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COMBINING ABILITY ASSESSMENTS OF SOME MORPHO-PHYSIOLOGICAL TRAITS FOR IMPROVED GRAIN PRODUCTION IN BREAD WHEAT UNDER WATER DEFICIT STRESS CONDITIONS

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Wheat is used as a staple diet by most of the people in Pakistan. It is cultivated on irrigated along-with rain-fed areas throughout the country. During wheat growing period Pakistan receives low rainfall as occasional showers, which is insufficient to mature the crop amicably thus putting the pressure on the limited canal and marginally fit ground water application. Subsequently crop yield is reduced due to the effects of moisture deficiency stress at various developmental stages. This situation demands the evolution of wheat genotypes showing improvements in different morpho-physiological traits suitable for water deficiency stress tolerance. For this purpose, combining ability studies help the breeders to recognize the best parental genotypes and their crosses. By employing line × tester mating design, eight lines and four testers were used to obtain thirty-two crosses. During November 2013 the seeds of crosses along with parents were planted in the field and data were collected for yield and water deficiency stress tolerance related traits. The combining ability effects analysis revealed that parents WN-66, WN-85, WN-104, GA-2002 and Lasani-2008 proved to be good general combiners for grain yield under water deficiency stress and non-stress environments. Similarly, WN-85, WN-104, WN-105 and Lasani-2008 showed lowest GCA values for relative cell injury percentage. The highest SCA values for grain yield were shown by the hybrids WN-66 × Lasani-2008, WN-66 × Uqab-2000 and WN-78 × GA-2002. The crosses WN-105 × Uqab-2000, WN-66 × Lasani-2008 and WN-114 × Lasani-2008 showed the lowest SCA values for relative cell injury percentage. These parents and their hybrids showing good GCA and SCA values could be used in wheat breeding programs focusing on yield improvements under water deficiency stress environments.
Keywords: Bread wheat, line × tester analysis, general combining ability, specific combining ability

INTRODUCTION

At present agriculture is facing constant decline in the availability of good quality irrigation water and arable land. The cultivation of crops in areas with optimal and sub-optimal environmental conditions could play an important role to ensure sustainable and productive agriculture. The information being received from genetic, physiological, biochemical and molecular studies could be integrated to evolve moisture deficiency stress tolerant crop plants.

The per capita availability of cultivable land with good quality water is being worsened day by day due to unprecedented growth rate of human population. The plant potential to develop appropriately and give economical yield under insufficient moisture availability is moisture deficit stress tolerance. Water deficiency stress is a familiar and generally occurring natural phenomenon which decreases crop yields, as grain yield is positively and linearly correlated with crop transpiration (Musick *et al*., 1994).

Wheat (*Triticum aestivum* L.) has been ranked third among the cereals in terms of yield (Ram and Singh, 2003) and is one of the main food crops of the world. It's a reliable crop regarding production, cooking qualities, nutritive value, storage and adaptation. It is a principal grain crop and enjoys the key position in the cropping pattern of Pakistan. An area of about 8.7 million hectares was allocated for its cultivation which produced 25.49 million tonnes (Anonymous, 2018). It plays a vital role in the economic development and stability of the country, because its failure would cost billions of rupees to national exchequer in terms of its import. Desalgen *et al*. (2001) reported that water deficiency stress was the main cause of decline in wheat cultivated area and production. The water requirements of wheat differ from genotype to genotype and with the crop growth stage (Akram, 2011; Qadir *et al*., 2019; Sahin *et al*., 2019). It is vital to supply sufficient water during its growth period to utilize the maximum crop potential and the applied irrigation water must be utilized effectively and efficiently. The wheat genotypes producing more yields on per unit area, per unit of time and on per unit of applied water basis could be the best answer to achieve this goal. The development of moisture deficiency stress tolerant wheat genotypes could be the cheapest, sustainable and most eco-friendly answer to the issue of drought stress since allocation of extra resources like water and funds would not be needed for good crop production in these areas. For quick improvement the combining ability studies would suggest the most appropriate parents and hybrids to be used in wheat breeding programs. The research review has revealed that general and specific combining abilities were involved in the inheritance of yield and its component traits (Khaliq *et. al*., 2004; Akbar *et. al*., 2009; Istipliler *et. al*., 2015). Therefore, to improve yield under normal and moisture deficiency stress environments, general and specific combining abilities of wheat parents and their hybrids were estimated. The selected parents and their hybrids were assessed for their general combining abilities (GCA) and specific combining abilities (SCA) and provided useful information about the extent of genetic variance.

MATERIALS AND METHODS

The research was conducted at the research farm of the Department of Plant Breeding and Genetics (PBG), University of Agriculture, Faisalabad (UAF). Twelve genotypes *viz*; WN-66, WN-78, WN-79, WN-85, WN-91, WN-104, WN-105 and WN-114 (female parents) and Shahkar-95, Uqab-2000, GA-2002 and Lasani-2008 (male parents) were selected on the basis of their performance in the screening experiment (data not shown). The line × tester mating design (Kempthorne, 1957) was used to cross these genotypes in 2012-13 and thirty-two F_1 hybrids were developed.

Under control (T_1) and simulated drought environments (T_2), seeds of the crosses and their parents were sown in Randomized Complete Block Design (RCBD) with split plot arrangement in three replications. Each replication comprised of both the irrigation treatments i.e., T_1 and T_2, while each treatment consisted of all the crosses and parents. The plant to plant and row to row distances were kept 15cm and 30cm, respectively. With the help of dibbler two seeds were sown in each hole, which were thinned to one seedling per site after the completion of germination. Four irrigations were applied to treatment T_1 at the developmental stages of tillering, booting, heading and grain filling. After 25 days of sowing, 1st irrigation was applied to the treatment T_2 and later on was allowed to grow under natural rain-fed conditions. Except irrigation all other cultural practices were uniformly applied to both the treatments, and on both sides of every line one plant was kept as non-experimental and next ten plants in the line were tagged. Data were recorded from these tagged plants for plant height (PH), tillers per plant (T/P), peduncle length (PL), spike length (SL), spikelets per spike (S/S), spike density (SD), biological yield (BY), grains per spike (G/S), grain weight per spike (GW/S), grains per plant (G/P), grains weight per plant (GW/P), thousand grains weight (TGW) and harvest index percentage (HI%) at maturity. The flag leaf area (FLA) and relative cell injury percentage (RCI %) were recorded when the plants were still green and the flag leaves were in fully expanded condition (Pask *et al*., 2008). Effects of drought were judged by the rise in RCI% in comparison with the normal conditions. These studies revealed that genotypes with minimum damage to plasma membrane were found to be tolerant, whereas the genotypes showing excessive electrolytes leakage from the cell due to more damage to cell membrane exhibited moisture deficiency stress susceptibility (Renu *et al*., 2004; Ali *et al*., 2013). The electrolyte leakage was determined by the method described by Guo *et al*. (2006). While evaluating the data, rainfall received during the experimentation from sowing to harvesting was recorded and considered.

The recorded data regarding different traits were subjected to the analysis of variance (Steel *et al.*, 1997) as per design used, and significance of differences among genotypes including parent and hybrids was tested. Then further analysis was done to estimate the general combining ability (GCA) of parents including lines and testers and specific combining ability of crosses (SCA).

RESULTS AND DISCUSSION

All the genotypes showed significant differences with respect to the investigated parameters; hence it was possible to calculate the general and specific combining abilities in the population.

Table 1 showed that highly significant differences were found for all the investigated parameters among the treatments (T), genotypes (G) and the interaction between treatment and genotypes (T × G). The Tables 2 and 3 revealed non-significant variations due to replications for all the parameters under normal (T_1) and water deficiency stress (T_2) conditions,

Table 1. Analysis of variance for various traits in 8 × 4 line × tester analysis.

SOV	Degree of freedom	Plant Height	Tillers/ Plant	Flag Leaf Area	Peduncle Length	Spike Length	Spikelets/ Spike	Spike Density	Biological Yield	Grains/ Spike	Grains Weight / Spike	Grains/ Plant	Grains Weight/ Plant	Thousand Grains Weight	Harvest Index %	Relative Cell Injury %
Rep. (R)	2	418.97	92.21	204.35	179.35	38.94	21.71	0.098	2577.0	2126.51	4.45	841731	1049.59	256.10	481.36	632.7
Treat. (T)	1	3427.4**	676.51**	1005.6**	835.21**	194.26**	175.91**	0.241**	23508**	9944.8**	24.71**	4.83e7**	6192.8**	1257.4**	794.60**	11970**
Error (R×T)	2	1.76	0.35	6.34	3.13	0.09	0.03	0.002	148.5	36.12	0.03	57358	43.86	8.99	2.78	4.5
Genotype(G)	43	58.44**	33.50**	26.80**	39.54**	3.47**	3.43**	0.030**	587.4**	189.29**	0.43**	95689**	113.66**	33.66**	21.65**	350.4**
T×G	43	6.92**	7.57**	1.93**	2.97**	0.25**	0.40**	0.002**	126.9**	32.40**	0.08**	25471**	26.13**	5.51**	21.40**	124.2**
Error	172	1.62	0.56	1.05	1.21	0.06	0.06	0.0003	31.3	12.27	0.03	7574	7.63	1.80	3.89	3.1
Total	263															

**, Significant at P≤0.01; *, Significant at P≤0.05; NS, Non-significant at P>0.05

Table 2. Mean squares for traits in 8 × 4 Line × Tester analysis under normal (T_1) conditions.

SOV	df	Plant height	Tillers / plant	Flag leaf area	Pedu-ncle length	Spike length	Spike-lets / spike	Spike density	Biological yield	Grains /spike	Grains weight / spike	Grains /plant	Grains weight /plant	Thousand grains weight	Harvest index %	Relative cell injury %
Replic.	2	11.94^{NS}	2.70^{NS}	1.27^{NS}	4.75^{NS}	0.49^{NS}	0.31^{NS}	0.001^{NS}	125.84^{NS}	37.32^{NS}	0.10^{NS}	26997^{NS}	64.61^{NS}	0.29^{NS}	9.74^{NS}	5.06^{NS}
Genotypes	43	34.78**	29.15**	14.70**	20.98**	2.10**	1.87**	0.017**	494.60**	126.39**	0.30**	92850**	98.81**	15.81**	21.18**	158.90**
Parents (P)	11	44.63**	9.97**	12.35**	20.12**	2.60**	1.73**	0.012**	162.51^{NS}	89.02*	0.23**	17604^{NS}	30.36^{NS}	20.44**	11.43**	205.64**
P Vs C	1	12.92^{NS}	225.0**	159.2**	112.4**	15.39**	6.25**	0.046**	6791.9**	1310.77**	0.16**	1156070**	1473.97**	2.18^{NS}	12.10^{NS}	77.13**
Crosses (C)	31	31.99**	29.63**	10.27**	18.33**	1.50**	1.78**	0.017**	409.30**	101.44**	0.20**	85252**	78.74**	14.60**	24.94**	144.95**
Lines (L)	7	16.75*	5.15**	11.57*	22.49**	2.84**	1.76**	0.017**	151.11^{NS}	88.35**	0.21*	13622^{NS}	33.96^{NS}	21.62**	8.14^{NS}	206.14**
Testers (T)	3	117.7**	17.07**	17.61**	17.75**	2.90**	2.20**	0.005**	228.12^{NS}	119.72**	0.18^{NS}	29444^{NS}	32.08^{NS}	3.20^{NS}	13.79*	56.51**
L × T	21	24.81**	39.59**	9.68**	17.02**	0.85**	1.72**	0.019**	521.25**	103.19**	0.20**	117102**	100.33**	13.89**	32.12**	137.19**
Error	86	6.62	1.62	4.06	2.88	0.47	0.29	0.001	90.25	40.39	0.08	12844	27.93	3.35	4.33	5.14
Total	131															

**, Significant at P≤0.01; *, Significant at P≤0.05; NS, Non-significant at P>0.05

Table 3. Mean squares for traits in 8 × 4 Line × Tester analysis under water deficit conditions (T_2).

SOV	Df	Plant height	Tillers/ plant	Flag leaf area	Peduncle length	Spike length	Spikelets/ spike	Spike density	Biological yield	Grains/ spike	Grains weight / spike	Grains/ plant	Grains weight/ plant	Thousand grains weight	Harvest index %	Relative cell injury %
Replication	2	2.10^{NS}	2.02^{NS}	3.24^{NS}	2.04^{NS}	0.81^{NS}	0.19^{NS}	0.002^{NS}	2.88^{NS}	20.57^{NS}	0.10^{NS}	8437^{NS}	0.47^{NS}	0.66^{NS}	6.37^{NS}	10.83^{NS}
Genotypes	43	30.58**	11.92**	14.04**	21.53**	1.61**	1.96**	0.015**	219.62**	95.30**	0.22**	28311**	40.95**	23.36**	21.87**	313.32**
Parents (P)	11	40.64**	6.66**	9.20**	17.74**	2.00**	1.75**	0.015**	116.80^{NS}	50.04**	0.13^{NS}	15707**	18.86**	19.04**	11.68^{NS}	244.93**
P Vs C	1	1.34^{NS}	43.22**	134.95**	52.40**	9.09**	3.79**	0.039**	1050.24**	363.06**	1.08**	159475**	200.55**	58.61^{NS}	1.32^{NS}	8.39^{NS}
Crosses (C)	31	27.95**	12.78**	11.85**	21.88**	1.23**	1.98**	0.014**	229.32**	102.72**	0.22**	28552**	43.64**	23.76**	26.15**	347.42**
Lines (L)	7	12.51*	2.75*	6.20*	22.64**	2.07**	1.27**	0.022**	131.01^{NS}	44.08**	0.12^{NS}	17167**	23.61**	18.85**	15.32*	278.16**
Testers (T)	3	104.33**	14.33**	12.21**	8.83*	2.52**	3.38**	0.003^{NS}	115.47**	73.13*	0.15^{NS}	12236^{NS}	13.98*	0.75^{NS}	3.42^{NS}	230.86**
L × T	21	22.19**	15.90**	13.69**	23.49**	0.77^{NS}	2.01**	0.013**	278.35**	126.49**	0.26**	34678**	54.55**	28.68**	33.00**	387.16**
Error	86	5.36	1.26	2.28	2.20	0.50	0.33	0.002	13.94	19.08	0.07	4992	4.62	3.07	6.49	10.80
Total	131															

**, Significant at P≤0.01; *, Significant at P≤0.05; NS, Non-significant at P>0.05

respectively. Highly significant differences for all the parameters were found among all the genotypes under both the irrigation levels.

At T_1 level of irrigation as shown by the Table 2, among parents all the parameters exhibited significant differences excluding biological yield, grains per plant and grains weight per plant which exhibited non-significant differences. The parents vs crosses component exhibited significant differences for all the parameters excluding plant height, thousand grains weight and harvest index percentage of mature plants, which showed non-significant differences. The crosses showed significant differences for all the traits and were divided into lines (female parents), testers (male parents) and line × tester interactions. The lines showed significant differences for all the parameters except biological yield, grains per plant, grain weight per plant and harvest index percentage which showed non-significant differences. The testers exhibited significant differences for all the investigated parameters, except biological yield, grains weight per spike, grains per plant, grains weight per plant and thousand grains weight, which showed non-significant differences. All the traits exhibited significant differences in case of line × tester interactions component.

At T_2 level of moisture availability as shown by the Table 3, all the parameters showed significant differences among the parents, excluding biological yield, grains weight per spike and harvest index percentage which showed non-significant differences. The component of parents vs crosses exhibited significant differences for all the investigated parameters, except plant height, thousand grains weight, harvest index percentage and relative cell injury percentage of mature plants which showed non-significant differences. All the crosses exhibited significant differences under water deficiency stress conditions for all the investigated parameters. Lines demonstrated significant differences for all the studied parameters, except biological yield and grains weight per spike which exhibited non-significant differences. Testers showed significant differences for all the studied traits except spike density, grains weight per spike, grains per plant, thousand grains weight and harvest index percentage which showed non-significant differences. The component of line × tester interactions showed significant differences for all the investigated traits parameters excluding spike length which showed non-significant differences.

Combining ability analysis:

***Plant height*:** For plant height negative GCA and SCA effects are considered important since more emphasis is paid upon the selection of short statured wheat plants, because they would be more responsive to the application of heavy doses of inputs and tolerant to lodging. The Table 4 shows that under normal conditions lines WN-78 (-2.56), WN-91 (-2.69) and tester Uqab-2000 (-2.52) manifested the lowest GCA values. Table 5 revealed that lines WN-78 (-2.01), WN-91 (-1.34) and tester Uqab-2000 (-1.38) showed the minimum negative GCA values under water deficiency stress conditions. Table 6 showed that under normal conditions, crosses WN-91 × Uqab-2000 (-2.02), WN-105 × Shahkar-95 (-1.95) and WN-79 × Lasani-2008 (-1.75) showed the lowest SCA values for plant height. Under moisture deficiency stress environments as shown by the Table 7, crosses WN-91 ×

Table 4. Estimation of general combining ability for some characters in bread wheat at T_1 level of irrigation.

SOV	Lines								Testers			
	WN-66	WN-78	WN-79	WN-85	WN-91	WN-104	WN-105	WN-114	Shahkar -95	Uqab-2000	GA-2002	Lasani-2008
PH	-0.79	-2.56	3.04	-0.03	-2.69	0.09	-0.69	3.62	-0.48	-2.52	3.24	-0.24
T/P	1.71	-1.39	-0.57	2.14	-0.44	-1.66	2.32	-2.11	0.71	-2.02	1.55	-0.25
FLA	1.00	-0.15	-1.45	2.35	0.83	-0.54	-1.06	-0.98	0.20	0.62	0.12	-0.94
PL	0.67	-2.85	-0.08	-0.77	0.79	-1.87	2.22	1.89	-0.22	0.70	0.11	-0.60
SL	-0.23	-0.79	-0.56	0.00	0.23	0.34	0.79	0.21	0.08	-0.04	0.15	-0.20
S/S	-0.36	0.33	-0.64	1.09	0.29	0.22	0.04	-0.98	-0.07	0.33	-0.16	-0.09
SD	-0.00	0.10	0.01	0.07	-0.00	-0.02	-0.07	-0.09	-0.02	0.03	-0.03	0.01
BY	-0.18	-6.60	-3.25	9.35	-2.84	-1.22	7.26	-2.52	1.93	-7.68	7.46	-1.72
G/S	-0.24	-1.11	-4.02	4.01	-0.25	4.64	0.37	-3.40	-0.83	-2.23	4.89	-1.82
GW/S	-0.00	-0.12	-0.21	0.15	-0.05	0.20	-0.07	0.10	-0.09	-0.10	0.20	-0.01
G/P	40.73	-71.44	-57.19	137.98	-18.60	-55.02	96.98	-73.44	21.23	-75.19	91.60	-37.65
GW/P	1.70	-3.18	-2.04	3.35	-1.45	0.02	2.22	-0.61	0.66	-2.82	2.49	-0.32
TGW	0.52	-1.32	-0.54	-1.07	-1.28	0.46	0.40	2.82	-0.56	0.11	-0.71	1.17
HI	2.23	-0.28	-1.09	-1.33	0.35	0.64	-1.30	0.78	-0.45	1.18	-1.15	0.42
RCI%	-0.98	0.85	-1.53	-4.11	2.39	-2.04	-1.91	7.35	4.29	0.39	-1.70	-2.98

Table 5. Estimation of General Combining Ability for some characters in bread wheat at T_2 level of irrigation.

SOV	Lines								Testers			
	WN-66	WN-78	WN-79	WN-85	WN-91	WN-104	WN-105	WN-114	Shahkar-95	Uqab-2000	GA-2002	Lasani-2008
PH	-1.10	-2.01	0.68	0.08	-1.34	1.06	-0.11	2.74	-1.32	-1.38	2.64	0.07
T/P	-0.35	0.48	-0.41	0.29	0.36	-0.09	1.10	-1.37	0.07	-0.77	0.59	0.11
FLA	-0.31	-0.11	-1.34	2.56	0.78	0.15	-0.70	-1.02	-0.08	0.72	-0.35	-0.29
PL	-1.02	-2.59	-0.19	-0.27	0.90	-0.80	1.97	1.99	-0.59	0.72	-0.44	0.30
SL	-0.14	-0.58	-0.51	-0.03	0.07	0.44	0.52	0.22	0.18	-0.03	-0.03	-0.13
S/S	-0.22	0.01	-0.72	1.12	-0.23	0.62	0.16	-0.73	-0.05	0.26	-0.14	-0.08
SD	-0.00	0.07	-0.00	0.09	-0.03	-0.00	-0.05	-0.08	-0.03	0.03	-0.01	0.01
BY	2.50	0.29	-0.69	4.58	-4.44	-0.24	-1.04	-0.96	-1.87	-1.50	0.48	2.89
G/S	-1.51	-2.86	-5.22	5.86	-0.25	6.17	-0.66	-1.53	0.59	-0.76	1.52	-1.35
GW/S	-0.06	-0.19	-0.14	0.20	-0.11	0.38	-0.10	0.01	0.01	-0.08	0.02	0.05
G/P	24.34	28.59	-6.32	63.43	-48.66	-24.24	-7.74	-29.41	14.76	-12.82	4.72	-6.66
GW/P	1.26	0.84	-0.18	2.20	-3.21	0.02	-0.82	-0.11	-0.29	-0.53	0.29	0.54
TGW	0.41	-0.40	1.14	-1.98	-2.65	2.40	-1.76	2.82	-0.70	-0.47	-0.49	1.66
HI	1.22	1.89	0.70	0.87	-4.26	-0.21	-0.94	0.73	1.34	-0.38	0.10	-1.06
RCI%	2.55	1.40	-4.28	-5.12	-2.08	-8.01	11.00	4.55	7.96	-2.10	-2.03	-2.94

Uqab-2000 (-4.36), WN-66 × GA-2002 (-3.60) and WN-78 × GA-2002 (-2.54) manifested the lowest SCA values. Yao *et al*. (2011), Masood *et al*. (2014), Ashraf *et al*. (2015), Istipliler *et al*. (2015), Kalhoro *et al*. (2015) and Muneer *et al*. (2016) also reported negative and positive and low and high GCA and SCA values for plant height in wheat.

Tillers per plant**:** To improve wheat grain yield, traits like tillers per plant plays crucial role because more tillers per plant are expected to give more grain yield. Table 4 revealed that lines WN-85 (2.14), WN-105 (2.32) and tester GA-2002 (1.55) showed the highest GCA values under normal conditions. Table 5 showed that under water deficiency stress environments, lines WN-78 (0.48), WN-105 (1.10) and tester GA-2002 (0.59) exhibited the maximum positive GCA values. Table 6 showed that under normal conditions, crosses WN-79 × Uqab-2000 (4.57), WN-85 × Shahkar-95 (4.55) and WN-78 × GA-2002 (3.24) showed the highest positive SCA values. Table 7 showed that under water deficiency stress conditions, crosses WN-78 × GA-2002 (3.58), WN-66 × Lasani-2008 (3.21) and WN-105 × Shahkar-95 (3.02) showed the highest positive SCA values. Gomaa *et al*. (2014) and Masood *et al*. (2014) witnessed high GCA and SCA values for tillers per plant in wheat. Kalhoro *et al*. (2015), Baloch *et al*. (2016) and Muneer *et al*. (2016) reported negative and positive GCA and SCA effects for tillers per plant in wheat.

Flag leaf area**:** For flag leaf area, negative GCA effects are considered more important because it significantly influence the transpiration losses due to exposure to sunlight and ultimately affects the wheat grain yield which is the ultimate objective. Therefore, selection of genotypes with smaller flag leaf is emphasized. Under normal conditions as shown by the Table 4, lines WN-79 (-1.45), WN-105 (-1.06) and tester Lasani-2008 (-0.94) exhibited the lowest negative GCA values.

Table 6. Estimation of Specific Combining Ability for some traits in bread wheat at T_1 level of irrigation.

SOV	Characters														
Crosses	**PH**	**T/P**	**FLA**	**PL**	**SL**	**S/S**	**SD**	**BY**	**G/S**	**GW/S**	**G/P**	**GW/P**	**TGW**	**HI%**	**RCI%**
WN-66 × Shahkar-95	1.35	-4.53	-0.75	-1.82	-0.19	-0.13	0.01	-13.96	-0.72	-0.01	-216.0	-6.66	0.71	-0.47	-0.68
WN-66 × Uqab-2000	-0.19	-0.94	1.76	0.44	0.74	0.64	-0.03	6.46	3.21	0.24	57.0	2.97	0.02	0.43	-8.01
WN-66 × GA-2002	-0.55	2.34	-0.17	-1.19	-0.50	-0.40	0.02	-15.45	-4.63	-0.27	-219.4	-8.40	1.02	-2.17	8.34
WN-66 × Lasani-2008	-0.61	3.13	-0.84	2.57	-0.05	-0.11	-0.00	22.95	2.13	0.04	378.4	12.10	-1.75	2.21	0.35
WN-78 × Shahkar-95	-0.65	-0.16	1.43	-0.08	0.16	-0.70	-0.07	-2.69	-6.04	-0.29	-69.5	-2.01	-0.42	-1.48	-0.48
WN-78 ×Uqab-2000	0.56	-1.36	-2.02	1.15	0.08	0.79	0.05	-1.26	2.06	0.19	-38.4	0.46	1.46	1.93	-0.63
WN-78 ×GA-2002	-1.12	3.24	-1.80	-2.00	-0.08	0.33	0.03	14.43	5.02	0.19	267.4	6.81	-1.61	0.59	-0.17
WN-78 × Lasnani-2008	1.21	-1.72	2.38	0.93	-0.17	-0.42	-0.01	-10.48	-1.04	-0.09	-159.3	-5.26	0.56	-1.04	1.28
WN-79 × Shahkar-95	1.36	-1.83	-1.75	-0.58	-0.86	-0.51	0.05	-6.56	-0.44	-0.03	-63.4	-1.41	0.64	2.62	-7.99
WN-79 × Uqab-2000	1.45	4.57	2.91	3.92	1.06	0.26	-0.09	12.01	9.88	0.37	136.6	4.13	0.04	-2.06	10.05
WN-79 × GA-2002	-1.07	-1.10	-0.73	-1.30	-0.33	0.15	0.04	-1.55	-6.24	-0.30	-12.8	-0.51	-0.47	0.08	-3.99
WN-79 × Lasani-2008	-1.75	-1.64	-0.44	-2.05	0.13	0.11	-0.00	-3.91	-3.20	-0.05	-60.2	-2.22	-0.21	-0.64	1.93
WN-85 × Shahkar-95	1.26	4.55	0.67	2.23	1.13	0.75	-0.06	14.94	3.03	0.24	200.3	7.14	-0.74	0.65	-2.95
WN-85 × Uqab-2000	-1.35	-2.06	-1.00	-0.31	-0.71	-0.65	0.03	-3.85	-3.23	-0.13	25.1	-1.88	-1.77	-0.44	3.60
WN-85 × GA-2002	0.71	-2.91	0.60	0.80	-0.37	0.12	0.04	-2.43	0.88	0.14	-101.3	-0.06	2.76	1.74	-1.81
WN-85 × Lasani-2008	-0.62	0.42	-0.28	-2.72	-0.05	-0.23	-0.01	-8.66	-0.68	-0.25	-124.1	-5.20	-0.26	-1.94	1.16
WN-91 × Shahkar-95	1.09	2.29	0.04	0.45	0.29	0.00	-0.03	7.65	0.12	-0.07	17.6	2.41	2.23	-1.79	7.03
WN-91 × Uqab-2000	-2.02	-3.31	-0.37	-1.53	-0.60	0.16	0.07	-15.13	2.02	-0.03	-113.9	-4.05	-1.05	5.88	-3.47
WN-91 × GA-2002	-0.73	-0.56	0.59	-0.11	0.42	-0.35	-0.06	4.51	2.24	-0.03	183.2	4.24	-3.58	2.46	-2.43
WN-91 × Lasani-2008	1.66	1.58	-0.25	1.19	-0.11	0.19	0.02	2.97	-4.39	0.13	-86.8	-2.59	2.40	-6.56	-1.12
WN-104× Shahkar-95	-1.74	-0.15	1.39	-0.79	-0.42	0.13	0.05	0.90	1.41	0.06	49.0	0.36	-0.74	0.15	2.80
WN-104 × Uqab-2000	-0.65	1.30	-1.96	-4.10	-0.68	-0.22	0.05	-4.91	-5.91	-0.30	-103.5	-4.59	0.15	-4.65	-4.48
WN-104 × GA-2002	2.34	-1.11	0.08	2.79	0.77	0.12	-0.06	1.37	3.11	0.20	10.9	1.01	0.18	0.76	3.88
WN-104 × Lasani-2008	0.05	-0.03	0.49	2.10	0.33	-0.02	-0.03	2.64	1.40	0.04	43.5	3.23	0.41	3.74	-2.20
WN-105 × Shahkar-95	-1.95	0.37	1.08	-0.29	-0.15	0.47	0.05	0.82	1.18	0.01	122.0	0.92	-2.00	0.65	-8.25
WN-105 × Uqab-2000	0.62	-1.24	-0.45	-0.63	-0.36	-1.11	-0.04	-1.35	-10.14	-0.32	-66.5	0.48	3.76	0.83	-2.51
WN-105 × GA-2002	0.70	2.36	1.48	1.97	0.06	0.29	0.01	6.87	2.13	0.01	4.6	-0.17	-0.73	-3.98	1.80
WN-105 × Lasani-2008	0.62	-1.50	-2.11	-1.05	0.45	0.36	-0.02	-6.34	6.84	0.29	-60.1	-1.23	-1.03	2.51	8.96
WN-114 × Shahkar-95	-0.72	-0.54	-2.11	0.88	0.03	-0.01	-0.00	-1.09	1.44	0.10	-39.9	-0.74	0.32	-0.32	10.53
WN-114 Uqab-2000	1.57	3.04	1.13	1.05	0.48	0.15	-0.03	8.02	2.12	-0.02	103.8	2.49	-2.61	-1.93	5.46
WN-114× GA-2002	-0.28	-2.25	-0.06	-0.97	0.02	-0.25	-0.02	-7.76	-2.50	0.04	-132.6	-2.92	2.41	0.52	-5.63
WN-114 × Lasani-2008	-0.57	-0.25	1.04	-0.96	-0.53	0.12	0.06	0.83	-1.07	-0.12	68.65	1.16	-0.11	1.73	-10.35

Table 7. Estimation of Specific Combining Ability for some traits in bread wheat at T_2 level of irrigation.

SOV	Characters														
Crosses	**PH**	**T/P**	**FLA**	**PL**	**SL**	**S/S**	**SD**	**BY**	**G/S**	**GW/S**	**G/P**	**GW/P**	**TGW**	**HI%**	**RCI%**
WN-66×Shahkar-95	-0.16	-4.92	-2.86	-3.86	-0.78	-0.47	0.05	-19.29	-2.17	-0.16	-218.5	-7.88	1.34	0.79	10.25
WN-66×Uqab-2000	-0.28	1.20	2.78	1.63	1.16	0.62	-0.08	9.35	9.17	0.38	126.4	4.88	1.48	1.99	-8.37
WN-66×GA-2002	-3.60	0.52	-1.58	-1.51	-0.75	-0.68	0.03	-4.69	-12.20	-0.44	-38.8	-1.78	-2.64	-0.32	9.53
WN-66×Lasani-2008	4.04	3.21	1.65	3.74	0.37	0.53	-0.00	14.62	5.19	0.21	130.9	4.78	-0.18	-2.46	-11.41
WN-78×Shahkar-95	0.95	0.03	0.60	2.37	0.44	0.12	-0.04	2.92	0.17	-0.03	64.5	0.25	-2.46	-2.36	0.60
WN-78×Uqab-2000	2.40	-1.06	-1.58	2.43	-0.37	0.20	0.06	-0.28	1.68	0.02	-62.5	0.49	2.30	2.16	-7.59
WN-78×GA-2002	-2.54	3.58	-1.57	-4.14	0.34	0.40	-0.01	10.28	-1.13	-0.01	124.6	4.32	-1.91	-0.13	-7.71
WN-78×LasAni-2008	-0.81	-2.55	2.55	-0.66	-0.42	-0.72	-0.01	-12.92	-0.73	0.02	-126.6	-5.06	2.07	0.33	14.70
WN-79×Shahkar-95	-2.36	-1.28	-1.84	-0.86	-0.58	-0.46	0.03	-8.26	-1.13	-0.04	-103.5	-2.98	1.76	1.38	4.37
WN-79×Uqab-2000	4.26	1.01	2.46	3.80	0.79	0.40	-0.06	8.68	3.38	0.19	77.7	3.36	-0.15	-0.23	7.15
WN-79×GA-2002	0.23	0.27	0.12	-1.78	0.13	0.33	0.01	2.28	-3.23	-0.12	30.8	0.44	-0.72	-1.18	-8.10
WN-79×Lasani-2008	-2.12	-0.00	-0.73	-1.16	-0.34	-0.26	0.02	-2.70	0.98	-0.03	-5.0	-0.82	-0.90	0.02	-3.42
WN-85×Shahkar-95	1.17	1.24	1.71	2.67	0.56	0.48	-0.03	12.34	2.01	0.10	133.4	4.70	1.14	-1.13	-7.85
WN-85×Uqab-2000	-0.90	-1.14	-1.67	-1.57	-0.42	-0.11	0.04	-13.89	-9.70	-0.49	-48.6	-5.39	-4.69	1.42	7.34
WN-85×GA-2002	0.99	0.02	0.30	1.30	-0.32	-0.24	0.02	5.26	6.69	0.50	-50.5	2.35	4.00	0.19	3.68
WN-85×Lasani-2008	-1.25	-0.12	-0.34	-2.39	0.17	-0.13	-0.03	-3.70	1.00	-0.11	-34.1	-1.65	-0.45	-0.48	-3.17
WN-91×Shahkar-95	4.34	2.48	0.26	-0.61	0.86	1.05	-0.02	8.73	0.18	0.19	130.8	4.76	0.20	3.67	-0.93
WN-91×Uqab-2000	-4.36	-3.21	0.91	-0.76	-1.11	-0.93	0.05	-11.44	-1.09	-0.08	-168.9	-6.34	-1.20	-7.15	8.58
WN-91×GA-2002	-0.36	0.59	1.11	1.65	0.01	-0.86	-0.07	-4.32	5.96	-0.01	0.2	-1.02	-0.58	2.88	-4.38
WN-91×Lasani-2008	0.38	0.13	-2.27	-0.28	0.24	0.75	0.03	7.04	-5.05	-0.11	37.9	2.60	1.57	0.60	-3.27
WN-104×Shahkar-95	-1.61	0.41	2.24	-0.75	-0.11	-0.08	0.01	-1.89	1.48	-0.03	-15.9	-0.54	-0.95	-0.60	-4.89
WN-104×Uqab-2000	-1.26	1.02	-2.29	-4.39	-0.39	0.22	0.06	-3.15	-1.23	-0.01	-47.3	-2.41	0.49	-1.58	2.91
WN-104×GA-2002	3.60	-0.70	0.04	4.35	0.20	-0.04	-0.02	4.53	0.84	0.12	71.4	2.24	1.47	0.96	7.97
WN-104×Lasani-2008	-0.73	-0.72	0.01	0.78	0.30	-0.10	-0.04	0.51	-1.09	-0.08	-8.1	0.71	-1.00	1.22	-5.99
WN-105×Shahkar-95	-0.65	3.02	0.83	0.82	-0.07	0.32	0.03	5.38	3.96	0.12	25.5	2.04	-0.35	-0.35	-6.02
WN-105×Uqab-2000	-0.17	-0.34	-1.25	-1.76	-0.09	-0.59	-0.04	0.88	-3.68	0.02	-9.8	0.99	2.82	2.22	-12.26
WN-105×GA-2002	1.53	-3.09	1.63	0.89	0.30	0.58	0.01	-6.89	1.81	-0.16	-78.3	-4.33	-1.36	-4.12	-0.51
WN-105×Lasani-2008	-0.70	0.41	-1.21	0.05	-0.14	-0.31	-0.01	0.63	-2.09	0.02	62.6	1.30	-1.11	2.25	18.79
WN-114×Shahkar-95	-1.67	-0.98	-0.93	0.21	-0.33	-0.95	-0.03	0.07	-4.49	-0.15	-16.4	-0.34	-0.68	-1.39	4.47
WN-114Uqab-2000	0.31	2.52	0.64	0.63	0.43	0.19	-0.03	9.84	1.46	-0.04	133.1	4.41	-1.05	1.16	2.24
WN-114×GA-2002	0.16	-1.19	-0.05	-0.76	0.09	0.51	0.03	-6.44	1.25	0.12	-59.3	-2.22	1.73	1.72	-0.47
WN-114×Lasani-2008	1.20	-0.36	0.34	-0.08	-0.18	0.25	0.04	-3.47	1.78	0.07	-57.3	-1.85	-0.00	-1.49	-6.24

Appendix 1a. List of accessions screened against two water regimes in green house.

Code	Deptt. Code	Original name	Code	Deptt. of PBG Name	Original name
V1	WN-64	41st INTL Bread wheat 1064 (2008-09)	V51	WN-73	41st INTL Bread wheat 1073 (2008-09)
V2	WN-65	41st INTL Bread wheat 1065 (2008-09)	V52	WN-72	41st INTL Bread wheat 1072 (2008-09)
V3	WN-63	41st INTL Bread wheat 1063 (2008-09)	V53	WN-71	41st INTL Bread wheat 1071 (2008-09)
V4	WN-62	41st INTL Bread wheat 1062 (2008-09)	V54	WN-69	41st INTL Bread wheat 1069 (2008-09)
V5	WN-61	41st INTL Bread wheat 1061 (2008-09)	V55	WN-66	41st INTL Bread wheat 1066 (2008-09)
V6	WN-59	41st INTL Bread wheat 1059 (2008-09)	V56	WN-105	41st INTL Bread wheat 1105 (2008-09)
V7	WN-58	41st INTL Bread wheat 1058 (2008-09)	V57	WN-111	41st INTL Bread wheat 1111 (2008-09)
V8	WN-57	41st INTL Bread wheat 1057 (2008-09)	V58	WN-113	41st INTL Bread wheat 1113 (2008-09)
V9	WN-54	41st INTL Bread wheat 1054 (2008-09)	V59	WN-114	41st INTL Bread wheat 1114 (2008-09)
V10	WN-53	41st INTL Bread wheat 1053 (2008-09)	V60	WN-115	41st INTL Bread wheat 1115 (2008-09)
V11	WN-52	41st INTL Bread wheat 1052 (2008-09)	V61	WN-116	41st INTL Bread wheat 1116 (2008-09)
V12	WN-51	41st INTL Bread wheat 1051 (2008-09)	V62	WN-117	41st INTL Bread wheat 1117 (2008-09)
V13	WN-50	41st INTL Bread wheat 1050 (2008-09)	V63	WN-118	41st INTL Bread wheat 1118 (2008-09)
V14	WN-49	41st INTL Bread wheat 1049 (2008-09)	V64	WN-119	41st INTL Bread wheat 1119 (2008-09)
V15	WN-48	41st INTL Bread wheat 1048 (2008-09)	V65	WN-120	41st INTL Bread wheat 1120 (2008-09)
V16	WN-45	41st INTL Bread wheat 1045 (2008-09)	V66	WN-86	41st INTL Bread wheat 1086 (2008-09)
V17	WN-43	41st INTL Bread wheat 1043 (2008-09)	V67	WN-87	41st INTL Bread wheat 1087 (2008-09)
V18	WN-42	41st INTL Bread wheat 1042 (2008-09)	V68	WN-89	41st INTL Bread wheat 1089 (2008-09)
V19	WN-41	41st INTL Bread wheat 1041 (2008-09)	V69	WN-90	41st INTL Bread wheat 1090 (2008-09)
V20	WN-40	41st INTL Bread wheat 1040 (2008-09)	V70	WN-91	41st INTL Bread wheat 1091 (2008-09)
V21	WN-38	41st INTL Bread wheat 1038 (2008-09)	V71	WN-93	41st INTL Bread wheat 1093 (2008-09)
V22	WN-35	41st INTL Bread wheat 1035 (2008-09)	V72	WN-98	41st INTL Bread wheat 1098 (2008-09)
V23	WN-32	41st INTL Bread wheat 1032 (2008-09)	V73	WN-100	41st INTL Bread wheat 1100 (2008-09)
V24	WN-30	41st INTL Bread wheat 1030 (2008-09)	V74	WN-104	41st INTL Bread wheat 1104 (2008-09)
V25	WN-29	41st INTL Bread wheat 1029 (2008-09)	V75	9407	Elite lines of Dept. of PBG
V26	WN-28	41st INTL Bread wheat 1028 (2008-09)	V76	8177	Elite lines of Dept. of PBG
V27	WN-27	41st INTL Bread wheat 1027 (2008-09)	V77	9459-1	Elite lines of Dept. of PBG
V28	WN-25	41st INTL Bread wheat 1025 (2008-09)	V78	9432	Elite lines of Dept. of PBG
V29	WN-24	41st INTL Bread wheat 1024 (2008-09)	V79	9381	Elite lines of Dept. of PBG
V30	WN-23	41st INTL Bread wheat 1023 (2008-09)	V80	9317	Elite lines of Dept. of PBG
V31	WN-2	41st INTL Bread wheat 1002 (2008-09)	V81	9272	Elite lines of Dept. of PBG
V32	WN-20	41st INTL Bread wheat 1020 (2008-09)	V82	9451	Elite lines of Dept. of PBG
V33	WN-19	41st INTL Bread wheat 1019 (2008-09)	V83	9242	Elite lines of Dept. of PBG
V34	WN-18	41st INTL Bread wheat 1018 (2008-09)	V84	9469	Elite lines of Dept. of PBG
V35	WN-22	41st INTL Bread wheat 1022 (2008-09)	V85	8121	Elite lines of Dept. of PBG
V36	WN-21	41st INTL Bread wheat 1021 (2008-09)	V86	9277	Elite lines of Dept. of PBG
V37	WN-17	41st INTL Bread wheat 1017 (2008-09)	V87	9452	Elite lines of Dept. of PBG
V38	WN-14	41st INTL Bread wheat 1014 (2008-09)	V88	9253	Elite lines of Dept. of PBG
V39	WN-11	41st INTL Bread wheat 1011 (2008-09)	V89	8053	Elite lines of Dept. of PBG
V40	WN-10	41st INTL Bread wheat 1010 (2008-09)	V90	9444-6	Elite lines of Dept. of PBG
V41	WN-6	41st INTL Bread wheat 1006 (2008-09)	V91	6142	Elite lines of Dept. of PBG
V42	WN-85	41st INTL Bread wheat 1085 (2008-09)	V92	6529-11	Elite lines of Dept. of PBG
V43	WN-83	41st INTL Bread wheat 1083 (2008-09)	V93	9233	Elite lines of Dept. of PBG
V44	WN-82	41st INTL Bread wheat 1082 (2008-09)	V94	8073	Elite lines of Dept. of PBG
V45	WN-81	41st INTL Bread wheat 1081 (2008-09)	V95	7012	Elite lines of Dept. of PBG
V46	WN-80	41st INTL Bread wheat 1080 (2008-09)	V96	8126	Elite lines of Dept. of PBG
V47	WN-79	41st INTL Bread wheat 1079 (2008-09)	V97	9466	Elite lines of Dept. of PBG
V48	WN-78	41st INTL Bread wheat 1078 (2008-09)	V98	5039	Elite lines of Dept. of PBG
V49	WN-75	41st INTL Bread wheat 1075 (2008-09)	V99	9247	Elite lines of Dept. of PBG
V50	WN-74	41st INTL Bread wheat 1074 (2008-09)	V100	4770	Elite lines of Dept. of PBG

Table 5 showed that under moisture deficiency stress environments, lines WN-79 (-1.36), WN-114 (-1.02) and tester GA-2002 (-0.35) exhibited minimum negative GCA values. Under normal conditions as shown by the Table 6, crosses WN-105 × Lasani-2008 (-2.11), WN-114 × Shahkar-95 (-2.11) and WN-78 × Uqab-2000 (-2.02) manifested the lowest negative SCA values. Table 7 showed that under water deficiency stress conditions crosses WN-66 × Shahkar-95 (-2.86), WN-104 × Uqab-2000 (-2.29) and WN-91 × Lasani-2008 (-2.27) showed the lowest negative SCA values.

Masood *et al*. (2014), Ashraf *et al*. (2015) and Muneer *et al*. (2016) reported negative and positive and low and high GCA and SCA values for flag leaf area in wheat.

Appendix 1b. List of accessions screened against two water regimes in green house.

Code	Deptt. Code	Original name
V101	7028	Elite lines of Dept. of PBG
V102	9021	Elite lines of Dept. of PBG
V103	9451	Elite lines of Dept. of PBG
V104	9479	Elite lines of Dept. of PBG
V105	9436	Elite lines of Dept. of PBG
V106	4072	Elite lines of Dept. of PBG
V107	9438	Elite lines of Dept. of PBG
V108	9428	Elite lines of Dept. of PBG
V109	7086-1	Elite lines of Dept. of PBG
V110	6500	Elite lines of Dept. of PBG
V111	6039	Elite lines of Dept. of PBG
V112	9486	Elite lines of Dept. of PBG
V113	9476	Elite lines of Dept. of PBG
V114	9189	Elite lines of Dept. of PBG
V115	9957	Elite lines of Dept. of PBG
V116	9244	Elite lines of Dept. of PBG
V117	9227	Elite lines of Dept. of PBG
V118	9268	Elite lines of Dept. of PBG
V119	9964	Elite lines of Dept. of PBG
V120	9967	Elite lines of Dept. of PBG
V121	8031-2	Elite lines of Dept. of PBG
V122	LU-26	Approved varieties
V123	Manthar-2003	Approved varieties
V124	Kohinoor-83	Approved varieties
V125	Lasani-2008	Approved varieties
V126	Chakwal-86	Approved varieties
V127	Chenab-2000	Approved varieties
V128	Punjab-96	Approved varieties
V129	Uqab-2000	Approved varieties
V130	AS-2002	Approved varieties
V131	Rawal-87	Approved varieties
V132	Pitic-62	Approved varieties
V133	GA-2002	Approved varieties
V134	Barani-83	Approved varieties
V135	Faisalabad-83	Approved varieties
V136	Shahkar-95	Approved varieties
V137	Kohistan-97	Approved varieties
V138	Faisalabad-2008	Approved varieties
V139	PBW-222	Approved varieties
V140	Pasban-90	Approved varieties
V141	Perwaz-94	Approved varieties
V142	Punjab-85	Approved varieties
V143	Bhakkar-2002	Approved varieties
V144	Iqbal-2000	Approved varieties
V145	Ufaq-2002	Approved varieties
V146	LU-26S	Selection from LU-26
V147	Sehar-2006	Approved varieties
V148	SH-2002	Approved varieties
V149	Pak-81	Approved varieties
V150	Chakwal-50	Approved varieties

***Spike length*:** Longer spike has the capability to produce more spikelets per spike and more grains per spike, which ultimately results in better wheat grain yield production. Hence increase in spike length is always one of the main objectives of wheat breeders. Table 4 exhibited that lines WN-104 (0.34), WN-105 (0.79) and tester GA-2002 (0.15) exhibited the highest positive GCA values. Table 5 showed that lines WN-104 (0.44), WN-105 (0.52), and tester Shahkar-95 (0.18) showed the maximum positive GCA values under water deficit stress conditions. Under normal conditions crosses WN-85 × Shahkar-95 (1.13), WN-79 × Uqab-2000 (1.06) and WN-104 × GA-2002 (0.77) showed the highest positive SCA values for spike length as shown by the Table 6. Table 7 showed that crosses WN-66 × Uqab-2000 (1.16), WN-91 × Shahkar-95 (0.86) and WN-79 × Uqab-2000 (0.79) showed the highest positive SCA values under moisture deficiency stress conditions. Yao *et al*. (2011), Masood *et al*. (2014) and Ashraf *et al*. (2015) reported high GCA and SCA values for spike length in wheat. Istipliler *et al*. (2015), Kalhoro *et al*. (2015), Baloch *et al*. (2016) and Muneer *et al*. (2016) reported negative and positive GCA and SCA effects for spike length in wheat.

***Grains per spike*:** The trait grains per spike plays a positive role to improve yield, hence positive GCA effects are more important. Table 4 showed that lines WN-85 (4.01), WN-104 (4.64) and tester GA-2002 (4.89) exhibited the maximum positive GCA values. Under moisture deficiency stress environments as shown by the Table 5, lines WN-85 (5.86) and WN-104 (6.17) and tester GA-2002 (1.52) exhibited the highest positive GCA values. Table 6 revealed that under normal conditions crosses WN-79 × Uqab-2000 (9.88), WN-105 × Lasani-2008 (6.84) and WN-78 × GA-2002 (5.02) manifested the highest positive SCA effects. Table 7 showed that under water deficiency stress conditions, crosses WN-66 × Uqab-2000 (9.17), WN-85× GA-2002 (6.69) and WN-91 × GA-2002 (5.96) showed highest positive SCA values. Saeed *et al*. (2010) reported significant GCA and SCA effects for grains per spike under well irrigated and drought environments. Khiabani *et al*. (2015), Baloch *et al*. (2016) and Muneer *et al*. (2016) reported negative and positive GCA and SCA effects for grains per spike in wheat.

***Grains per plant*:** The average number of grains per plant is one of the most important yield contributing traits and positive SCA values are anticipated for yield enhancement. Table 4 showed that lines WN-85 (137.98), WN-105 (96.98) and tester GA-2002 (91.60) exhibited the highest positive GCA values in control conditions. Similarly, Table 5 showed that under water deficiency stress conditions lines WN-78 (28.59), WN-85 (63.43) and tester Shahkar-95 (14.76) exhibited the maximum positive GCA values. Under normal conditions as shown by the Table 6, crosses WN-66 × Lasani-2008 (378.48), WN-78 × GA-2002 (267.40) and WN-85 × Shahkar-95 (200.35) showed the highest SCA values for this trait. The Table 7 showed that under moisture deficiency stress conditions, crosses WN-85 × Shahkar-95 (133.41), WN-114 × Uqab-2000 (133.16) and WN-66 × Lasani-2008 (130.91) showed the highest positive SCA values.

***Grains weight per plant*:** The grains weight per plant plays the crucial role among yield contributing traits and helps to improve yield on per unit area. It was revealed by the Table 4 that under normal environments lines WN-85 (3.35), WN-105 (2.22) and tester GA-2002 (2.49) showed the highest positive GCA values. Table 5 showed that lines WN-66 (1.26), WN-85 (2.20) and tester Lasani-2008 (0.54) showed the highest positive GCA values under water deficiency stress conditions. Under normal conditions as shown by the Table 6, crosses WN-66 × Lasani-2008 (12.10), WN-85 × Shahkar-95 (7.14) and WN-78 × GA-2002 (6.81) showed the highest positive SCA values. Similarly, under moisture deficiency stress conditions as shown in Table 7, crosses WN-66 × Uqab-2000 (4.88), WN-66 × Lasani-2008 (4.78) and WN-91 × Shahkar-95 (4.76) manifested the highest positive SCA values. Saeed *et al*. (2010) under normal and water deficiency stress environments witnessed significant GCA and SCA values for grains yield per plant in wheat. Masood *et al*. (2014) and Istipliler *et al*. (2015) reported high GCA and SCA values for grain yield per row. Kalhoro *et al*. (2015), Khiabani *et al*. (2015), Baloch *et al*. (2016) and Muneer *et al*. (2016) also reported negative and positive GCA and SCA effects for grains weight per plant in wheat.

***Thousand grains weight*:** Thousand grains weight is an important yield contributing trait which contributes positively towards yield, so positive combining ability effects would also be favorable for genetic improvement in wheat yield. Under normal conditions as shown by the Table 4 lines WN-66 (0.52), WN-114 (2.82) and tester Lasani-2008 (1.17) manifested the highest positive GCA value in normal conditions. Table 5 revealed that under moisture deficiency stress conditions, lines WN-104 (2.40), WN-114 (2.82) and tester Lasani-2008 (1.66) showed the highest positive GCA values. Under normal conditions as shown by the Table 6, crosses WN-105 × Uqab-2000 (3.76), WN-85 × GA-2002 (2.76) and WN-114 × GA-2002 (2.41) manifested the maximum positive SCA values. Under moisture deficiency stress conditions as shown by the Table 7, crosses WN-85 × GA-2002 (4.00), WN-105 × Uqab-2000 (2.82) and WN-78 × Uqab-2000 (2.30) showed the highest positive SCA values. Akbar *et al*. (2009), Masood *et al*. (2014), Ashraf *et al*. (2015), Istipliler *et al*. (2015), Kalhoro *et al*. (2015), Khiabani *et al*. (2015) and Baloch *et al*. (2016) reported high GCA and SCA values for thousand grains weight in wheat.

***Harvest index percentage*:** Better harvest index percentage contributes positively in getting better economical grain yield of wheat. Table 4 showed that under normal conditions lines WN-66 (2.23), WN-114 (0.78) and tester Uqab-2000 (1.18) showed the highest positive GCA values. Under water deficiency stress conditions as shown by the Table 5, lines WN-66 (1.22), WN-78 (1.89) and tester Shahkar-95 (1.34) manifested the maximum positive GCA values. Under normal conditions as shown by the Table 6, crosses WN-91 × Uqab-2000 (5.88), WN-104 × Lasani-2008 (3.74) and WN-79 × Shahkar-95 (2.62) manifested the highest positive SCA values for harvest index percentage. Likewise, under water deficiency stress conditions as shown by the Table 7, crosses WN-91 × Shahkar-95 (3.67), WN-91 × GA-2002 (2.88) and WN-105 × Lasani-2008 (2.25) manifested the maximum positive SCA values. Saeed *et al*. (2010) under water deficiency stress and well irrigated conditions witnessed significant GCA and SCA values for harvest index in wheat. Khiabani *et al*. (2015) and Baloch *et al*. (2016) also reported negative and positive GCA and SCA effects for harvest index in wheat.

***Relative cell injury percentage*:** Genotypes showing low relative cell injury percentage (RCI%) are favored for moisture deficiency stress environment, because increased RCI% is the consequence of increased electrolyte leakage due to damaged cell membrane under water deficiency stress. It was evident from the Table 4 that under normal conditions, lines WN-85 (-4.11), WN-104 (-2.04) tester Lasani-2008 (-2.98) manifested the minimum negative GCA values. Table 5 showed that lines WN-85 (-5.12), WN-104 (-8.01) and tester Lasani-2008 (-2.94) showed the lowest negative GCA values under moisture deficiency stress environments. Under normal conditions of moisture availability as shown by the Table 6, crosses WN-114 × Lasani-2008 (-10.35), WN-105 × Shahkar-95 (-8.25) and WN-66 × Uqab-2000 (-8.01) manifested the lowest negative SCA values of RCI%. Similarly, under moisture deficiency stress conditions as shown by the Table 7, crosses WN-105 × Uqab-2000 (-12.26), WN-66 × Lasani-2008 (-11.41) and WN-79 × GA-2002 (-8.10) showed the minimum SCA values of RCI%. Yildirim *et al*. (2009) assessed wheat plants at seedling, stem elongation and milking stages and found positive and similar combining ability effects for membrane thermostability (MTS) and relative injury (RI). They observed that membrane thermostability decreased towards the maturity of the crop. Our results also indicated same relationship that RCI % was increased with maturity and less tolerance to drought.

***Conclusion*:** The results revealed that there was significant genotypic variation among the genotypes for the studied characters. Selection for parents with high GCA effects and crosses with high SCA effects would be a suitable strategy for yield improvement in wheat. Under control and water deficiency stress conditions, the lines WN-66, WN-85, WN-104 and testers GA-2002 and Lasani-2008 showed good GCA values for various yield contributing parameters. Among crosses WN-66 × Lasani-2008, WN-66 × Uqab-2000 and WN-85 × GA-2002 showed the good SCA values for different yield contributing traits. These parental genotypes and their crosses manifesting good GCA and SCA values could be used in future wheat breeding programs aiming at yield improvements under water deficiency stress environments.

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