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Genetics of yield components for drought tolerant wheat (*Triticum aestivum* L.) genotypes

Sharmin Ashraf[1], Ihsan Khaliq[1], Saif-ul-Malook[1], Saeed Ahmad Qasrani[2*], Sofia Jabeen[1], Rabia Faridi[1], Hafiz Mahboob Ahamed[1], Muhammad Naeem Yousaf[1], Ahmad Raza[3]

[1]*Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan*

[2]*Department of Environmental Sciences, COMSATS Institute of Information Technology, Vehari, Pakistan*

[3]*National Institute of Food Science and Technology, University of Agriculture Faisalabad, Pakistan*

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Abstract

Drought tolerance is a polygenic trait, with a complicated phenotype, often confused by plant phenology. Breeding for water stress is more complex since many types of abiotic stress, such as drought, heat and salt. High yielding wheat genotypes viz., Miraj-06, 9452, 9469, 9272, 9277, CMS-127 and three testers Chakwal-50, Kohistan-97 and Aas-11 were crossed in line × tester mating design. Seed obtained from crosses was evaluated in field conditions for various agronomic traits under drought conditions. Recorded data were subjected to analysis of variance to determine the genetic variability. The data were analyzed statistically and combining ability studies were tested using line × tester analysis to find the relationship between different traits of wheat. High significant differences were observed among the lines and testers for yield related traits under stress conditions. The female line 9452 proved to be best line on the basis of mean performance of traits under water stress. In case of testers, the male parent variety Chakwal-50 retained its performance in maximum number of traits closely followed by Aas-11. The cross combination 9272 × Aas-11 proved best for attaining highest mean for most of traits. In case of GCA effects line 9277 and tester Aas-11 proved best. The cross combinations 9277 × Chakwal-50, 9452 × Kohistan-97 exhibited highest SCA effects. The superior genotypes and crosses can be combined to develop new promising and improved varieties under water stress conditions.

* **Corresponding Author:** Saeed Ahmad Qasrani ✉ saeed.qaisrani@ciitvehari.edu.pk

Introduction

Wheat (Tritium aestivum L.) is the most important crop and among the major three cereal crops that provides 20 percent of the total energy requirement in human food. It is a member of family Poaceae and is the King of cereals. The archeological records suggest that wheat was first found in the regions known as Fertile Cresecent and Nile Delta (Lev-Yadun *et al.* 2000). It is staple food crop of 1/3rd world's community. It is one of the 1st cereal crop known to be domesticated for food. Wheat is cultivated almost all parts of the world. In Asia major wheat producing countries are China, India, Iran, Pakistan, Russia and Turkey. Wheat is grown on rainfed land, and about 37 % of the area of developing countries consists of semiarid environments in which available moisture constitutes a limitation in wheat production. (Dhanda *et al.,* 2004).

Wheat is used for making bread, flour, bakery products (cakes, cookies, and pretzels), semolina and breakfast cereals. It is important in regard to nutritive value, production, storage space qualities, utilization, adaptation and transaction. (Hogg *et al*., 2004). Wheat is a rich and cheaper source of protein. In Pakistan, wheat is cultivated as staple food and cash crop that's why Pakistan's economy conspicuously depends on this crop. The situation of wheat production in Pakistan is much improved than before but still constant efforts are needed to keep the pace with the ever ever-increasing population. It is backbone of economy of Pakistan with share of 10.1 % value added in agriculture and contributes 2.2 % to gross domestic product (GDP) of Pakistan. Wheat production has increased from 23.5 million tons to 24.2 million tons showing an increase of 3.2 % but target was not achieved, there was 5 % decline in yield. (Pakistan Economic Survey, 2012-13).

At present, the estimated population of Pakistan is over 187 million. Requirement of food is increasing day by day with the growing population. Demand of wheat is increasing with increasing population. So there is need to breed varieties with high production even in water stress conditions. Wheat breeders are trying to get maximum yield with limiting resources. The special effects of drought on yield of crops depend on the stage of plant growth during which they occur. The first stage of growth that is sensitive to water deficit is seed germination. Water limitation is a big problem among all the major problems. It is a great challenge for a plant breeder to face different types of drought (HongBo *et al*., 2006).

Total rainfed area under cultivation is 1.24 million hectares where the crop suffers from severe water stress. There is also severe shortage of water in canal irrigated areas due to low level of water in rivers and unequal distribution of water to provinces. There are two ways to increase the production either to increase the land area or increasing yield per acre. Water stress causes the production of less dry matter. Due to water stress the grains are desiccated and also results in early maturity of the crop. Drought stress can influence the senescence of leaf, causing drop in crop yield. Wheat is grown under a diverse range of areas and environmental conditions. The unstable nature of drought and the complication of the genetic control of plant responses find out the difficulties in developing high yielding cultivars under water stress environments (Sadiq *et al*., 1994). The growing period for wheat after rice is enough while it is late when grown after either cotton or sugarcane. Therefore these problems should be eliminated. Breeders are doing their best to develop wheat cultivars with high yield as well as drought tolerance.

Yield is a polygenic trait and influenced by environment. Yield can be increased by making uncultivated lands arable by modern cultivation practices or by improving our commercial varieties using germplasm resources and breeding practices. To develop high yielding, drought resistant varieties understanding of various morphological characters need special attention. Hybridization is the basic step for improving wheat varieties for yield and yield related traits. Palve et al. (1987) revealed that the female genotype HD 2278 revealed high general combining ability while for grain per year and ear length, UP 215 was best general combiner. For ear length cross N 1181 × HD 2189 was good specific combiner and N 18306 × HY 65 for number of spikelet. Zeeshan et al. (2013) observed that dominant genes were important in the inheritance of all traits. The research was conducted to find gene action for water stress environment related morphological traits in preferred genotypes and selecting the superior combinations to be further used in new breeding program.

Materials and methods

The proposed study was carried out to assess the quantitative traits under water stress conditions. Six wheat (*Triticum aestivum* L.) variety / lines: Miraj-06, 9452, 9469, 9272, 9277 and CMS-127 were crossed with each of the three testers: Chakwal-50, Kohistan-97 and Aas-11. The materials were crossed was in line × tester fashion (table 1). The parent varieties and their F_1 hybrids were examined in randomized complete block design, with three replications.

All parents were selected on the basis of different phenotypic expression and geographic origin. The experiment was conducted at the experiment field of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad during 2013-2014. Data on 10 guarded plants of 18 F_1 hybrids and 9 parents were recorded for following yield related traits, Plant height, Days to maturity, number of tillers per plant, Flag leaf area, Spike length, number of spikelet per spike, number of grains per spike, Grains weight per spike, 1000-grain weight, Grain yield per plant (g).

Statistical analysis

The data recorded were subjected to analysis of variance according to Steel et al. (1997). Combining ability studies were made to estimate general and specific combining ability by using line × tester analysis as described by Kempthorne (1957).

Results and discussion

Hybridization for enviable genotype requires selection of parental line having ability to mingle and generate desirable genotypic combination. Combining ability analysis technique is important in estimating the best combiner or donor parents for every fastidious trait. The results of combining ability effects attained after conducting line × tester analysis are discussed here.

Table 1. Crosses made in line × tester fashion.

Sr. No.	Name	Sr. No.	Name
1	CMS-127 × Aas-11	10	9452 × Aas-11
2	CMS-127 × Chakwal-50	11	9452 × Chakwal-50
3	CMS-127 × Kohistan-97	12	9452 × Kohistan-97
4	Miraj-06 × Aas-11	13	9272 × Aas-11
5	Miraj-06 × Chakwal-50	14	9272 × Chakwal-50
6	Miraj-06 × Kohistan-97	15	9272 × Kohistan-97
7	9469 × Aas-11	16	9277 × Aas-11
8	9469 × Chakwal-50	17	9277 × Chakwal-50
9	9469 × Kohistan-97	18	9277 × Kohistan-97

The examination of the results showed that the variation due to replication remained high significant for 1000-grain weight and excised leaf water loss; significant for peduncle length, number of spikelet per spike, grains weight per spike and grain yield but non-significant for plant height, days to heading, days to maturity, number of tillers per plant, leaf area, spike length, number of grains per spike and relative water content. High significant differences were observed among all the genotypes for all the traits.

The total sum of squares of wheat genotypes was further partitioned into genotypes, parents, parents vs. crosses, crosses, lines, testers and Line × Tester which revealed significant differences among themselves (Table 2).

Mean Performance of lines, testers and crosses

The genotypes sharing common alphabets were not significant from each other but significant from other genotypes (Table 3a and 3b).

Table 2. Mean square values for various yields related traits in wheat under drought conditions.

SOV	df	PH (cm)	DM	NT	FLA	SL	SPS	GPS	GWP	1000 GW	GYP (g)	RWC	ELWL
Replication	2	40.6^{NS}	14.2^{NS}	2.3^{NS}	9.3^{NS}	1.8^{NS}	2.1^{*}	5.9^{NS}	0.16^{*}	66.4^{**}	9.7^{*}	4.3^{**}	0.03^{**}
Genotypes	26	2933.3^{**}	8065.3^{**}	16.6^{**}	188.7^{**}	60.3^{**}	151.0^{*}	1373.4^{**}	2.39^{**}	719.6^{**}	86.7^{**}	4587.6^{**}	0.18^{**}
Parents	8	2311.0^{**}	6467.5^{**}	13.8^{**}	173.9^{**}	48.7^{**}	129.3^{**}	1137.4^{**}	1.29^{**}	419.7^{**}	50.2^{**}	3699.7^{**}	0.12^{**}
Crosses	17	3397.5^{**}	9286.1^{**}	18.7^{**}	206.1^{**}	69.30^{**}	168.6^{**}	1564.2^{**}	2.96^{**}	885.1^{**}	107.7^{**}	5274.4^{**}	0.20^{**}
P vs C	1	22.3^{NS}	93.7^{**}	2.7^{NS}	11.8^{NS}	0.9^{NS}	25.2^{**}	18.5^{NS}	1.50^{**}	306.0^{**}	22.5^{**}	15.6^{**}	0.31^{**}
Lines	5	11228^{**}	31525^{**}	52.3^{**}	611.7^{**}	224.8^{**}	564.7^{**}	5269.7^{**}	8.49^{**}	2575.3^{**}	276.4^{**}	17615.1^{**}	0.43^{**}
Testers	2	418.3^{**}	0.1^{NS}	8.1^{**}	77.3^{**}	8.5^{**}	3.8^{**}	24.7^{**}	1.56^{**}	288.6^{**}	30.4^{**}	115.4^{**}	0.02^{**}
L × t	10	1928.9^{**}	5207.2^{**}	15.3^{**}	169.4^{**}	42.7^{**}	109.5^{**}	931.0^{**}	1.66^{**}	525.6^{**}	81.2^{**}	3097.2^{**}	0.24^{**}
Error	52	35.5	10	1.4	8.4	0.8	0.5	8.2	0.04	10.2	2.7	1.5	0.003
Total	80	977.4	2628.1	6.3	67	20.1	49.5	451.8	0.81	242.2	30.2	1492	0.06

G=Genotypes, PH= Plant height, DH= Days to heading, DM= Days to maturity, NT= No. of tillers, FLA= Flag leaf area, SL= Spike length, PL= Peduncle Length, NSPS= No. of spikelet per spike, NGPS= No. of grains per spike, GWPS= Grain weight per spike, TGW = 100 Grain weight, GY= Grain yield, RWC= Relative water contents, ELWL= Excised leaf water los.

Plant height (cm)

Plant height varied from 78.47 cm to 89.45 cm for lines. The line 9452 had maximum plant height (89.45 cm) followed by 9469 (83.87 cm) and 9272 (82.55 cm). Among testers, plant height varied from 79.09 cm to 82.85 cm. The tester, Aas-11 had maximum value (82.85 cm) followed by Kohistan-97 (80.83 cm) and Chakwal-50 (79.087 cm). Among crosses, plant height varied from (68.55 cm) to (94.71 cm) with minimum value for 9272 × Chakwal-50 (68.55 cm) and maximum value for 9452 × Aas-11 (94.71 cm) (table 3a). The genotypes sharing common alphabets were not significant from each other but significant from other genotypes (table 3a and 3b). High plant height may be fruitful for breeding high yielding varieties under drought (Akbar *et al.* 2009). Results were in contrast with the findings of Singh *et al.* (2002) while confirm the findings of Ivanovic *et al.* (2003).

Days to maturity

It was persuaded from table 3a that the mean values of days to maturity varied from 135.33 to 141.67 for lines. The line 9452 had maximum days to heading (141.67) followed by 9272 (138.67) and 9469 (137.67). Among testers, days to maturity varied from 134.33 to 142.00. The tester, Kohistan-97 had maximum value (142.00) followed by Chakwal-50 (140.67) and Aas-11 (134.3). Among crosses, days to maturity varied from (132.67) to (149.00) with minimum value for Miraj-06 × Kohistan-97 (132.67) and maximum value for 9277 × Chakwal-50 (149.00). Results were in contrast with the findings of Singh *et al.* (2002) while confirm the findings of Ivanovic *et al.* (2003).

Number of tillers

Table 3a showed that the mean values of number of tillers varied from 4.63 to 6.93 for lines. The line Miraj-06 had maximum number of tillers (6.93) followed by 9469 (6.87) and CMS-127 (6.33). Among testers, number of tillers varied from 134.33 to 142.00. The tester, Chakwal-50 had maximum value (6.53) followed by Kohistan-97 (5.93) and Aas-11 (4.87). Among crosses, number of tillers varied from (4.13) to (7.47) with minimum value for 9272 × Chakwal-50 (4.13) and maximum value for 9469 × Kohistan-97 (7.47).

Flag Leaf area

In case of flag leaf are the mean values of flag leaf area was varied from 14.07 cm^2 to 27.59 cm^2 for lines. The line 9272 had maximum flag leaf area (27.59 cm^2) followed by 9277 (18.75 cm^2) and 9452 (16.52 cm^2). Among testers, flag leaf area varied from 11.97 cm^2 to 22.47 cm^2. The tester, Aas-11 had maximum value (22.47 cm^2) followed by Kohistan-97 (14.21 cm^2) and Chakwal-50 (11.97 cm^2). Among crosses, flag leaf area varied from (13.75 cm^2) to (23.20 cm^2) with minimum value for 9452 × Chakwal-50 (13.75 cm^2) and maximum value for 9277 × Kohistan-97 (23.20 cm^2) (Table 3a). High flag leaf area contributed higher photosynthesis and had positive correlated with grain yield.

Table 3a. Mean values of lines, testers and crosses for various yields related traits in wheat under drought conditions.

Genotypes	PH (cm)	DH	DM	NT	FLA	SL
Aas-11	82.853^{cdefg}	134.33^{jk}	4.8667^{ghij}	22.473^{cd}	24.800^{bcdefg}	13.633^{a}
Chakwal-50	79.087^{efg}	140.67^{defgh}	6.5333^{abcd}	11.967^{k}	16.937^{i}	10.740^{hi}
Kohstan-97	80.833^{cdefg}	142.00^{bcdef}	5.9333^{cdefg}	14.207^{hijk}	20.830^{fghi}	12.133^{cdefgh}
CMS-127	81.433^{cdefg}	135.33^{ijk}	6.3333^{bcde}	15.607^{fghijk}	22.050^{defghi}	10.507^{i}
Miraj-06	81.160^{cdefg}	137.00^{fghijk}	6.9333^{abc}	16.310^{efghijk}	25.207^{bcdefg}	11.827^{defghi}
9469	83.867^{bcdefg}	137.67^{fghijk}	6.8667^{abc}	14.067^{ijk}	20.433^{ghi}	11.080^{fghi}
9452	89.453^{abc}	141.67^{bcdef}	4.7333^{hij}	16.917^{efghij}	23.353^{cdefgh}	12.020^{cdefgh}
9272	82.547^{cdefg}	138.67^{fghij}	4.6333^{hij}	27.593^{ab}	27.287^{abcde}	11.933^{defgh}
9277	78.473^{fg}	136.33^{ghijk}	5.0000^{ghij}	18.750^{cdefghi}	23.327^{cdefgh}	11.187^{fghi}
CMS-127 × Aas-11	90.247^{abc}	141.33^{cdefg}	4.4667^{ij}	18.367^{defghij}	23.443^{cdefgh}	11.940^{defgh}
CMS-127×chakwal-50	82.427^{cdefg}	136.00^{hijk}	5.2667^{efghi}	19.707^{cdefg}	23.157^{cdefgh}	12.207^{bcdefg}
CMS-127 × Kohistan-97	88.953^{abcd}	138.00^{fghij}	6.4000^{abcd}	15.083^{ghijk}	22.820^{cdefghi}	10.787^{ghi}
Miraj-06 × Aas-11	90.013^{abc}	138.00^{fghij}	5.0667^{ghij}	18.837^{cdefgh}	26.770^{abcdef}	12.380^{abcdef}
Miraj-06 × Chakwal-50	81.233^{cdefg}	140.33^{efghi}	5.0000^{ghij}	15.367^{ghijk}	21.400^{efghi}	11.107^{fghi}
Miraj-06 × Kohistan-97	83.073^{cdefg}	132.67^{k}	5.4667^{defghi}	17.940^{defghij}	27.227^{abcde}	11.807^{defghi}
9469 × Aas-11	88.127^{abcdef}	145.00^{abcde}	5.0667^{ghij}	19.723^{cdefg}	25.320^{bcdefg}	12.087^{cdefgh}
9469 × Chakwal-50	79.540^{defg}	144.67^{abcde}	7.0667^{ab}	17.270^{efghij}	20.327^{ghi}	12.280^{abcdef}
9469 × Kohistan-97	86.387^{abcdefg}	146.33^{abc}	7.4667^{a}	20.740^{cde}	25.380^{bcdefg}	12.327^{abcdef}
9452 × Aas-11	94.707^{a}	139.33^{fghij}	5.8667^{cdefg}	19.330^{cdefg}	27.857^{abcd}	13.427^{abc}
9452 × Chakwal-50	78.000^{gh}	140.67^{defgh}	5.1333^{fghij}	13.750^{jk}	24.980^{bcdefg}	8.827^{j}
9452 × Kohistan-97	93.167^{ab}	146.00^{abc}	6.2000^{bcdef}	20.933^{cde}	26.620^{abcdef}	12.953^{abcde}
9272 × Aas-11	86.567^{abcdefg}	145.67^{abcd}	4.4000^{ij}	28.360^{a}	32.217^{a}	13.613^{ab}
9272 × Chakwal-50	68.553^{h}	145.00^{abcde}	4.1333^{j}	15.040^{ghijk}	18.310^{hi}	11.940^{defgh}
9272 × Kohistan-97	88.373^{abcde}	146.67^{ab}	5.6667^{defgh}	20.380^{cde}	28.573^{abc}	13.140^{abcd}
9277 × Aas-11	84.953^{bcdefg}	145.67^{abcd}	4.4667^{ij}	23.263^{bc}	30.420^{ab}	12.867^{abcde}
9277 × Chakwal-50	85.427^{abcdefg}	149.00^{a}	7.1333^{ab}	20.230^{cdef}	28.130^{abc}	11.060^{fghi}
9277 × Kohistan-97	81.647^{cdefg}	146.33^{abc}	5.4667^{defghi}	23.203^{bc}	26.279^{abcdefg}	11.533^{efghi}

G=Genotypes, PH= Plant height, DH= Days to heading, DM= Days to maturity, NT= No. of tillers, FLA= Flag leaf area, SL= Spike length, GWPS=Grains weight per spike.

Spike length

It was illustrated from table 3a that the mean values of spike length varied from 10.51 cm to 12.02 cm for lines. The line 9452 had maximum spike length (12.02 cm) followed by 9272 (11.93 cm) and Miraj-06 (11.83 cm). Among testers, spike length varied from 10.74 cm to 13.63 cm. The tester, Aas-11 had maximum value (13.63 cm) followed by Kohistan-97

(12.13 cm) and Chakwal-50 (10.74 cm). Among crosses, spike length varied from (8.83 cm) to (13.43 cm) with minimum value for 9452 × Chakwal-50 (8.83 cm) and maximum value for 9452 × Aas-11 (13.43 cm).

Number of spikelet per spike

For number of spikelet per spike the mean values range was from 17.73 to 20.50 for lines (table 3b). The line 9277 had maximum number of spikelet per spike (20.50) followed by CMS-127 (20.47) and 9272 (19.67) (table 3b). Among testers, number of spikelet per spike varied from 18.10 to 20.03. The tester, Chakwal-50 had maximum value (20.03) followed by Kohistan-97 (18.27) and Aas-11 (18.10). Among crosses, number of spikelet per spike varied from (14.33) to (21.00) with minimum value for Miraj-06 × AAS-11 (14.33) and maximum value for CMS-127×Kohistan-97 (21.00).

Table 3b. Mean values of lines, testers and crosses for various yields related traits in wheat under drought conditions.

Genotype	SPS	GPS	GWP	1000 GW	GYP (g)	RWC	ELWL
Aas-11	18.100fghi	57.600def	1.8800ghijk	33.527ghij	9.463ij	109.24de	0.6200d
Chakwal-50	20.033abc	63.200a	1.9467ghij	30.703jkl	12.833defg	112.34b	0.0200n
Kohstan-97	18.267fghi	55.733efg	1.6933ijk	30.347jkl	10.253ghij	104.49gh	0.3300i
CMS-127	20.467ab	59.267abcdef	1.8600ghijk	31.220ijk	12.067efghi	108.77de	0.3500i
Miraj-06	18.400efghi	50.533hi	1.8000hijk	35.453fghi	12.780defg	95.32lm	0.4900f
9469	17.733hi	57.200def	1.9933fghi	36.407efg	13.720bcdef	92.66n	0.2500jk
9452	18.667defgh	48.800i	2.0933efgh	40.683de	10.760ghij	93.47mn	0.2300l
9272	19.667bcd	60.667abcd	1.9667ghij	32.423hijk	9.637ij	101.36k	0.1800m
9277	20.500ab	54.800fgh	1.8600ghijk	34.163ghij	9.713ij	104.36hi	0.2600jk
CMS-127×Aas-11	20.167ab	60.267abcde	2.1467efg	35.077fghi	9.980hij	102.53ijk	0.2400kl
CMS127×Chakwal50	17.800ghi	56.067defg	2.0133fghi	36.110efg	9.047jk	101.33k	0.2700j
CMS127×Kohistan97	21.000a	62.467abc	2.5333bcd	40.733de	16.267b	101.47k	0.2400kl
Miraj-06 × Aas-11	14.333j	56.933def	2.3133def	40.000def	11.473fghij	111.43bc	0.3300i
Miraj-06×Chakwal-50	18.467efghi	59.267abcdef	2.4067cde	41.003de	11.960efghi	112.34b	0.5800e
Miraj-06×Kohistan97	19.467bcde	58.800abcdef	2.3733cde	40.783de	14.533bcde	111.41bc	0.6100d
9469 × Aas-11	19.537bcde	62.533abc	2.9200a	46.957bc	14.100bcdef	116.53a	0.5800e
9469 × Chakwal-50	18.990cdef	63.067ab	1.7667hijk	28.220kl	12.460defgh	97.21l	0.3900h
9469 × Kohistan-97	19.667bcd	59.933abcde	2.3133def	38.457efg	15.720bc	107.61ef	0.4300g
9452 × Aas-11	19.733bcd	57.133def	2.6867abc	46.750bc	15.587bc	106.34fg	0.3900h
9452 × Chakwal-50	18.667defgh	52.067ghi	1.6467jk	31.193ijkl	9.687ij	115.39a	0.6800c
9452 × Kohistan-97	20.367ab	57.600def	2.1800efg	37.733efg	14.040bcdef	102.61ijk	0.5000f
9272 × Aas-11	19.767bcd	58.533bcdef	2.9267a	49.743ab	13.520cdef	115.47a	0.9000a
9272 × Chakwal-50	17.333i	58.867abcdef	1.5467k	26.087l	6.420k	94.68m	0.2700j
9272 × Kohistan-97	18.733defgh	58.333cdef	2.5733bcd	44.213cd	14.773bcd	105.78fg	0.3800h
9277 × Aas-11	18.800defgh	58.533bcdef	2.8200ab	48.127abc	12.527defgh	103.46ij	0.5000f
9277 × Chakwal-50	20.267ab	50.533hi	2.6200abcd	52.147a	20.553a	102.03jk	0.7200b
9277 × Kohistan-97	18.933cdefg	54.733fgh	2.1067efgh	33.527ghij	11.567fghij	110.23cd	0.3500i

PL= Peduncle Length, NSPS= No. of spikelet per spike, NGPS= No. of grains per spike, GWPS= Grain weight per spike, TGW = 100 Grain weight, GY= Grain yield, RWC= Relative water contents, ELWL= Excised leaf water loss 1000-grain weight.

Number of grains per spike

The mean values of number of grains per spike varied from 48.80 to 60.67 for lines.

The line 9272 had maximum number of grains per spike (60.67) followed by CMS-127 (59.23) and 9469 (59.23). Among testers, number of grains per spike varied from 55.73 to 63.20 (table 3a).The mean values of grains weight per spike varied from 1.80 g to 2.09 g for lines (3b). The line 9452 had maximum grains weight per spike (2.09 g) followed by 9272 (1.97) and 9469 (1.99). Among testers, grains weight per spike varied from 1.69 g to 1.95 g. The tester, Chakwal-50 had maximum value (1.95 g) followed by Aas-11 (1.88

g) and Kohistan-97 (1.69 g). Among crosses, grains weight per spike varied from (1.55 g) to (2.93 g) with minimum value for 9272 × Chakwal-50 (1.55 g) and maximum value for 9272 × Aas-11 (2.93 g).

The mean values of grains weight per spike varied from 31.22 g to 40.68 g for lines.

The tester, Chakwal-50 had maximum value (63.20) followed by Aas-11 (57.60) and Kohistan-97 (55.73). Among crosses, number of grains per spike varied from (50.53) to (63.07) with minimum value for 9277 × Chakwal-50(50.53) and maximum value for 9469 × Chakwal-50 (63.07) (Table 4).

Table 4. General combining ability effects of lines and testers for yield related traits under drought conditions**.**

Genotypes	PH	DH	DM	NT	FLA	PL	SL	NSPS	NGPS	GWPS	TGW	GY	RWC	ELWL
Lines														
CMS-127	2.13	1.06	-4.15	-0.4	-1.6	-2.4	-0	0.7	1.51	-0.1	-2.8	-1.3	-4.8	-0.2
Miraj-06	-0.3	-0.6	-5.59	-0.3	-1.9	-0.4	-0	-0.7	0.24	0.04	0.5	-0.4	5.18	0.04
9469	-0.39	-0.2	2.74	0.94	-0.1	-1.8	0.2	1.2	3.75	0.01	-2.2	1.08	0.57	0
9452	3.55	-1.9	-0.59	0.14	-1.3	0.97	-0	-2.1	-2.5	-0.2	-1.5	0.09	1.57	0.06
9272	-3.91	0.5	3.19	-0.9	1.95	0.85	0.9	0.4	0.49	0.02	-0.1	-1.4	-1.2	0.05
9277	-1.07	1.17	4.41	0.54	2.93	2.76	-0	0.4	-3.5	0.19	6.1	1.87	-1.3	0.06
S.E.	1.99	0.96	1.06	0.39	0.96	1.28	0.3	0.2	0.95	0.07	1.1	0.55	0.4	0.01
Testers														
Aas-2011	4.03	0.06	-0.09	-0.8	2.01	2.16	0.7	0.3	0.9	0.31	4.4	-0.2	2.75	0.03
Chakwal-50	-5.88	-0.7	0.02	0.08	-2.4	-2.8	-1	-0.6	-1.5	-0.3	-4.3	-1.3	-2.7	0.02
Kohstan-97	1.86	0.67	0.07	0.68	0.41	0.64	0.1	0.3	0.55	0.02	-0.1	1.47	-0	-0.1
S.E.	1.4	0.68	0.75	0.28	0.68	0.91	0.2	0.2	0.67	0.05	0.8	0.39	0.29	0

G=Genotypes,PH= Plant height, DH= Days to heading, DM= Days to maturity,NT= No. of tillers, FLA= Flag leaf area, SL= Spike length, PL= Peduncle Length, NSPS= No. of spikelets per spike, NGPS= No. of grains per spike, GWPS= Grain weight per spike, TGW = 100 Grain weight, GY= Grain yield, RWC= Relative water contents, ELWL= Excised leaf water loss.

The line 9452 had maximum grains weight per spike (40.68 g) followed by 9469 (36.41) and Miraj-06 (35.45). Among testers, grains weight per spike varied from 30.35 g to 33.53 g. The tester, Aas-11 had maximum value (33.53 g) followed by Chakwal-50 (30.70 g) and Kohistan-97 (30.35 g). Among crosses, grains weight per spike varied from (26.09 g) to(49.74 g) with minimum value for 9272 × Chakwal-50(26.09 g) and maximum value for 9272 × Aas-11 (49.74 g) as shown in Table 3b.

Grain yield

The mean values of grain yield varied from 9.64 g to 13.72 g for lines. The line 9469 had maximum grain yield (13.72 g) followed by Miraj-06 (12.78) and CMS-127 (12.78 g) (table 3b). Among testers, grain yield varied from 9.46 g to 12.83 g. The tester, Chakwal-50 had maximum value (12.83 g) followed by Kohistan-97 (10.25 g) and Aas-11 (9.46 g). Among crosses, grain yield varied from (6.42 g) to (20.55 g) with minimum value for 9272 × Chakwal-50(6.42 g) and maximum value for 9277 × Chakwal-50 (20.55 g).

Relative water content

It was showed from table 3b that the mean values of relative water content varied from 92.66 % to 108.77 % for lines. The line CMS-127 had maximum relative water content (108.77 %) followed by 9277 (104.36 %) and 9272 (101.36). Among testers, relative water content varied from 104.49 % to 112.34 %. The tester, Chakwal-50 had maximum value (112.34 %) followed by Aas-11 (109.24 %) and Kohistan-97 (104.49 %). Among crosses, relative water content varied from (94.68 %) to (116.53 %) with minimum value for 9272×Chakwal-50 (94.68 %) and maximum value for 9277×Chakwal-50 (116.53 %).

Excised leaf water loss

It was cleared from table 3b that mean values of excised leaf water loss varied from 0.18 to 0.49 for lines. The line Miraj-06 had maximum excised leaf water loss (0.35) followed by CMS-127 (36.41) and 9277 (0.26). Among testers, excised leaf water loss varied from 0.02 to 0.62. The tester, Aas-11 had maximum value (0.62) followed by Kohistan-97 (0.33) and Chakwal-50 (0.02). Among crosses, excised leaf water varied from (0.24) to (0.72) with minimum value for CMS-127 × Aas-11 (0.24) and maximum value for 9277 × Chakwal-50 (0.72).

Table 5. Specific combining ability effects of crosses for yield related traits in bread under drought conditions wheat.

Genotypes	PH	DH	DM	NT	FLA	PL	SL	NSPS	NGPS	GWPS	TGW	GY	RWC	ELWL
CMS127×Aas11	-46.5	-45	-70.3	-2.18	-13.8	-18	-7.3	-9.19	-29.4	-1.9	-32.4	-8.62	-60	-0.4
CMS-127×Chakwal-50	-8.23	-1.5	-2.37	-0.23	0.27	-1.83	-0.04	-1.54	-4.3	-0.5	-4.92	-2.59	-2.8	-0
CMS-127 × Kohistan-97	-0.11	-1.4	-0.52	0.9	-3.04	-0.96	-0.93	0.56	2.31	0.28	3.47	3.03	-0.3	0.03
Miraj-06 × Aas-11	1.22	-0.8	1.09	0.21	-0.55	-0.52	-0.09	-0.12	-2.3	-0.4	-4.94	-1.03	-3	-0.2
Miraj-06 × Chakwal-50	2.34	1.28	3.31	-0.37	0.4	-0.94	0.12	0.04	2.38	0.37	4.71	0.63	3.33	0.05
Miraj-06 × Kohistan-97	-3.56	-0.4	-4.41	0.16	0.15	1.46	-0.03	0.08	-0.09	-0	0.23	0.41	-0.3	0.15
9469 × Aas-11	-0.58	-1.6	-0.24	-0.7	-1.53	-0.51	-0.85	-0.7	-0.21	0.28	4.73	0.15	6.67	0.09
9469 × Chakwal-50	0.74	1.17	-0.69	0.45	0.44	-0.55	0.83	0.96	2.67	-0.2	-5.36	-0.31	-7.2	-0.1
9469 × Kohistan-97	-0.15	0.44	0.93	0.25	1.09	1.07	0.02	-0.26	-2.46	-0	0.63	0.16	0.52	0.01
9452 × Aas-11	2.06	-2.2	-2.57	0.9	-0.68	-0.79	0.99	0.68	0.64	0.21	3.84	2.63	-4.5	-0.2
9452 × Chakwal-50	-4.74	0.61	-1.35	-0.68	-1.84	1.29	-2.13	-1.96	-2.09	-0.2	-3.06	-2.09	10	0.14
9452 × Kohistan-97	2.69	1.56	3.93	-0.21	2.52	-0.5	1.14	1.28	1.45	-0	-0.78	-0.54	-5.5	0.02
9272 × Aas-11	1.38	0.39	-0.02	0.43	5.09	3.69	0.01	-0.12	-0.94	0.27	5.38	2.1	7.41	0.36
9272 × Chakwal-50	-6.73	-1.5	-0.8	-0.68	-3.81	-5.26	-0.18	0.78	1.74	-0.5	-9.63	-3.83	-7.9	-0.3
9272 × Kohistan-97	5.35	1.11	0.81	0.25	-1.29	1.57	0.17	-0.66	-0.8	0.21	4.25	1.73	0.5	-0.1
9277 × Aas-11	-3.08	2.06	-1.24	-0.9	-0.97	-0.01	0.34	0.06	3.04	0	-2.43	-2.21	-4.5	-0.1
9277 × Chakwal-50	7.3	-0.8	1.98	2.25	0.41	2.65	0.02	0.95	-2.62	0.43	10.2	7	-0.5	0.18
9277 × Kohistan-97	-4.22	-1.2	-0.74	-1.35	0.56	-2.63	-0.36	-1.01	-0.42	-0.4	-7.8	-4.79	5.01	-0.1
S.E. of SCA effects	3.44	1.67	1.83	0.68	1.67	2.22	0.5	0.41	1.65	0.12	1.84	0.96	0.7	0.01
S.E (gi-gj) lines	2.81	1.36	1.49	0.55	1.36	1.81	0.41	0.33	1.35	0.1	1.51	0.78	0.57	0.01
S.E (gTi-gTj) testers	1.99	0.96	1.06	0.39	0.96	1.28	0.29	0.24	0.95	0.07	1.06	0.55	0.4	0.01
S.E (sij-skl)	4.86	2.36	2.59	0.96	2.36	3.14	0.71	0.58	2.33	0.17	2.61	1.35	0.99	0.02

G=Genotypes,PH= Plant height, DH= Days to heading, DM= Days to maturity,NT= No. of tillers, FLA= Flag leaf area, SL= Spike length, PL= Peduncle Length, NSPS= No. of spikelets per spike, NGPS= No. of grains per spike, GWPS= Grain weight per spike, TGW = 100 Grain weight, GY= Grain yield, RWC= Relative water contents, ELWL= Excised leaf water loss.

Combining ability studies

General combining ability

General combining ability is average performance of genotypes in a series of crosses. Table 4 showed the general combining ability of various parents. It is due to additive genetic variance and estimate of variation due to GCA were portioned for male and female parents for all characters studied to search out the potential parent for subsequent future breeding program.

Plant height (cm)

In case of plant height, negative general combining ability effects are more important since more emphasis is placed upon selection for short stature segregants in segregating population because the ultimately produce short stature line which is more responsive to fertilizer and tolerant to lodging. From this point of view, Miraj-06, 9469, 9272 and 9277 among lines and Chakwal-50 among testers were potential parents and their values of general combining ability were -0.30, -0.39, -3.91, -1.07 and -5.88 respectively. These results are in contrast with the findings of Singh et al. (2002) while confirm the findings of Ivanovic et al. (2003),Mumtaz et al., 2014, Shabbir et al. (2012), Saif ul Malook et al. 2014ab and Zeeshan et al. (2013) for plant height.

Days to maturity

Among lines, 9277 had highest and positive GCA effects (4.41) followed by 9272 (3.19) and 9469 (2.74), while Miraj-06 had negative GCA effects (-5.59). Among testers, Kohistan-97 had highest and positive GCA effects (0.07) followed by Chakwal-50 (0.02). The tester, Aas-11 had negative GCA effects Aas-11 (-0.09). The line 9277 and tester Kohistan-97 was best general combiner for days to maturity among other lines and testers. Similar results were reported by Saleem and El-Sawi (2006) for days to maturity.

Flag Leaf area

For flag leaf area, negative general combining ability effects are more important because flag leaf area is much influenced by transpiration losses due to exposure to sunlight and ultimately affects the grain yield which is our main objective. So much emphasis is placed upon selection of genotypes with smaller flag leaf area. From this point of view, CMS-127, Miraj-06, 9469 and 9452 among lines and Chakwal-50 among testers were potential parents and their values of general combining ability were -1.59, -1.93, -0.06, -1.30 and -2.41 respectively. These results are in accordance with the results of Saeed et al. (2001). However, these results are in contradiction with the findings of Nazir et al. (2005).

Number of tillers per plant

Number of tillers per plant also plays an important role in the grain yield as more number of tillers are expected to result in better yielding ability. General combining ability effects calculated for this trait were of moderate magnitude. Among female parents, 9469 (0.94) and 9452 (0.14) and 9277 (0.54) showed higher and positive general combining ability effects followed by male parent as Chakwal-50 (0.08) and Kohistan-97 (0.68). These findings are in accordance with the results of Siddique et al. (2000) and Srivastava et al. (2012). Apart from the above parents, rest of others showed the negative general combining ability.

Spike length (cm)

Spike length is an important component, since greater spike length has more number of spikelet per spike and grains per spike which ultimately results in the better grain yield potential. Therefore, increased spike length is an objective of a breeder. For this trait, parents with positive general combining ability are required. Two parents, 9469 and 9272 among females followed by male parent as Aas-11 and Kohistan-97 showed positive values (0.22, 0.88, 0.70 and 0.08, respectively) for general combining ability effects. Similarly studies have also been discussed by Malik et al. (2005) and Srivastava et al. (2012). However these results do not match with the consequences of Gorjanovic et al. (2007).

Number of Spikelet per spike

Spikelet per spike contribute positively towards grain yield. More the number of spikelet per spike, greater will be the grain yield. Therefore, selection for higher number of spikelet per spike, greater will be the grain yield. Therefore, selection for

High number of spikelet per spike may ultimately lead to the evaluation of better yielding lines. Among the male parents, Aas-11 and Kohistan-97 showed the positive GCA value i.e. 0.25 and 0.32, while female parents viz., 9469, 9272 and 9277 were found to reveal positive general combining ability effects. These results are in the agreement with the results reported by Saeed et al. (2005), and Cheema et al.

(2007), Singh et al. (2012) for number of spikelet per spike.

Number of grains per spike

Number of grains per spike is also an important factor because as the number of grains will be more, grain yield will also increase. Therefore, positive general combining ability effects are more important due to positive contribution of grain yield. Among male parents, Aas-11(0.90) and Kohistan-97 (0.55) showed positive values of general combining ability for number of gains per spike. Among female parents, CMS-127, Miraj-06, 9469 and 9272 showed positive values 1.21, 0.24, 3.75 and 0.49, respectively. It should be noted that values of female parents were high than male parents. These results match with the findings of Saeed et al. (2001) and Khan et al. (2007). The results of Sarfaraz et al. 2014 andNazir et al. (2005) differ from these findings.

1000-Grain weight (g)

The female parent 9277 showed the maximum value (6.12) for 1000-grain weight followed by the male parents Aas-11 (4.35). Among lines CMS-127, 9469, 9252 9272 and two male parents Chakwal-50 and Kohistan-97 revealed negative general combining ability effects for 1000-grain weight. Similar results also have been reported by Singh et al. (2002) and Kashif and Khan (2008). However results do not match with the values reported by Nazir et al. (2005).

Grain yield (g)

For grain yield three female parents 9469, 9452 and 9277 and one male parent Kohistan-97 exhibited positive general combining ability. Similar results were found by Saeed et al. (2005), Mustafa et al. 2014ab and Malik et al. (2005). The high effects were found in the female parent 9277 (1.87) followed by line 9469 (1.08).

Relative water contents

Plant having high relative water contents are consider good under drought conditions. The line Miraj-06 exhibited highest positive GCA effects of 5.18 closely followed by the lines CMS-127 and 9277 with GCA effects of 4.77 and 1.31. In case of testers of drought conditions, the male parent Aas-11 ranked first among the testers with GCA effects of 2.75 followed by the tester Chakwal-50 with GCA effects of 2.72 (Table 4). Saifulmalook et al et al. 2014cd and Saeed et al. (2001) also found high GCA values for this trait in their study.

Excised leaf water loss

Excised leaf water loss is a good character to study under drought conditions. Table 4 showed that four lines out of six showed positive GCA effects. Among these lines 9272 showed highest positive GCA effects of 0.06. The other lines were Miraj-06, 9272 and 9452 with GCA effects of 0.04, 0.05 and 0.06, respectively. While among the three testers, Aas-11 and Chakwal-50 exhibited positive GCA effects of 0.03 and 0.02 (Table 4).

Specific combining ability

It is average performance of a genotype in a series of crosses. Results for SCA effects of various morphological characters are presented in Table 5.

Plant height

Maximum positive SCA effects for plant height were presented in crosses 9277 × Chakwal-50, 9272 × Kohistan-97, 9452 × Kohistan-97 and 9452 × Aas-11 with values 7.30, 5.35, 2.69 and 2.06, respectively. While CMS-127 × Aas-11, CMS-127 × Chakwal-50, 9272 × Chakwal-50 and 94277 × Kohistan-97 revealed useful negative SCA effects with values -46.48, -8.23, -6.73 and -4.22 respectively. These findings are in agreement with the result of Zubair et al. (1987) for plant height.

Days to maturity

In case for days to maturity highest positive SCA effects was found in crosses 9452 × Kohistan-97 (3.93) followed by Miraj-06 × Chakwal-50 (3.31) 9277 × Chakwal-50 (1.98) respectively while all others cross combination showed negative SCA effects ranged from CMS-127 × Aas-11 (-70.30) to Miraj-06 × Kohistan-97 (-4.41). Similar results were also observed by Ajmal et al. (2004) for days to maturity.

Number of tillers per plant

Number of tillers per plant is an important yield contributing trait. The best SCA effects were found in cross 9277 × Chakwal-50 (2.25) followed by CMS-127 × Kohistan-97 (0.90). These results are in conformity with those of Sarkar et al. (1987) for number of tillers per plant.

Flag Leaf area

For flag leaf area the cross combination 9272 × Aas-11 showed maximum specific combining ability effects. If more flag leaf area is required then crosses 9272 × Aas-11, 9469 × Kohistan-97 and 9277 × Kohistan-97 can be used in further breeding program because they have value 2.52, 1.09 and 0.56. Same results have also been found Saeed et al. (2001) for flag leaf area.

Spike length

For spike length positive specific combining ability effects are desired. Best cross combination is those having positive and higher value for specific combining ability effects. The cross 9452 × Kohistan-97 (1.14) indicates highest positive SCA effects. Five crosses namely CMS-127 × Aas-11, 9452 × Chakwal-50, CMS127 × Kohistan-97, 9469 × Aas-11 and 9277 × Kohistan-97 displayed negative SCA effects with values -7.30, -2.13, 0.93 -0.85, and -0.36, respectively. Similar results have also been reported by Palve et al. (1987) for spike length.

Number of spikelet per spike

For number of spikelet per spike larger positive SCA effects were found in cross combination 9452 × Kohistan-97, 9469 × Chakwal-50, 9277 × Chakwal-50 and 9272 × Chakwal-50 with values 1.28, 0.96, 0.95 and 0.78, respectively while crosses, CMS-127 × Aas-11, 9452 × Aas-11, CMS-127 × Chakwal-50 and 9277 × Kohistan-97 showed negative SCA effects with values -9.19, -1.96, -1.54 and -1.01, respectively. Similar results have also been reported by Ajmal et al. (2004 for number of spikelet per spike.

Number of grains per spike

For number of grains per spike larger positive SCA effects were found in cross combination 9277 × Aas-11, , 9469 × Chakwal-50, Miraj-06 × Chakwal-50 and 9452 × Kohistan-97 with values 3.04, 2.67, 2.38 and 1.45, respectively. While all other crosses, exhibited negative SCA effects ranged from CMS-127 × Aas-11 (-29.42) to CMS-127 × Chakwal-50 (-4.30). These results are in best accordance with finding of Sarkar et al. (1987) and Khan et al. (2008) for number of grains per spike.

Grain weight per spike

Grain weight per spike have positive SCA effects ranged from 0.43 (9277 × Chakwal-50) to 0.28 (CMS-127 × Kohistan-97) while the maximum negative specific combining ability effects were observed in crosses CMS-127 × Aas-11 (-1.91).

1000-grain weight

As regard 1000-grain weight, average magnitude of SCA effects were examined ranging from 4.71 to 10.23. The maximum positive specific combining ability effects showed in twelve crosses out of eighteen crosses. The best specific combiners were found to be 9277 × Chakwal-50 (10.23) and 9469 × Aas-11 (4.73). The maximum negative specific combining ability effects (-32.36) were shown by the cross CMS-127 × Aas-11. Similar results have also been reported by Sarkar et al. (1987), Saifulmalook et al., 2015 and Kamaluddin et al. (2007) for 1000-grain weight.

Grain yield

SCA effects were found more different among crosses for grain yield per plant. The cross 9277 × Chakwal-50 showed the maximum positive SCA effects (7.00) for grain yield per plant while lower in cross with respect to this trait was CMS-127 × Aas-11 (-8.62). These results are conformity with those of already given by Saeed et al. (2001) for grain yield.

Relative water contents

Plant having high relative water contents are consider good under drought conditions. 9452 × Chakwal-50 exhibited highest positive SCA effects of 10.00 closely followed by 9272 × Aas-11 and 9469 × Aas-11 with SCA effects of 7.41 and 6.67. The maximum negative specific combining ability effects (-60.40) were shown by the cross CMS-127 × Aas-11. Similar results were reported by Wang et al. (1993) and Rahman et al. (2000) for relative water contents.

Excised leaf water loss

For Excised leaf water loss larger positive SCA effects were found in cross combination 9272 × Aas-11, 9272 × Chakwal-50, Miraj-06 × Kohistan-97 and 9452 × Chakwal-50 with values 0.36, 0.18, 0.15 and 0.14, respectively while crosses , CMS-127 × Aas-11, 9272 × Chakwal-50, 9452 × Aas-11 and 9277 × Kohistan-97 showed negative SCA effects with values -0.40, -0.27, -0.16 and -0.13, respectively. Similar results were reported by Wang et al. (1993) and Rahman et al. (2000) for excised leaf water loss.

Conclusion

High significant differences were observed among the genotypes for agronomic traits under drought conditions. Line 9452 proved to be best line on the basis of mean performance for yield related traits. Male parent variety Chakwal-50 and cross combination 9272 × Aas-11 showed high mean for quantitative traits under drought conditions. Line 9277 showed high GCA effect while tester Aas-11 and cross combinations 9277 × Chakwal-50, 9452 × Kohistan-97 exhibited high SCA effects and may be useful for future stress breeding program.

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