.022	-5.799	-3.615	-0.065	0.096	-4.770	-1.427	-2.336	-0.744	-0.302	-0.831
9252	-0.015	-0.001	1.764	-2.217	0.236	0.335	0.636	-3.417	-0.779	-1.596	-1.702	-1.175
9247	-0.056	-0.069	0.206	0.554	0.032	0.015	1.644	-0.679	1.137	-0.431	0.392	-0.434
Nesser	0.123	0.133	-0.072	1.238	-0.272	-0.268	7.683	1.772	2.407	0.711	-1.657	0.419
Baviacore	-0.048	-0.094	4.745	3.409	-0.046	0.166	-1.391	8.119	0.427	3.516	1.744	2.099

Table 5. Estimates of specific combining ability effects for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Crosses	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
9267 x 9258	0.033	-0.029	2.633	-1.912	0.047	-0.018	5.743	6.925	3.008	2.779	0.648	1.766
9267 x 9252	-0.001	-0.014	-2.573	3.907	0.180	0.084	-2.747	3.515	-0.500	2.123	1.374	1.512
9267 x 9247	0.015	-0.023	3.198	2.859	-0.132	0.198	0.303	6.995	-2.263	2.683	-3.919	1.142
9267 x Nesser	-0.048	0.056	-0.096	-0.848	0.408	0.071	0.886	-3.628	2.869	-2.555	3.537	-3.497
9267 x Baviacore	-0.009	0.004	-4.262	3.245	0.013	0.040	1.722	-2.928	0.441	-1.303	0.540	0.248
9258 x 9252	-0.038	0.009	5.891	-2.118	-0.023	-0.031	1.841	-3.471	0.032	-1.113	-1.666	-0.501
9258 x 9247	-0.006	-0.028	-0.650	-0.727	0.158	-0.045	6.742	-7.169	5.376	-2.160	3.674	-0.398
9258 x Nesser	0.028	0.026	5.271	4.548	-0.056	0.105	-5.433	1.258	-3.947	0.457	-2.595	0.816
9258 x Baviacore	-0.044	0.035	2.867	-5.228	-0.481	0.006	-4.732	4.821	-3.678	2.250	2.360	1.538
9252 x 9247	-0.012	0.052	4.608	4.460	0.060	0.169	-5.418	4.276	-3.380	1.066	-1.507	-0.770
9252 x Nesser	0.038	-0.012	-4.576	-2.129	-0.028	0.260	10.486	3.341	3.543	0.512	-1.081	-1.242
9252 x Baviacore	-1.338	-1.263	0.685	-5.891	-0.219	0.060	3.247	5.169	3.690	0.593	3.326	-1.978
9247 x Nesser	-0.018	-0.102	-0.392	-4.358	-0.152	0.079	-6.090	-3.363	-1.493	-0.867	1.554	0.846
9247 x Baviacore	0.025	0.047	0.070	2.751	0.114	0.021	-7.315	0.807	-3.696	0.665	-0.037	0.887
Nesser x Baviacore	-0.026	-0.068	0.287	-0.665	0.289	0.002	4.540	-7.294	2.657	-2.917	0.610	-1.127

Table 6. Estimates of reciprocal combining ability effects for spike density, number of grains per spike, 100-grain weight, biological yield per plant, grain yield per plant and harvest index from 6 x 6 diallel cross of wheat

Crosses	Spike density		Number of grains per spike		100-grain weight		Biological yield per plant		Grain yield per plant		Harvest Index	
	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
Baviacore x 9267	0.000	-0.027	-2.685	-13.687	0.056	-0.379	-5.538	-2.742	-2.855	0.347	-0.267	3.268
Baviacore x 9258	0.020	-0.083	1.964	-3.832	0.019	-0.434	-6.542	0.050	-1.807	-0.353	2.230	-0.748
Baviacore x 9252	0.057	0.061	-8.012	-3.178	-0.292	-0.655	3.293	-2.775	1.798	0.472	0.279	2.781
Baviacore x 9247	-0.044	0.033	6.146	0.963	-0.098	.0.049	-6.362	-0.317	-2.521	-0.248	0.998	-0.272
Baviacore x Nesser	0.051	0.096	-3.352	-0.229	-0.088	-0.180	-0.900	-0.233	0.394	-0.410	1.120	-0.807
Nesser x 9267	0.031	-0.049	-1.930	-3.171	0.100	0.017	-6.233	-5.312	-2.628	-0.637	0.666	2.834
Nesser x 9258	-0.058	0.002	-1.181	-3.634	0.272	-0.007	-7.156	-3.340	-2.649	0.622	0.508	4.281
Nesser x 9252	-0.072	-0.059	-3.793	-10.029	0.080	-0.225	1.993	-3.833	4.650	-1.139	4.741	0.046
Nesser x 9247	-0.093	-0.062	-5.093	-2.692	-0.374	-0.158	-9.421	-6.100	-6.801	-1.738	-3.773	0.809
9247 x 9267	-0.056	0.043	02.352	0.789	0.583	-0.247	7.157	1.650	3.527	1.018	0.662	1.169
9247 x 9258	0.032	0.047	-7.114	-10.453	0.088	0.283	-4.763	-2.495	-2.874	-1.240	-0.789	-1.572
9247 x 9252	-0.046	-0.029	0.330	-2.975	0.239	0.029	6.571	1.350	3.329	0.747	0.836	0.891
9252 x 9267	-0.048	-0.005	1.016	-2.265	-0.096	-0.041	7.613	9.233	2.841	4.787	-1.321	5.151
9252 x 9258	0.005	0.016	0.432	-5.682	-0.060	-0.222	-6.508	-6.611	-3.939	-2.455	-2.001	-0.542
9258 x 9267	0.052	0.001	-5.424	0.951	-0.163	0.168	-3.703	-2.033	-1.902	-0.387	-0.232	0.751

results of the previous workers like Chowdhry *et al.* (1999) and Kumar *et al.* (2003).

Grain yield per plant: Irrigated conditions: The analysis of variance showed significant differences among genotypes under irrigated conditions (Table 1). The estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were highly significant for grain yield per plant (Table 2). High GCA and SCA variance was found for this trait (Table 3). This indicated both additive and non-additive variations were contributing for the control of this trait. Similar trends were observed in stress conditions for this trait.

The highest positive GCA effects for grain yield per plant under irrigated condition (Table 4) were found for Nesser (2.407), whereas, the lowest GCA effects were observed for 9258 (-2.336). Positive GCA effects in descending order were exhibited by the genotypes, Baviacore and 9247, respectively. Negative GCA effects, however, in ascending order were exhibited by 9267 and 9252, respectively. The cross, 9258 × 9247, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9258 × Nesser. For grain yield per plant, eight crosses showed positive SCA effects and seven crosses negative SCA effects. The cross Nesser × 9252 showed maximum reciprocal effect followed by 9247 × 9267 (Table 6). More than half of the crosses exhibited negative reciprocal effects for this trait, while six of them showed positive reciprocal effects. Similar response was observed under water stress condition for reciprocal effects.

Grain yield per plant: Water stress conditions: The highest positive GCA effects for grain yield per plant under water stress conditions (Table 4) were found for Baviacore (3.516), whereas, the lowest GCA effects were observed for 9252 (- 1.596). Positive GCA effects in descending order were closely followed by the genotypes Nesser. Negative GCA effects however, in ascending order were exhibited by the genotype 9267 and 9258, respectively. The cross, 9267 × 9258, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross Nesser × Baviacore. For this trait, nine crosses showed positive SCA effects and six crosses negative SCA effects. The cross 9252 × 9267 showed maximum reciprocal effect followed by 9247 × 9267 (Table 6).

Harvest Index: Irrigated conditions: Significant differences were observed among genotypes tested in this study under irrigated conditions (Table 1). The estimates of mean squares due to general combining ability, specific combining ability and reciprocal effects revealed that results were highly significant for harvest index (Table 2). High GCA and SCA variance was found for this trait (Table 3). Thus indicating both additive and non-additive variations were contributing for the control of this trait. Similar results were depicted for this trait under water stress conditions.

The highest positive GCA effects for harvest index under irrigated condition (Table 4) were found for Baviacore (1.744), whereas, the lowest GCA effects were observed for 9252 (- 1.702) and same was case under water stress environment. Positive GCA effects in descending order were exhibited by the genotypes, 9267 and 9247, respectively. Negative GCA effects, however, in ascending order were exhibited by Nesser and 9258, respectively. The cross, 9258 × 9247, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9267 × 9247. For harvest index per plant, seven crosses showed positive SCA effects and eight crosses negative SCA effects. The cross Nesser × 9252 showed maximum reciprocal effect followed by Baviacore × 9258 (Table 6). More than half of the crosses exhibited positive reciprocal effects for this trait, while six of them showed negative reciprocal effects.

Harvest Index: Water stress conditions: Positive GCA effects in descending order were followed by the genotype Nesser. Negative GCA effects however, in ascending order were exhibited by the genotype 9258 and 9247, respectively. The cross, 9267 × 9258, which performed the best of all, had maximum SCA effects among all of the 15 crosses (Table 5). The lowest estimates of SCA effects were found for the cross 9267 × Nesser. For harvest index, eight crosses showed positive SCA effects and seven crosses negative SCA effects. The cross 9252 × 9267 showed maximum reciprocal effect followed by Nesser × 9258 (Table 6). More than half of the crosses exhibited positive reciprocal effects for this trait, while five of them showed negative reciprocal effects.

DISCUSSION

Development of wheat varieties possessing improved yield related characters has been the major objective of wheat breeders. Availability of genetically based variation for these traits like spike density, number of grains per spike, 100-grain weight, biological yield, grain yield and harvest index is a pre requisite for the selection of new cultivars. Present wheat material was studied to generate information on general and specific combining ability for these traits. The genetic differences were significant for all the above mentioned traits studied under irrigated as well as water stress conditions. Significant variation among genotypes for grain yield and related traits in different varieties of wheat were also reported by various wheat breeders (Ahmadi *et al.*, 2003; Ajmal *et al.*, 2000; Chowdhry *et al.*, 2005; Joshi *et al.,* 2004; Hakim *et al.* 2007; Kamaluddin *et al.,* 2007; Krystkowiak *et al.*, 2009; Mohammadi *et al.*, 2007; Seboka *et al.*, 2009; Pang *et al.*, 2010). Mean squares due to general combining ability, specific combining ability and reciprocals were highly significant for all of the studied characters except spike density and 100-grain yield under both of the environmental conditions (Table 2). The values of GCA were higher than SCA and reciprocal but the calculations of variances components revealed that SCA variances were greater than GCA variances (Table 3) which indicated preponderance of non-additive genetic effects for these traits except spike density and 100-grains weight where the values of GCA and SCA variances were found equivalent to zero and indicated presence of both additive and non-additive variations for these traits. The results are in agreement with the findings of Kumar *et al.* (2003). Singh and Singh (2003) reported non-additive while Kant *et al.* (2001) and Kashif and Khaliq (2003) reported additive genetic control for spike density. Singh and Singh (2003) also reported non-additive genetic control for number of grains per spike, 100-grain weight, grain yield per plant and harvest index. The results of this study were in agreement with the findings of Kumar *et al.* (2003) for biological yield per plant. Variation in GCA and SCA present in parents and crosses is also in agreement with the findings of the previous workers who studies and reported GCA and SCA variation in different times like Ahmadi *et al.* (2003), Ajmal *et al.* (2000), Chowdhry *et al.* (2005), Joshi *et al.* (2004), Hakim *et al.* (2007), Kamaluddin *et al.* (2007), Kant *et al.* (2001), Krystkowiak *et al.* (2009), Kumar *et al.* (2003), Mohammadi *et al.* (2007), Pang, *et al.* (2010), Seboka *et al.* (2009) and Singh and Singh (2003).

CONCLUSIONS

The results revealed that there was significant genotypic variation among the genotypes for the studied characters. Variety Baviacore could be used as donor parent for the improvement of number of grains per spike and harvest index for irrigated and water stress conditions, while it could be used for the improvement of biological yield and grain yield for water stress conditions. The line 9252, showed potential for the improvement of 100-grain weight for both environmental conditions. The cross 9258 x 9247 holds promise for yielding better segregates with improved grain yield per plant and harvest index. The cross 9267 x 9258 has potential for the improvement of grain yield per plant and harvest index for water stress conditions. The selection of promising lines for water stress condition from the progeny of the crosses 9258 x Baviacore and 9267 x 9258 may be made for further evaluation/

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