G.J.B.B., VOL.7 (4) 2018: 642-650 ISSN 2278 – 9103

GLOBAL JOURNAL OF BIO-SCIENCE AND BIOTECHNOLOGY

www.scienceandnature.org

GENE ACTION AND COMBINING ABILITY ANALYSIS OF QUANTITATIVE TRAITS ASSOCIATED WITH GRAIN YIELD IN WHEAT UNDER DROUGHT STRESS AND NORMAL IRRIGATION CONDITIONS

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ABSTRACT
Wheat (*Triticum aestivum* L.) is the widely-adopted crop for human food consumption worldwide. Besides being important as staple food in Pakistan it is also contributing in the economy of the country. Drought is one of the leading stress in world food supply that affects plant growth and development, ultimately affecting yield and yield contributing trait. This study was conducted to examine the impact of drought stress on wheat. Five lines viz. 9737, 9738, 9739, 9740, 9741 and three testers *viz*. Kohistan-97, Chakwal-50, Chakwal-86 were crossed in line × tester mating design using randomized complete block design layout with factorial arrangements. Three replications of 15 F_1's along with their parents were grown and evaluated in field under normal irrigation and drought stress conditions to investigate certain yield parameters affected by drought stress. Data was recorded for days to heading, days to maturity, plant height, flag leaf area, spike length, spikelets per spike, spike density and grain yield. The recorded parameters were assessed through line × tester analysis. General and specific combining ability effects of the traits were evaluated. Gene action and proportional distribution of lines, testers and line × tester interaction to total variance were measured to know about the nature of inheritance of the trait (additive & non-additive) and contribution of parents and their interaction for each trait. The information derived from this study can be useful in the development of high yielding genotypes under drought stress in further breeding programs.

KEYWORDS: Wheat (*Triticum aestivum* L.), Drought stress, General combining ability, Specific combining ability, Gene action.

INTRODUCTION
Wheat is a self-pollinated crop belongs to family *Poaceae*. As a staple food, it is the most popular and grown widely on large acreage in Pakistan. Wheat contributes 2% of GDP and 9.9% of the value added in agriculture. In 2015-16 cultivation of wheat is increased to 9260 thousand hectares as compared to last year that was 9204 thousand hectares. The production of wheat increased 1.6 % compared to last year (2014-15) due to timely sowing and availability of moisture on particularly in "barani" track that supported wheat germination and growth. Wheat is widely adopted crop belongs to family *Poaceae,* grown in irrigated and rain fed areas. Drought stress is seriously affecting crop growth in most part of the world thus affecting crop productivity. It is necessary to identify the source and screening for improved traits under water deficit conditions for developing drought resistance varieties (Singh *et al*., 2014).
The abiotic stresses differently effect on different growth stages and always adversely affect the yield (Mahajan and Tuteja, 2005). Drought and heat stress are most common and usually occur together (Sadras *et al*.,2012). Drought is a limitation factor to quality and yield of crop due to unavailability of water at critical growth stages leading to decrease in number of fertile tillers, number of grains/spike, biological yield, plant height and harvest index (Shamsi *et al.*, 2011). With the continuous increase population world wheat demand is also increased specially in countries like Pakistan where it is used as a staple food. Wheat is important sources of nutrients (1/3rd of the world population use wheat as the source of protein and carbohydrates) as it has 12.1% protein, 70.20 % carbohydrates, 22% crude fibers, 2 % fat and 12 % water (Danda *et al*., 2004).
Line × tester being extensively used in wheat to find out combining ability effects as well as gene action. It provides us information regarding genetic mechanisms of various minor genes that can cumulatively control yield related traits (Rashid *et al*., 2007). Combining ability is important to assess the difference among the genotypes and is also valuable to select the suitable parents or crosses for crop improvement by the suitable breeding method (Salgotra *et al.*, 2009). General combining ability and specific combing ability are used as a tool to estimate additive and non-additive gene actions respectively (Iqbal *et al.*, 2007).
The objective of the present study to estimate the combining ability effects to determine the nature and magnitude of gene action for certain morphological and grain yield related traits through line × tester mating design under drought stress. The best general and specific combiners are identified and utilized in effective breeding programs to improve wheat production.

MATERIALS & METHODS

The present study was conducted to study the combing ability combining ability effects (GCA and SCA) by using Line × tester analysis in the experimental area of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. The experimental material comprised of five lines *viz*. 9737, 9738, 9739, 9740, 9741 as maternal parent and three testers *viz*. kohistan-97, Chakwal-50, Chakwal-86 as paternal parent. These genotypes were crossed in line × tester crossing scheme during 1st crop season, effective crossing was ensured by hand emasculated female spikes were bagged to protect them from any unwanted pollen contamination. At the time of ovary receptivity, these emasculated female spikes were hand pollinated through fresh pollens from the relevant male parents. Sufficient numbers of spikes were emasculated for each of 15 crosses and pollinated to obtained efficient seed setting. Seeds of each of the crosses were saved separately at the time of harvesting.

In the second year of research, the seeds of F1 and eight parents were grown in field in triplicated Randomized Complete Block Design. Two experiments were conducted to investigate the effect on grain yield and yield contributing traits under drought and normal conditions. Each F1 crossed seeds and parents were assigned randomly to the experimental units in each block. Plant to plant and row to row distance were 15 and 30 cm respectively. Two seeds per hole were sown with the help of dibbler that were later thinned to one seedling per hole after germination. Efforts were done to apply proper production technology till crop maturity. At maturity four well-guarded plants were randomly selected from each line of each replication for collection of data for following traits *viz* Days to heading, Days to maturity, Plant Height, Flag leaf area, Spike length, Spikelet per spike, Spike density and Grain yield per plant.

Data collected for all the characters was subjected to analysis of variance technique as given by the Steel *et al.*, (1997) to calculate the differences among parents and their respective crosses. Line × tester analysis by Kempthorne (1957) was used for further analysis of the traits showing significant differences. General combining ability (GCA) for lines and testers and specific combing ability (SCA) for crosses were estimated.

RESULTS & DISCUSSION

Line × Tester analysis was also used by Rawling and Thompson (1962) to estimate GCA and SCA effects on inbred parents. This technique was applied on 15 crosses that were derived from five lines (female parents) and three testers (male parents). All these cross seed along with their parents were grown under drought stress as well as normal water conditions. Data was collected for certain traits that were subjected to analysis of variance and Line × Tester analysis to interpret results. The results are presented as follows:

Under normal irrigation condition (Table 1) among lines (female parents) highly significant differences were observed for days to heading and maturity, plant height, flag leaf area, spikelets per spike, spike density and grain yield/plant while significant differences was found in lines for spike length. On the other hand, for testers that were used as paternal parents highly significant difference was recorded for all the traits under non-stress condition.

Source of variation	Degree of freedom	DOH	DOM	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant
Replication	2	0.04^{ns}	0.10 ^{ns}	0.59*	0.82 ^{ns}	0.06 ^{ns}	0.20 ^{ns}	0.0006 ^{ns}	1.52**
Genotypes	22	10.10**	12.86**	45.20 **	75.61**	16**	7.29**	0.0436**	65.72**
Parents	7	13.52**	12.45**	46.00 **	71.67**	1.68**	3.09**	0.0289**	61.06**
crosses	14	6.57 **	11.97**	43.45 **	82.65**	1.57 **	9.76**	0.0540**	72.39**
P vs C	1	35.74**	28.06**	64.34 **	4.70 **	1.49**	2.38**	0.0000 ^{ns}	4.68**
Lines	4	5.48**	7.24 **	44.73 **	63.55**	0.48*	13.87**	0.0656**	102.7**
Testers	2	4.69 **	29.96**	16.49 **	10.56**	1.09**	1.29**	0.0105**	52.3**
L × T	8	7.58 **	9.84 **	49.54 **	110.2**	2.24**	9.80**	0.0591**	62.25**
Error	44	0.26	0.25	0.14	0.56	0.17	0.09	0.0013	0.26

TABLE 1. Mean square values for various traits in wheat crop under normal irrigation condition

** = Highly significant at 1% probability level, *= Significant at 5% probability level, n.s = Non-significance

From the interactions of lines and testers under normal irrigation condition, highly significant differences were revealed for days to heading and maturity, plant height, flag leaf area, spikelets / spike, spike length and yield per plant. Parents results showed that parents had highly significant differences for all the traits under normal irrigated condition. Crosses and P vs C interaction had also showed highly significant differences for all the traits under study. Results were also conferred by Noorka and Silva (2014).

Under drought stress condition (Table 2) maternal parents (lines) showed highly significant difference for days to heading and maturity, plant height, flag leaf area, spike length, spikelets per spike, grain yield per plant and spike density. On the other hand, paternal parents (testers) also showed highly significant difference for all the traits. Line × tester interactions under drought stress condition showed that all the traits under study had highly significant difference for line × tester interactions. Parents and crosses were revealed highly significant difference for all the traits, their values are presented in Table 2. Under drought stress condition, parents' vs crosses interaction was found non-significant for the plant height, spike length and spike density. Significant difference was found for the number of spikelets per spike and highly significant for the flag leaf area, yield per plant, days to heading and maturity. Results were also reported by Jain and Sastry (2012), Fellahi ***et al.*** (2013) and Uzair *et al.* (2016).

Source of variation	Degree of freedom	DOH	DOM	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant
Replication	2	0.52 ns	0.54 ns	0.22 ns	6.86**	0.37 ns	0.06 ns	0.002 ns	1.03**
Genotypes	22	16.4**	22.05**	58.60**	93.35**	1.94**	5.80**	0.03**	53.98**
Parents	7	5.14**	10.66**	67.91**	143.9**	1.87 **	5.49**	0.03**	37.36**
Crosses	14	13.8**	18.90**	813.8**	74.4**	2.09 **	6.27**	0.03**	65.42**
P vs C	1	131.6**	145.9**	0.002 ns	5.17**	0.31 ns	1.57 *	0.001 ns	10.01**
Lines	4	30.5**	30.03**	38.13**	80.4**	0.95 **	3.81**	0.032**	39.58**
Testers	2	4.20**	37.22**	34.02**	5.29**	1.19**	5.11**	0.020**	95.16**
L × T	8	7.89**	8.75**	74.16**	88.3**	2.89**	7.78**	0.034 **	74.10**
Error	44	0.64	0.39	0.28	0.42	0.13	0.32	0.002	0.16

TABLE 2. Mean square values for various traits in wheat crop under drought stress condition
** = Highly significant at 1% probability level, *= Significant at 5% probability level, n.s = Non-significance

TABLE 3. Estimation of general combining ability (GCA) effects for certain traits in Wheat under normal irrigation condition

Parents	Days to heading	Days to maturity	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant (g)
Lines/ Females								
9737	-0.07	0.02	1.78	2.15	-0.28	-0.16	0.01	-3.08
9738	-0.84	-1.09	2.43	1.71	0.13	1.84	0.11	2.50
9739	-0.62	-0.64	-0.51	0.69	0.32	-1.58	-0.13	-2.34
9740	1.04	1.13	-3.21	-4.50	-0.10	0.31	0.03	4.64
9741	0.49	0.58	-0.48	-0.06	-0.06	-0.41	-0.02	-1.72
S.E	0.16	0.15	0.14	0.27	0.14	0.08	0.01	0.18
Testers/males								
Chakwal 50	0.36	1.51	0.43	-0.47	-0.31	-0.16	0.02	2.02
Kohistan 97	0.29	-1.29	0.77	0.97	0.11	0.34	0.01	-1.66
Chakwal 86	-0.64	-0.22	-1.19	-0.50	0.20	-0.18	-0.03	-0.37
S.E	0.12	0.12	0.11	0.21	0.11	0.06	0.009	0.14

Combining ability analysis:
Combining ability analysis is being excessively used in wheat crop in which parents are categorized on the base of their potential to transfer traits in hybrid combinations. In this technique, total genetic variation is split into general combining ability (GCA) effects and specific combining ability (SCA) effects. The present research was conducted to estimates the gene action responsible for inheritance of yield contributing traits in wheat using line by tester analysis of Kampthorne (1957).
Sprauge and Tatumn (1942) defined the general and specific combining ability in which the term GCA (general combing ability) is needed in those cases in which certain combination would be expected to perform relatively superior or inferior based on lines average performances. General combining ability is the average performance of the genotypes through series of crosses and it is due to additive gene action. In this research, five lines that were used as maternal parents and three testers that were used as paternal parent were evaluated for certain yield contributing traits to identify best desirable parents for hybrid development in further breeding program. Assessment of general combing ability was partitioned into male and female parents áunder normal irrigated and drought stress condition Table 4 and Table 5 respectively for all the characters under study to find out the potential parents for high yield.

TABLE 4. Estimation of general combining ability (GCA) effects for certain traits in Wheat under drought stress

Parents	Days to heading	Days to maturity	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spike--lets per spike	Spike density	Grain yield per plant(g)
Lines								
9737	-1.51	-0.96	1.24	1.58	-0.54	0.43	0.07	2.97
9738	-2.29	-2.73	2.13	2.39	0.21	0.79	0.04	0.43
9739	1.27	1.38	-0.42	0.32	0.22	-0.84	-0.08	-0.36
9740	2.04	1.60	-3.25	-5.16	-0.07	0.02	0.00	-0.82
9741	0.49	0.71	0.30	0.87	0.18	-0.04	-0.04	-2.22
S.E	0.30	0.21	0.19	0.23	0.14	0.21	0.02	0.15
Testers								
Chakwal 50	0.40	1.22	0.97	-0.35	-0.26	0.12	0.03	0.53
Kohistan 97	-0.60	-1.78	0.76	0.69	0.30	0.52	0.01	2.21
Chakwal 86	0.20	0.56	-1.73	-0.34	-0.04	-0.63	-0.04	-2.74
S.E	0.23	0.17	0.15	0.18	0.12	0.16	0.01	0.12

Crosses	DOH	DOM	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grains per spike	1000 grain weight (g)	Grain yield per plant (g)
9737×C50	1.53	1.71	0.37	0.05	0.23	-1.42	-0.12	-0.08	1.33	-5.35
9737×K97	-0.07	-0.16	2.09	3.76	0.19	-0.42	-0.04	-0.72	0.3	1
9737×C86	-1.47	-1.56	-2.46	-3.81	-0.42	1.84	0.16	0.8	-1.63	4.35
9738×C50	-2.36	-2.84	-5.6	-1.39	-0.75	0.83	0.12	4.69	-2.07	5.04
9738×K97	0.38	0.62	2.55	-5.52	0.43	-2.17	-0.18	0.39	-0.72	-3.11
9738×C86	1.98	2.22	3.05	6.92	0.32	1.34	0.05	-5.09	2.79	-1.92
9739×C50	-1.24	-1.29	3.32	1.41	1	-0.76	-0.12	-8.03	4.64	-1.56
9739×K97	0.82	0.84	-0.43	7.51	0.39	2.49	0.13	5.34	-2.53	2.54
9739×C86	0.42	0.44	-2.89	-8.92	-1.39	-1.74	0	2.69	-2.11	-0.98
9740×C50	1.42	1.6	-2.76	-1.86	-0.15	1.36	0.1	-0.56	-3.07	4.7
9740×K97	-0.84	-0.93	-0.11	-1.01	-0.56	-0.48	0.02	0.64	0.94	0.33
9740×C86	-0.58	-0.67	2.86	2.86	0.7	-0.88	-0.11	-0.09	2.13	-5.03
9741×C50	0.64	0.82	4.67	1.79	-0.34	-0.01	0.02	3.97	-0.83	-2.83
9741×K97	-0.29	-0.38	-4.11	-4.74	-0.45	0.58	0.08	-5.66	2.01	-0.77
9741×C86	-0.36	-0.44	-0.57	2.95	0.79	-0.57	-0.1	1.69	-1.18	3.59

TABLE 5. Specific combining ability for various yield contributing traits under normal irrigation condition

Crosses	DOH	DOM	Plant height (cm)	Flag leaf area (cm^{2})	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant (g)
9737×C50	-0.62	-0.78	-1.19	-0.55	0.14	-2.20	-0.16	-5.94
9737×K97	1.38	1.56	3.33	3.47	0.11	1.23	0.07	5.18
9737×C86	-0.76	-0.78	-2.14	-2.92	-0.24	0.97	0.09	0.76
9738×C50	-0.84	-1.00	-1.69	-1.74	-0.97	0.77	0.14	1.27
9738×K97	1.16	1.00	-0.80	-3.92	0.18	-1.54	-0.12	1.52
9738×C86	-0.31	-0.00	2.50	5.66	0.78	0.77	-0.02	-2.79
9739×C50	-0.40	-0.11	7.69	1.64	1.10	0.83	-0.04	0.50
9739×K97	-1.40	-1.44	0.09	6.89	0.56	0.93	0.02	2.51
9739×C86	1.80	1.56	-7.78	-8.53	-1.66	-1.76	0.02	-3.01
9740×C50	1.49	1.33	-3.24	0.76	0.33	1.38	0.06	5.80
9740×K97	-2.18	-2.33	-2.17	-2.47	-0.53	-0.27	0.03	-5.67
9740×C86	0.69	1.00	5.41	1.71	0.20	-1.12	-0.09	-0.13
9741×C50	0.38	0.56	-1.57	-0.11	-0.60	-0.78	-0.00	-1.64
9741×K97	1.04	1.22	-0.44	-3.97	-0.32	-0.35	0.01	-3.52
9741×C86	-1.42	-1.78	2.01	4.08	0.93	1.13	-0.00	5.16

TABLE 6. Specific combining ability for various yield contributing traits under stress condition

TABLE 7. Estimation of GCA, SCA, additive and dominance variances for traits under normal irrigation condition

	DOH	DOM	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant (g)
Cov. H.S (lines)	2.51	2.37	-4.00	-0.91	-0.22	-0.44	-0.0001	-4.55
Cov. H.S (testers)	-0.25	1.90	-2.68	-5.56	-0.11	-0.18	-0.0009	1.40
Cov. H.S (average)	0.21	0.36	-0.57	-0.50	-0.03	-0.05	-0.0001	-0.31
Cov. F. S	4.32	8.07	16.5	19.5	0.52	1.76	0.0087	22.6
Variance of GCA	0.21	0.36	-0.57	-0.50	-0.03	-0.05	-0.0001	-0.31
Additive variance when F=0	0.84	1.44	-2.27	-2.02	-0.11	-0.21	-0.0003	-1.23
Additive variance when F=1	0.42	0.72	-1.13	-1.008	-0.06	-0.11	-0.0002	-0.61
Dominance variance when F=0	9.47	11.12	98.4	117.5	3.62	9.84	0.0415	98.5
Dominance variance when F=1	2.37	2.78	24.6	29.4	0.91	2.46	0.0104	24.6
Variance of SCA	2.37	2.78	24.6	29.4	0.91	2.46	0.0104	24.6
σ^2 GCA / σ^2 SCA	0.09	0.13	-0.02	-0.02	-0.03	-0.02	-0.01	-0.01

General combining ability

Days to heading and maturity help us to find out the early and late maturing genotypes. Early maturing genotypes are considered valuable specially to escape from terminal drought stress period. In this research, desirable days to heading was found in line 9738 (-2.29) followed by line 9737 (-1.51) while among testers Kohistan-97 was found best with negative GCA value of -0.60 under drought stress condition. On the other hand, under normal irrigated condition, desirable negative GCA for days to heading was recorded in line 9738 (-0.84) followed by 9739 (-0.62) and 9737 (-0.07) while among testers Chakwal-86 was considered best with GCA value -0.64 and Chakwal-50 showed positive GCA value for days to heading with positive GCA value of 0.36. Results were also conferred by Akbar *et al*. (2009) and Fellahi *et al*. (2013).

High negative value for days to maturity means that genotype is early maturing and is considered best for both normal and stress conditions. Under drought stress condition, lines 9738 and 9737 were found best with negative GCA value of -2.73 and -0.96 respectively. Line 9740 was considered undesirable for this trait with high positive GCA value of 1.60. Among testers, Kohistan-97 was found desirable with GCA value of -1.78. Under normal irrigated condition, it was found that line 9738 (-1.09) and 9739 (-0.64) were performed best and are early maturing genotypes while line 9740 was late maturing with high positive GCA value of 1.13. On the other hand, among testers, Kohistan-97 was early maturing with GCA value -1.29 followed by Chakwal-86 (-0.22) while Chakwal-50 was late maturing with GCA value 1.51 for this trait. Results were also conferred by Akbar *et al*. (2009) and Zare-kohan and Heidari (2012).

Short plant height is preferred under both well irrigated as well as drought conditions as short plant height can resist lodging and is more responsive to fertilizers. In this research, line 9740 was found short stature with highly negative GCA value of -3.25 followed by 9739 (-0.42) while undesirable plant height was found in line 9738 with GCA value 2.13 under drought stress condition. Among testers, Chakwal-86 had desirable plant height with GCA -1.73 and Chakwal-50 was tall in stature with GCA value 0.97. On the other hand, under normal irrigation condition, line 9740 was found desirable for this character with highly negative GCA value of -3.21 followed by 9739 (-0.51) and 9741 (-0.48) while 9738 was undesirable with highly positive GCA of 2.43. Among testers, Chakwal-86 was considered suitable for plant height with negative GCA -1.19. Findings were also given in Akbar *et al*. (2009), Zare-kohan and Heidari (2012) and Uzair *et al*. (2016).

Flag leaf is very important trait required to enhance production as it is involved in photosynthetic activity and plays a vital role in grain development during grain filling stage. Hence, emphasize should be on selection of genotypes with larger flag leaf area. In present study, genotype 9738 had higher positive GCA for flag leaf area that was 2.39 followed by 9737 with GCA value 1.58 while negative GCA was found in genotype 9740 (-5.16) under drought stress condition. Among testers, Kohistan-97 was found good for this trait with positive GCA value that was 0.69. Under normal irrigation condition, it was found that genotype 9737 was considered most desirable for this trait with high positive value for GCA that was 2.15 followed by 9738 (1.71) while genotype 9740 showed undesirable value for this trait with negative GCA of -4.50. Among testers, Kohistan-97 performed best with positive GCA of 0.97. While Chakwal-86 and Chakwal-50 had negative value of GCA that were -0.50 and -0.47 respectively. . Results were according to Akram *et al*. (2011), Noorka and Tabasum (2015).

Spike length is important yield potential character that is needs to increase in production hence, large spike length is considered valuable. In this study under drought stress condition, genotype 9739 showed high spike length with GCA value 0.22 followed by 9738 (0.21) and 9741 (0.18) while other lines showed negative GCA values that were not preferred. Among testers Kohistan-97 performed best with GCA value 0.30 while Chakwal-50 and Chakwal-86 showed negative GCA. Under normal irrigation conditions, 9739 was performed well with high positive GCA value among female parents that was 0.32 followed by 9738 (0.13) while other lines showed negative value for this trait. Among testers Chakwal-86 was showed high GCA value (0.20) under proper irrigated condition followed by Kohistan-97 (0.11) while Chakwal-50 had negative value of GCA (-0.31) that was not preferred. Results were given in the findings of Ahmad *et al*. (2013) and Uzair *et al*. (2016)

Spikelets/spike is directly related to the number of grains that can increase yield potential hence, more number of spikelets/spike is preferred under both normal as well as drought stress conditions. In the current study, genotype 9738 among lines had high positive value of GCA that was 0.79 followed by 9737 with GCA value 0.43 under drought stress that was considered good for enhancing yield while genotype 9739 didn't performed good for this trait having negative GCA value of -0.84. Among testers Kohistan-97 performed good with GCA value 0.52 followed by Chakwal-50 (0.12) while Chakwal-86 did not performed well for this trait and showed negative GCA value (-0.63). Under normal irrigation condition, 9738 showed high positive GCA (1.84) that showed its best performance for this trait followed by 9740 with GCA value 0.31 while other genotypes had negative values for GCA that were not considered good. Among testers Kohistan-97 was performed best with GCA 0.34. findings were also conferred by Anwar *et al*. (2011) and Uzair *et al*. (2016). Spike density gives information about genotypes with more dense spikes that leads to increase in no. of grains that ultimately enhance crop yield. In this study, 9737 showed high spike density with GCA value 0.07 followed by 9738 with GCA value 0.04 while among testers Chakwal-50 had high spike density having GCA value 0.03 followed by Kohistan-97 with GCA value 0.01 under drought stress condition. Under normal irrigation condition, genotype 9738 showed high GCA value 0.11 that is considered good for enhancing yield followed by 9740 with GCA value 0.03. Among testers Chakwal-50 performed good with positive GCA value 0.02 followed by Kohistan-97 (0.01). Results were according with the findings of Mahpara *et al*. (2008) and Saeed *et al*. (2010).

Grain yield is important trait that must be focused especially under drought areas. Among lines 9737 was considered as good general combiner for yield as it showed high positive GCA value (2.97) for this trait followed by 9738 (0.43), other lines showed negative value for GCA under drought stress condition. Among testers Kohistan-97 performed well with GCA value 2.21 followed by Chakwal-50 (0.53). Under non-stress condition, 9740 performed well for this trait with positive GCA value of 4.64 followed by 9738 having GCA value 2.50 while other lines showed negative value for this trait. Among testers, Chakwal-50 was considered good general combiner for this trait with GCA value 2.02. Results were also conferred by Saeed et al. (2010), Akram *et al*. (2011), Noorka and Tabasum (2015) and Uzair *et al*. (2016).

Specific Combining Ability

The SCA effects of all the crosses for days to heading were measured. High positive SCA effects for this trait were observed in 9739 × Chakwal-86 that was 1.80 followed by 9740 × Chakwal-50, 9737 × Kohistan-97, 9738 × Kohistan-97 that were 1.49, 1.38 and 1.16 respectively while negative SCA effects were observed in 9740 × Kohistan-97 that was -2.18 followed by 9741 × Chakwal-86 and 9739 × Kohistan-97 that were -1.42 and -

1.40 respectively under drought stress condition. Under normal irrigation condition, high positive SCA effects observed in 9738 × Chakwal-86 that was 1.98 followed by 9737 × Chakwal-50 that was 1.53 while high negative SCA effect was found in 9738 × Chakwal 50 that was -2.36 followed by 9737 × Chakwal-86 that was -1.47. Results were in accord with the findings of Akbar *et al*. (2009) and Akram *et al*. (2011).

In case of days to maturity, high positive SCA effects were found in 9739 × Chakwal-86 and 9737 × Kohistan-97 that were 1.56 followed by 9740 × Chawal-50 and 9741 × Kohistan-97 that were 1.33 and 1.22 respectively while high negative SCA effects were observed in 9740 × Kohistan-97 that was -2.33 followed by 9741 × Chakwal-86 and 9739 × Kohitsan-97 that were -1.78 and -1.44 respectively under drought stress condition. Under non-stress condition, high positive SCA effects observed in 9738 × Chakwal-86 that was 2.22 followed by 9737 × Chakwal-50 that was 1.71 while high negative SCA effects were found in 9738 × Chakwal-50 that was -2.84 followed by 9737 × Chakwal-86 that was -1.56. Results were also conferred by Akram *et al*. (2011) and Akbar *et al*. (2009).

In case of plant height high positive SCA effect was found in 9739 × Chakwal-50 that was 7.69 followed by 9740 × Chakwal-86, 9737 × Kohistan-97, 9738 × Chakwal-86 and 9741 × Chakwal-86 that were 5.41, 3.33, 2.5 and 2.01 respectively while high negative SCA effect was found in 9739 × Chakwal-86 that was -7.78 followed by 9740 × Chakwal-50 and 9740 × Kohistan-97 that were -3.24 and -2.17 respectively under drought stress condition. Under normal irrigation condition, high positive SCA effect was found in 9741 × Chakwal-50 that was 4.67 followed by 9739 × Chakwal-50 that was 3.32 while high negative SCA effect was found in 9741 × Kohistan-97 that was -4.11. Results were also given by Akram *et al*. (2011), Akbar *et al*. (2009) and Singh *et al.* (2013).

High positive SCA effect was found in 9739 × Kohistan-97 that was 6.89 followed by 9738 × Chakwal-86, 9741 × Chakwal-86 and 9737 × Kohistan-97 that were 5.66, 4.08 and 3.47 respectively while high negative SCA effects were observed in 9739 × Chakwal-86 that was -8.53 followed by 9741 × Kohistan-97, 9738 × Kohistan-97 and 9737 × Chakwal-86 that were -3.97, -3.92 and -2.92 respectively under drought stress condition. Under normal irrigation condition, high positive SCA effect was found in 9739 × Kohistan-97 (7.51) followed by 9738 × Chawal-86 (6.92) while high negative SCA effects observed in 9739 × Chakwal-86 (-8.92). Results were in according with the findings of Akram *et al*. (2011), Mahpara *et al.* (2008) and Srivastava *et al.* (2012).

Under stress condition, positive SCA effect for spike length was found in 9739 × Chakwal-50 that was 1.10 followed by 9741 × Chakwal-86 (0.93) and 9738 × Chakwal-86 (0.78) while high negative SCA effect was found in 9739 × Chakwal-86 that was -1.66 followed by 9738 × Chakwal-50 and 9741 × Chakwal-50 that were -0.97 and -0.60 respectively. Under non-stress condition, high positive SCA effect was found in 9739 × Chakwal-50 (1) while high negative SCA effect was found in 9739 × Chakwal-86 (-1.39). Results were also presented by Akbar *et al*. (2009), Akram *et al*. (2011), Singh *et al*. (2013) and Hammad *et al*. (2013).

In case of spikelet/spike under drought stress condition, high positive SCA effect was found in 9740 × Chakwal-50 that was 1.38 followed by 9737 × Kohistan-97 and 9741 × Chakwal-86 that were 1.23 and 1.13 respectively while high negative SCA effects for this trait were found in 9737 × Chakwal-50 that was -2.20 followed by 9739 × Chakwal-86 and 9738 × Kohistan-97 that were -1.76 and -1.54 respectively. Under normal irrigation condition, high positive SCA was found in 9739 × Kohistan-97 (2.49) followed by 9737 × Chakwal-86 (1.84) while high negative SCA effect was found in 9738 × Kohistan-97 (-2.17). Results were in according with the findings of Akbar *et al*. (2009), Saeed *et al*. (2010), Akram *et al*. (2011), Singh *et al*. (2013) and Hammad *et al*. (2013).

Under drought stress condition, high positive SCA effect for spike density was found in 9738 × Chakwal-50 that was 0.14 followed by 9737 × Chakwal-86 and 9737 × Kohoistan-97 that were 0.09 and 0.07 respectively while high negative SCA effect was found in 9737 × Chakwal-50 that was -0.16 followed by 9740 × Chakwal-86 that was -0.09. Under normal irrigation high positive SCA effect was found in 9737 × Chakwal-86 (0.16) while high negative SCA effect was found in 9738 × Kohistan-97 (-0.18). Results were also presented by Mahpara *et al*. (2008) and Saeed *et al*. (2010).

High positive SCA effect was observed for this trait in 9740 × Chakwal-50 that was 5.80 followed by 9737 × Kohistan-97 and 9741 × Chakwal-86 that were 5.18 and 5.16 respectively while high negative SCA effect was found in 9737 × Chakwal-50 that was -5.94 followed by 9740 × Kohistan-97 and 9741× Kohistan-97 that were -5.67 and -3.52 respectively under drought stress condition. Under normal irrigation condition, high positive SCA was found in 9738 × Chakwal-50 (5.04) followed by 9740 × Chakwal-50 (4.7) while high negative SCA was found in 9737 × Chakwal-50 (-5.35). Results were also presented by Akbar *et al*. (2009), Saeed *et al*. (2010), Akram *et al*. (2011) and Fellahi *et al*. (2013).

Gene action

As we know that additive gene action is exhibited if GCA variance is higher than SCA variance in such case early selection is preferred and considered useful for varietal development programs. On the other hand, if SCA variance is greater than GCA variance, it indicates non-additive gene action that can be used for hybrid breeding programs. In Table 7 and 8 additive variances, non-additive variances, GCA and SCA variance along with GCA to SCA ratio for drought stress and normal irrigation conditions respectively are presented. From GCA to SCA ratio under drought stress condition it was found that inheritance of all the traits was controlled by non-additive genes as shown by both tables of drought stress condition as well as normal irrigated condition.Hence, hybrid breeding will be suggested most useful in this case. Results of non-additive gene action in traits like days to heading and maturity, plant height, flag leaf area, number of productive tillers per plant, peduncle length, spike length, awn length, chlorophyll contents, spikelets per spike, spike density, 1000-grain weight, grain per spike and grain yield per plant were also reported by Ajmal *et al*. (2004), Vanpariya *et al*. (2006), Chema *et al*. (2007), Iqbal and khan (2006), Akbar *et al*. (2009), Zare-Kohan and Heider (2012) and Srivastava *et al*. (2012).

Proportional contribution of lines, testers and their interaction to the total variance

To get the proportional distribution of lines, testers and their interactions to total variance, line by tester scheme was adopted using five lines (female parents) and three testers (male parents) for various traits. Table 10 contained the value for drought stress condition. It was found that for days to heading, lines played significant role (63.01%) followed by line × tester interaction (32.64%) and testers (4.34%). For days to maturity, contribution of lines was 45.41% followed by testers (28.14%) and line × tester interaction (26.46%). In case of plant height, line × tester interaction played significant role (72.90%) followed by lines (18.74%) and testers (8.36%). For flag leaf, line × tester interaction was important with proportional contribution 68.10% followed by lines 30.89% and testers 1.02

For spike length, line × tester interaction showed greater contribution that was 78.92% followed by lines (12.93%) and testers (8.15%). For spikelets per spike, interaction had greater contribution that was 70.98% followed by lines 17.36% and testers 11.66%. In case of spike density, interaction contributed 61.48% followed by lines 29.67% and testers 8.85. Line × tester interaction was contributed higher in case of grain yield per plant that was 64.72% followed by testers (20.78%) and lines (14.50%). Under normal irrigated condition, proportional contribution of line, testers and interactions showed the same proportional contribution as presented in Table 9. Results were also conferred by Akbar *et al*. (2009) and Fellahi *et al*. (2013).

TABLE 8. Estimation of GCA, SCA, additive and dominance variances for traits under drought condition

	DOH	DOM	Plant height (cm)	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Spike density	Grain yield per plant (g)
Cov. H.S (lines)	-0.23	-0.29	-0.53	-5.19	-0.195	0.45	0.0007	4.49
Cov. H.S (testers)	-0.19	1.34	-2.20	-6.64	-0.08	-0.57	-0.0032	-0.66
Cov. H.S (average)	-0.04	0.08	-0.21	-0.98	-0.02	-0.002	-0.0002	0.36
Cov. F. S	1.92	5.11	12.4	20.9	0.37	2.76	0.0148	23.8
Variance of GCA	-0.04	0.08	-0.22	-0.98	-0.02	-0.002	-0.0002	0.36
Additive variance when F=0	-0.14	0.30	-0.86	-3.90	-0.09	-0.008	-0.0007	1.43
Additive variance when F=1	-0.07	0.15	-0.43	-1.95	-0.05	-0.004	-0.0004	0.72
Dominance variance when F=0	9.81	12.9	65.8	146.1	2.74	12.98	0.0773	82.62
Dominance variance when F=1	2.45	3.21	16.5	36.5	0.69	3.25	0.0193	20.7
Variance of SCA	2.45	3.21	16.5	36.5	0.69	3.25	0.0193	20.7
σ^2 GCA/ σ^2 SCA	-0.01	0.02	-0.01	-0.03	-0.03	-0.0006	-0.01	0.01

TABLE 9. Proportional contribution of lines, testers and line × tester interaction to the total variance under normal irrigation condition

Traits	Lines	Testers	L × T interaction
Days to heading	23.84	10.20	65.96
Days to maturity	17.29	35.74	46.98
Plant height	29.42	5.42	65.16
Flag leaf area	21.97	1.83	76.21
Spike length	8.66	9.90	81.44
Spikelets per spike	40.65	1.90	57.45
Spike density	34.70	2.78	62.52
Grain yield per plant	40.54	10.32	49.14

10. Proportional contribution of lines, testers and line × tester interaction to the total variance under drought stress condition

Traits	Lines	Testers	L × T interaction
Days to heading	63.01	4.34	32.64
Days to maturity	45.41	28.14	26.46
Plant height	18.74	8.36	72.90
Flag leaf area	30.89	1.02	68.10
Spike length	12.93	8.15	78.92
Spikelets per spike	17.36	11.6	70.98
Spike density	29.67	8.85	61.48
Grain yield per plant	14.50	20.78	64.72

CONCLUSION

Among female parents 9737 showed best general combiner for spike density and grain yield per plant while 9738 was considered as best general combiner for spikelets per spike, flag leaf area, days to heading and maturity. 9739 proved as best general combiner spike length under drought stress condition. On the other hand, line 9737 was showed best general combiner for flag leaf area, 9738 was considered as good general combiner for spikelets per spike, spike density, days to heading and maturity under non-stress condition. Line 9739 was found as best general combiner for spike length, line 9740 was revealed good general combiner for plant height and grain yield under normal irrigated condition.

Among testers, Kohistan-97 was found best general combiner for most of the traits *viz.* flag leaf area, spike length, number of spikelet per spike, days to heading and maturity under drought stress condition while Chakwal-50 was considered as best general combiner for plant length. Chakwal-86 was proved best general combiner for spike density and plant height under stress condition. On the other hand, Kohistan-97 was also considered as best general combiner for most of the traits while for grain yield per plant and spike density Chakwal-50 was best general combiner and Chakwal-86 was best general combiner spike length under normal irrigation condition.
Among crosses, 9738 × Chakwal-50 was considered as best specific combiner for spike density, 9739 × Chakwal-50 was best specific combiner for spike length, 9739 × Kohistan-97 was found best specific combiner for flag leaf area, 9739 × Chakwal-86 was proved best for plant height, 9740 × Chakwal-50 was revealed best specific combiner for grain yield per plant, 9740 × Kohistan-97 was best for days to heading and maturity.
Hence, results concluded that under drought stress condition, 9737, 9738, Kohistan-97 are best general combiners while among cross combinations 9737 × Kohistan-97, 9740 × Chakwal-50 and 9741 × Chakwal-86 screened out for their best overall performance for traits contributing to grain yield.

REFERENCES

Singh, N.P., Pal, P.K. and Vaishali, S.K. (2014) Morpho-physiological characterization of Indian wheat genotypes and their evaluation under drought condition. African J. Biotech. 13.

Mahajan, S. and Tuteja, N. (2005) Cold, salinity and drought stresses. Arch. Biochem. Biophys. 444: 139-158.

Sadras, V., Lake, L., Chenu, K., McMurray, L. and Leonforte, A. (2012) Water and thermal regimes for field pea in Australia and their implications for breeding. *Crop Pasture Sci*. 63: 33-44.

Shamsi, K. and Kobraee, S. (2011) Bread wheat production under drought stress conditions. Ann. Biol. Res. 2.

Danda, S.D., Sethi, G.S. and Bhel, R.K. (2002) Tolerance to drought stress among selected under wheat cultivars. J. Agri. Res. 139(5): 319-326.

Rashid, M., Cheema, A.A. and Ashraf, M. (2007) Line × tester analysis in basmati rice. Pakistan J. Bot. 39(6): 2035-2042.

Salgotra, R., Gupta, B. and Singh, P. (2009) Combining ability studies for yield and yield components in basmati rice. ORYZA-An Inte. J. 46: 12-16.

Iqbal, M., Navabi, A., Salmon, D.F., Yang, R.C., Murdoch, B.M., Moore, S.S. and Spaner, D. (2007) Genetic analysis of flowering and maturity time in high latitude spring wheat. Euphytica 154**:** 207-218.

Kempthorne, O. (1957) An Introduction to Genetic Statistics. John Willey and Sons Inc., New York. Steel, R.G.D., J. H. Torrie and D.A. Dickey. 1997. Principles and Procedure of Statistics: A biometrical approach (3rd ed.). McGraw-Hill, New York.

Rawling, J.O. and Thompson, D.L. (1962) Performance level as criterion for choice of maize testers. Crop Sci. 2: 217-220.

Noorka, I.R. and J.A.T. da Silva (2014) Physical and morphological markers for adaptation of drought-tolerant wheat to arid environments. Pak. J. Agri. Sci. 51: 943-952.

Jain, S.K. and Sastry, E. (2012) Heterosis and combining ability for grain yield and its contributing traits in bread wheat (*Triticum aestivum* L.). J. Agri. Allied Sci. 1(1): 17-22.

Fellahi, Z.E.A., Hannachi, A., Bouzerzour, H. and Boutekrabt, A. (2013) Line × tester mating design analysis for grain yield and yield related traits in bread wheat (*Triticum aestivum* L.). Int. J. Agron. 2013.

Uzair, M., Ali, Z., Mahmood, T., Karim, I., Akram, U., Mahmood, N. (2016) Genetic Basis of Some Yield Related Traits in Wheat (*Triticum aestivum* L.) under Drought Conditions. Imp. J. Interdiscip. Res. 2.

Spraugue, G.F. and Tatum, L.A. (1942) General versus specific combining ability in single crosses of corn. J. Amer. Soc. Agron. 34: 923-932.

Zare-kohan, M. and Heidari, B. (2012) Estimation of genetic parameters for maturity and grain yield in diallel crosses of five wheat cultivars using two different models. J. Agri. Sci. 4: 74.

Akbar, M., Anwar, J., Hussain, M., Qureshi, M.H. and Khan, S. (2009) Line × tester analysis in bread wheat (*Triticum aestivum* L.). J. Agric. Res. 47: 411.

Akram, M. (2011) Growth and yield components of wheat under water stress of different growth stages. Bangladesh J. Agril. Sci. 36: 455-468.

Noorka, I.R. & Tabasum, S. (2015) Dose response behavior of water scarcity towards genetical and morphological traits in spring wheat (*Triticum aestivum* L.). Pak. J. Bot. 47: 1225-1230.

Ahmad, M., Iqbal, M., Shahzad, A., Asif, M. and Sajad, M. (2013) Genetic analysis of yield and yield contributing quantitative traits in bread wheat under sodium chloride salinity.J. Agric. Sci. 5: 156.

Anwar, J., Akbar, M., Hussain, M., Asghar, S., Ahmad, J. and Owais, M. (2011) Combing ability estimates for grain yield in wheat. Pak. J. Bot. 43(3): 1527-1530.

Mahpara, S., Ali, Z. and Ahsan, M. (2008) Combining ability analysis for yield and yield related traits among wheat varieties and their F1 hybrids. Int. J. Agri. Biol. 10(6): 599-604.

Saeed, A., Khan, A.S., Khaliq, I. and Ahmad, R. (2010) Combining ability studies on yield related traits in wheat under normal and water stress conditions. Pak. J. Agri. Sci. 47: 345-354.

Akbar, M., Anwar, J., Hussain, M., Qureshi, M.H. and Khan, S. (2009) Line× tester analysis in bread wheat (*Triticum aestivum* L.). J. Agric. Res. 47: 411.

Singh, K., Singh, U.B. and Sharma, S.N. (2013) Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L. em. Thell.). J. Wheat Res. 5(1): 63-67.

Srivastava, M.K., Singh, D. and Sharma, S. (2012) Combining ability and Gene action for seed yield and its components in Bread Wheat (*Triticum aestivum* L.). Electron. J. Plant Breed. 3(1): 606-611

Hammad, G., Kashif, M., Munawar, M., Ijaz, U., Raza, M.M., Saleem, M. and Abdullah (2013) Genetic analysis of quantitative yield related traits in spring wheat (*Triticum aestivum* L.). Am. Euras. J. Agri. Environ. Sci. 13(9): 1239-1245.

Saeed, A., Khan, A.S., Khaliq, I. and Ahmad, R. (2010) Combining ability studies on yield related traits in wheat under normal and water stress conditions. Pak. J. Agri. Sci. 47: 345-354.

Ajmal, S., Asif, M. and Munir, M. (2004) Implication of combining ability: Analysis of some characteristics of spring wheat. Quarterly Sci. 9(4): 1-5.

Cheema, N.M., Ihsan, M., Mian, M.A., Rabbani, G., Tariq M.A. and Mahmood, A. (2007) Gene action studies for some economic traits in spring wheat. Pakistan J. Agri. Res. 20(3/4): 99-104.

Vanpariya, L.G., Chovatia, V.P. and Mehta. D.R. (2006) Combining ability studies in bread wheat (*Triticum aestivum* L.). Natl. J. Plant Improvement. 8(2): 132-137.

Iqbal, M., Khan. A.A. (2006) Analysis of combining ability for spike characteristics in wheat (*Triticum aestivum* L.). Int. J. Agri. Biol. 8(5): 684-687.