

MORPHO-GENETIC INSIGHTS IN BREAD WHEAT (*TRITICUM AESTIVUM* L.) TO COMBAT PECULIAR WATER STRESS CONDITIONS

LUQMAN, M.* – IQBAL, M.

Department of Plant Breeding & Genetics, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, Bahawalpur, Pakistan

**Corresponding author
e-mail: luqmanmirza@hotmail.com*

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Abstract. The present research was undertaken to estimate the yield traits genetics of wheat in normal and water stress conditions. Six lines and three testers were crossed according to line \times tester mating fashion to develop eighteen crosses. Results depicted that variances due to genotypes and crosses were significant for all studied traits in both conditions. Significant differences between lines were witnessed for Plant height (cm), grains spike⁻¹ and biological yield plant⁻¹ under normal but significant for grains spike⁻¹ under water stress condition. Chakwal 86 possessed the highest general combining ability for number of tillers plant⁻¹, biological yield plant⁻¹ and grain yield plant⁻¹ in both conditions. Similarly, in both conditions, the best specific cross combinations were B 215 B 1103 \times Galaxy 2013 and GA 2002 \times 2511. Gene action was studied to evaluate the nature for inheritance of evaluated traits. All the observed traits reflected non-additive type of gene action except grains spike⁻¹ under both conditions. High heritability (H^2) under both conditions was witnessed for plant height, flag leaf area, tillers plant⁻¹, grains spike⁻¹ and biological yield plant⁻¹. The genotypes Chakwal 86, Galaxy 2013 and crosses B 215 B 1103 \times Galaxy 2013 and GA 2002 \times 2511 can be used in future for developing high yielding wheat varieties under water stress conditions.

Keywords: *line \times tester, combining ability, gene action, heritability*

Introduction

Wheat is grown almost all over the globe with a total production of 732.40 million tonnes. Major wheat producing countries include the European Union (136.86 million tonnes), China (131.43 million tonnes), India (99.87 million tonnes), Russia (71.69 million tonnes), United States (51.29 million tonnes), Canada (32.20 million tonnes) and Pakistan having production of 25.20 million tonnes (FAO, 2019). Wheat occupies a major place in the economic system of Pakistan and shares 8.9% value addition in agriculture and adds 1.6% to GDP of Pakistan. Production of wheat reached 25.195 million tonnes during 2018-19 with an increase of 119 million tonnes over 25.076 million tonnes during 2017-18 (Ministry of Food, Agriculture and Livestock, 2019).

Currently, the population of Pakistan is more than 210 million and is growing at a fast pace causing an increase in food demand. Therefore, we need to develop wheat varieties that can give better production even with less water requirement (Noorka et al., 2013). Scarcity of water is a global issue due to shrinkage of fresh water resources. It is a major concern for plant breeders to encounter various kinds of drought (HongBo et al., 2006). Different yield associated traits like plant height, spikelets spike, spike length, 1000-grain weight and grains per spikes are considerably reduced by water stress (Mirbahar et al., 2009; Noorka and Teixeira da Silva, 2014). We can enhance our overall production of wheat by improving our existing varieties by better utilization of available germplasm resources and breeding techniques (Ullah

et al., 2019). For checking the yield barrier levels and make wheat cultivation more attractive, it has now become necessary to explore alternative approaches. Among the potential alternatives, an important access for increasing wheat production has been the search for a desirable cross combination which can withstand vagaries of climate change (Noorka et al., 2013). The study of combining ability and heritability are important pre-requisites for a sound crop improvement program following conventional hybridization. Several mating designs have been used in different crop plants for estimating combining ability effects of the parents and identification of desirable genotypes for the production of hybrid. These designs provide information on various genetic parameters of variance. The line \times tester mating technique designed by Kempthorne (1957; Noorka and Taufiqullah, 2015) appears to be an effective method to evaluate diverse genotypes for assessing their combining ability effects. The design has an added advantage of its application in a situation of complete set of crosses. Different types of gene actions are estimated from combining ability variances which direct the manifestation of yield and yield relating parameters (Dreisigacker et al., 2005). Additionally, comprehensive information about the association among parents and hybrids is necessary to improve wheat hybrid breeding program (Longin et al., 2012; Noorka et al., 2020).

Keeping in view, the current research was commenced to identify the potential parents, crosses and their segregates for viable breeding program and to estimate the combining ability effects of parents and crosses both under normal and water stress conditions.

Materials and methods

Research areas

The present investigation was undertaken at experimental area of the Department of Plant Breeding and Genetics, University College of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Pakistan (the latitude of Bahawalpur, Pakistan is 29.39, and the longitude is 71.68; Bahawalpur is located with the GPS coordinates of 29° 24' N and 71° 40' E; *Table 1*) during the year 2016-17 by using six wheat genotypes as lines (Chakwal 86, BARS 2009, Chakwal 50, GA 2002, ESWYT P-117 and B215 B1103) and three genotypes as testers (Galaxy 2013, 2511 and Lasani 2008). These six lines (females) and three testers (males) were crossed according to line \times tester mating design to develop eighteen crosses.

Experimental details

During the year 2017-18, the F₀ seeds of eighteen crosses along with their parents were planted to develop F₁ under both environmental conditions in randomized complete block design (RCBD) with three replications. Plant to plant and row to row distance was maintained as 15 cm and 30 cm, respectively. All recommended cultural practices were applied for both environmental conditions except non application of irrigation at tillering stage for water stress environment. When the plants reached maturity, data of ten guarded plants for each genotype of normal and water stress conditions were taken for morphological traits like plant height (cm), flag leaf area (cm²), tillers plant⁻¹, spike length (cm), grains spike⁻¹, 1000-grain weight, biological yield plant⁻¹ and grain yield plant⁻¹.

Table 1. Monthly minimum, maximum, average temperature and total rainfall

Month	Temperature (Minimum °C)	Temperature (Maximum °C)	Temperature (Average °C)	Rainfall (Average mm)
December 2017	15	25	19	6.88
January 2018	14	24	18	0.00
February 2018	16	27	21	0.17
March 2018	21	34	27	0.02
April 2018	26	38	32	2.77
May 2018	32	43	38	3.65

Statistical analysis

Analyses of variances (ANOVA) were performed according to Steel et al. (1997). The general combining ability (GCA) of lines and testers and specific combining ability (SCA) of crosses were worked out by using line × tester mating technique as suggested by Kempthorne (1957). The ANOVA for Line × Tester used in the experiment is given in Table 2. Falconer (1989) formula was used to calculate broad sense heritability as under:

$$H^2 = V_G/V_P$$

where: H^2 = broad sense heritability, V_G = genotypic variance, V_P = phenotypic variance.

Table 2. Analysis of variance (ANOVA) for line × tester

Source of variation	Degree of freedom	Mean square
Replication (<i>r</i>)	(<i>r</i> - 1)	
Genotypes (<i>g</i>)	(<i>g</i> - 1)	MS ₂
Parents (<i>p</i>)	(<i>p</i> - 1)	
Parents versus crosses	1	
Crosses (<i>c</i>)	(<i>c</i> - 1)	
Lines (<i>l</i>)	(<i>l</i> - 1)	M_l
Testers (<i>t</i>)	(<i>t</i> - 1)	M_t
Lines × testers	(<i>l</i> - 1) (<i>t</i> - 1)	$M_{l \times t}$
Error	(<i>r</i> - 1) (<i>t</i> - 1)	MS ₁

MS₂ = genotypic mean square, M_l = line mean square, M_t = tester mean square, $M_{l \times t}$ = line × tester mean square, MS₁ = error mean square

Results and discussion

Line × tester - analysis of variance (ANOVA)

The analysis of variance was worked out for Plant height (cm), flag leaf area (cm²), tillers plant⁻¹, spike length (cm), grains spike⁻¹, 1000-grain weight (g), biological yield plant⁻¹ (g) and grain yield plant⁻¹ (g) for testing the differences among treatments. The mean sums of squares (MSS) for all the studied traits are reflected in Table 3a-d. The results depicted that the variances due to genotypes were significant for all the traits under both conditions. The variability present among hybrids is very useful in improvement of wheat varieties for water stress condition. Significant variation among

yield related traits has also been reported by Nawaz et al. (2013), Singh et al. (2014), Yao et al. (2014), Salman et al. (2014) and Saeed et al. (2016).

Table 3a. Analysis of variance through $L \times T$ for studied traits under normal and water stress conditions

Source of variance	Degree of freedom	Plant height		Flag leaf area	
		Normal	Water stress	Normal	Water stress
Replications	2	3.10	0.26	3.30	2.12
Genotypes	26	133.05**	71.89**	28.75**	29.44**
Parents	8	43.49**	41.23**	40.54**	37.09**
Crosses	17	152.97**	81.08**	24.88**	27.50**
Parents vs crosses	1	510.86**	160.98**	0.27	1.17
Lines	5	347.98**	132.76	26.50	22.65
Testers	2	78.59**	54.74**	30.46**	25.18**
Line \times tester	10	70.34**	60.51**	22.95**	30.39**
Error	52	1.60	2.91	0.75	0.71

Table 3b. Analysis of variance through $L \times T$ for studied traits under normal and water stress conditions

Source of variance	Degree of freedom	Tillers plant ⁻¹		Spike length	
		Normal	Water stress	Normal	Water stress
Replications	2	1.53	0.62	0.94	0.21
Genotypes	26	8.19**	6.51**	1.32**	1.05**
Parents	8	7.49**	6.24**	1.58**	1.40**
Crosses	17	8.90**	6.97**	1.12**	0.94**
Parents vs crosses	1	1.64	0.74	2.62**	0.01
Lines	5	9.73	7.67	1.35	1.11
Testers	2	18.76**	11.92**	0.05	0.14
Line \times tester	10	6.51**	5.63**	1.21**	1.02**
Error	52	0.33	0.26	0.25	0.07

Table 3c. Analysis of variance through $L \times T$ for studied traits under normal and water stress conditions

Source of variance	Degree of freedom	Grains spikes ⁻¹		1000-grain weight (g)	
		Normal	Water stress	Normal	Water stress
Replications	2	0.56	0.54	14.20	1.93
Genotypes	26	128.44**	77.79**	10.44**	16.56**
Parents	8	78.10**	46.61**	8.65	16.78**
Crosses	17	159.64**	96.66**	11.89**	17.02**
Parents vs crosses	1	0.58	6.52**	0.03	6.92**
Lines	5	527.82**	319.85**	16.15	18.07
Testers	2	13.71**	9.42**	17.98	20.65**
Line \times tester	10	4.74**	2.51**	8.55	15.76**
Error	52	1.78	0.90	4.78	0.40

Table 3d. Analysis of variance through $L \times T$ for studied traits under normal and water stress conditions

Source of variance	Degree of freedom	Biological yield plant ⁻¹ (g)		Grain yield plant ⁻¹ (g)	
		Normal	Water stress	Normal	Water stress
Replications	2	6.19	1.72	3.47	1.05
Genotypes	26	107.54**	68.91**	26.99**	12.77**
Parents	8	139.58**	70.93**	35.24**	17.63**
Crosses	17	88.93**	70.43**	24.60**	10.94**
Parents vs crosses	1	167.44**	26.89**	1.85	4.91**
Lines	5	203.30**	115.48	19.00	7.40
Testers	2	124.06**	86.69**	13.48**	8.52**
Line \times tester	10	24.73**	44.65**	29.62**	13.20**
Error	52	1.72	1.08	2.07	0.58

Mean variability, general combining ability and specific combining ability

Mean variability

Among parents for plant height, the variation was between 102.27 cm (Chakwal 86) to 114.67 cm (GA 2002) under normal condition while mean values ranged from 68.23 cm (Galaxy 2013) to 80.36 cm (Chakwal 86) under water stress condition. Among crosses, this range varied from 90.61 cm (BARS 2009 \times 2511) to 114.33 cm (GA 2002 \times Galaxy 2013) under normal whereas under water stress condition, the mean performance ranged from 63.92 cm (BARS 2009 \times Galaxy 2013) to 78.39 cm (B215 B 1103 \times 2511). Among parents for flag leaf area, the mean performance was witnessed between 29.56 cm² (ESYWT P 117) to 40.90 cm² (B 215 B 1103) for this parameter under normal condition while mean performance ranged from 23.12 cm² (ESYWT P 117) to 33.46 cm² (B 215 B 1103) under water stress condition. However, among crosses, the mean value varied from 31.81 cm² (ESYWT P 117 \times Lasani 2008) to 41.56 cm² (B 215 B 1103 \times Galaxy 2013) under normal condition whereas the mean performance ranged from 22.24 cm² (B 215 B 1103 \times Lasani 2008) to 34.32 cm² (B 215 B 1103 \times Galaxy 2013) under water stress condition. Among parents, the variation was between 9.54 (Galaxy 2013) to 14.22 (B 215 B 1103) for tillers plant⁻¹ under normal condition while mean values ranged from 6.10 (B 215 B 1103) to 10.71 (ESYWT P 117) for this character under water stress condition. Similarly, under normal condition among crosses, this range varied from 8.14 (ESYWT P 117 \times Lasani 2008) to 15.43 (B 215 B 1103 \times Galaxy 2013) whereas under water stress condition, the mean performance for crosses varied from 5.14 (ESYWT P 117 \times 2511) to 12.02 (B 215 B 1103 \times Galaxy 2013). For spike length among parents under normal condition, the mean values were between 8.10 cm (2511) to 10.17 cm (B 215 B 1103) while mean performance ranged from 6.75 cm (2511) to 8.95 cm (B 215 B 1103) under water stress condition. Among crosses, the mean values ranged from 7.73 cm (GA 2002 \times Galaxy 2013) to 10.28 cm (B 215 B 1103 \times Galaxy 2013) under normal condition whereas this mean value range in crosses under water stress condition was found between 7.04 cm (ESYWT P 117 \times Galaxy 2013) to 9.36 cm (B 215 B 1103 \times Galaxy 2013). For grains spike⁻¹ among parents under normal condition, the mean performance was observed between 49.70 (Galaxy 2013) to 65.27 (B 215 B 1103) while mean performance values ranged from 33.60 (Galaxy 2013) to 46.57 (B 215 B

1103) for this trait under water stress condition. Likewise, among crosses under normal condition, the mean value varied from 48.59 (BARS 2009 × 2511) to 68.13 (B 215 B 1103 × Galaxy 2013). The mean performance range in crosses under water stress condition for this character was found from 33.05 (BARS 2009 × 2511) to 47.40 (B 215 B 1103 × Galaxy 2013). Among parents, the mean values were between 49.00 (Galaxy 2013) to 54.48 (B 215 B 1103) under normal condition while mean performance ranged from 33.51 (Galaxy 2013) to 41.07 (B 215 B 1103) under water stress condition for 1000-grain weight. Among crosses, the mean values ranged from 49.70 (Chakwal 86 × 2511) to 56.53 (B 215 B 1103 × Galaxy 2013) for this trait under normal condition while under water stress condition the mean values range in crosses was found between 33.99 (Chakwal 86 × 2511) to 42.90 (B 215 B 1103 × Galaxy 2013). The mean performance range among parents varied between 50.74 (Galaxy 2013) to 68.39 (B 215 B 1103) for biological yield plant⁻¹ under normal conditions while mean values ranged from 40.10 (2511) to 52.69 (Chakwal 86) under water stress condition. Among crosses, the range varied from 53.03 (Chakwal 50 × Lasani 2008) to 70.84 (B 215 B 1103 × Galaxy 2013) under normal condition whereas this mean performance under water stress condition ranged from 38.31 (Chakwal 50 × Lasani 2008) to 53.40 (B 215 B 1103 × Galaxy 2013). Under normal condition, for grain yield plant⁻¹ among parents, the mean performance was found between 22.73 (Galaxy 2013) to 32.50 (B 215 B 1103) whereas this mean performance values ranged from 17.05 (Galaxy 2013) to 23.23 (B 215 B 1103) for this character under water stress condition. Similarly, among crosses, the mean values varied from 22.20 (B 215 B 1103 × Lasani 2008) to 35.55 (B 215 B 1103 × Galaxy 2013) under normal condition. Likewise, this mean performance range in crosses under water stress conditions was found from 16.73 (B 215 B 1103 × Lasani 2008) to 25.71 (B 215 B 1103 × Galaxy 2013).

Estimation of general combining ability (GCA)

Combining ability is an assessment of the value of parents on the basis of performance of their progenies by using a specific breeding approach. When crosses are more productive, they are supposed to have good combining ability. GCA effects of lines and testers for evaluated traits are reflected in *Table 4a-d*. The plant height with negative values of GCA effects is considered favorable as short stature plants are considered good due to their ability to withstand lodging (Muneer et al., 2016). Among lines under normal condition, Chakwal 86 and BARS 2009 were observed as good combiners having GCA values of (- 4.87) and (- 8.89), respectively whereas under water stress condition, lines BARS 2009 (-6.67), Chakwal 50 (-0.61) and ESWYT P 117 (-1.40) were good general combiners. Similarly, among testers under normal condition, Galaxy 2013 and 2511 were observed good combiner having GCA values of (-1.31) and (-1.10), respectively whereas under water stress condition, testers Galaxy 2013 (-0.97) and Lasani 2008 (-0.94) were found good general combiners. These results are in accordance with the findings of Muneer et al. (2016). Negative GCA effects for flag leaf area are favorable due to less transpirational loss. Lines BARS 2009, GA 2002 and ESWYT P 117, under both conditions, reflected negative and significant results while testers Lasani 2008 under normal condition and 2511 and Lasani 2008 under water stress condition were good general combiners. Tillers plant⁻¹ is a yield associated character and plants with higher number of fertile tillers result in more grain yield. Under both condition, lines BARS 2009, Chakwal 86

and Chakwal 50 exhibited positive and significant GCA effects with values 1.02, 0.58 and 0.83 for normal and 0.94, 0.35 and 0.53 under water stress condition, respectively. For testers, Galaxy 2013 was a good general combiner under both conditions. The findings of Majeed et al., (2011), Muneer et al. (2016), Saeed et al. (2016) and Iqbal et al. (2007) are also supportive to these findings. Spikes with greater length are desirable because of more spikelets per spike resulting in greater grain yield. Under normal condition, line B 215 B 1103 and under water stress condition, lines BARS 2009 and B 215 B 1103 were positive and significant general combiners. Grains spike-1 is a significant attribute contributing to overall grain yield and hence positive and significant GCA effects are desirable owing to yield per spike. Under both conditions among lines, GA 2002, ESWYT P 117 and B 215 B 1103 reflected positive and significant combining ability results. Among testers, Lasani 2008 was a good general combiner under both conditions. Muneer et al. (2016) and Iqbal et al. (2007) also witnessed the same results. Thousand-grain weight is a significant yield related trait and could be practiced as a selection criterion for high production in wheat. Among lines, B 215 B 1103 under both conditions showed maximum desirable GCA effects and thus proved to be good general combiners for this particular trait. However, testers Galaxy 2013 and Lasani 2008 under water stress condition reflected significant and positive GCA effects. For lines, biological yield plant-1, was positive and significant for Chakwal 86, ESWYT P 117 and B 215 B 1103 under both conditions whereas for testers, it proved to be positive and significant for Galaxy 2013 and 2511 under both conditions. Grain yield being a complex character, the plant breeders are particularly interested in developing high yielding varieties to cope with food demand of the masses by improving directly or indirectly this trait. Line Chakwal 86 demonstrated as a best general combiner under both conditions whereas the tester Galaxy 2013 reflected significant and positive GCA effects under both environmental conditions. These findings are in line with the results of Muneer et al. (2016), Sattar et al. (2018) and Jatav et al. (2014). It is suggested that line Chakwal 86 having high GCA for tillers plant-1, biological yield plant-1 and grain yield plant-1 under both conditions and tester Galaxy 2013 having good GCA for plant height, tillers plant-1, biological yield plant-1 and grain yield plant-1 under both environmental conditions can be easily employed for exploring high yielding wheat varieties in future.

Table 4a. GCA effects of lines and testers under normal and water stress conditions

Genotypes	Plant height		Flag leaf area	
	Normal	Water stress	Normal	Water stress
Chakwal 86	-4.87**	3.03**	-0.01	-0.16
BARS 2009	-8.89**	-6.67**	-0.97**	-0.73**
Chakwal 50	0.95**	-0.61**	2.11**	2.26**
GA 2002	9.07**	3.74	-0.95**	-0.72**
ESWYT P 117	1.45**	-1.40**	-2.14**	-2.08**
B 215 B 1103	2.30**	1.92**	1.96**	1.43**
Galaxy 2013	-1.31**	-1.07**	1.41**	1.36**
2511	-1.10**	2.01**	-0.26	-0.58**
Lasani 2008	2.41**	-0.94**	-1.15**	-0.78**

Table 4b. GCA effects of lines and testers under normal and water stress conditions

Genotypes	Tillers plant ⁻¹		Spike length	
	Normal	Water stress	Normal	Water stress
Chakwal 86	1.02**	0.94**	0.24	0.07
BARS 2009	0.58**	0.35**	0.20	0.26**
Chakwal 50	0.83**	0.53**	-0.21	-0.29**
GA 2002	-0.32	-0.35**	-0.64**	-0.43**
ESWYT P 117	-1.77**	-1.678**	-0.03	-0.11
B 215 B 1103	-0.34	0.20	0.44**	0.51**
Galaxy 2013	1.12**	0.83**	0.05	0.09
2511	-0.25	-0.80**	-0.05	-0.08
Lasani 2008	-0.87**	-0.30	-0.01	-0.01

Table 4c. GCA effects of lines and testers under normal and water stress conditions

Genotypes	Grains spike ⁻¹		1000-grain weight	
	Normal	Water stress	Normal	Water stress
Chakwal 86	-5.36**	-4.06**	-1.04	-0.55**
BARS 2009	-7.79**	-6.15**	-1.01	-0.94**
Chakwal 50	-7.57**	-5.92**	-0.78	-0.27
GA 2002	5.62**	4.64**	-0.35	-0.56**
ESWYT P 117	6.88**	5.15**	0.86	-0.54**
B 215 B 1103	8.22**	6.35**	2.32**	2.86**
Galaxy 2013	0.16	-0.17	0.56	0.69**
2511	-0.94**	-0.62**	-1.15**	-1.23**
Lasani 2008	0.78**	0.79**	0.60	0.54**

Table 4d. GCA effects of lines and testers under normal and water stress conditions

Genotypes	Biological yield plant ⁻¹		Grain yield plant ⁻¹	
	Normal	Water stress	Normal	Water stress
Chakwal 86	2.45**	2.44**	1.97**	1.57**
BARS 2009	-3.26**	-1.19**	-2.36**	-1.09**
Chakwal 50	-7.85**	-6.02**	-0.66	-0.53**
GA 2002	0.55	-0.67	0.14	-0.24
ESWYT P 117	4.94**	4.34**	0.80	-0.06
B 215 B 1103	3.17**	1.11**	0.11	0.35
Galaxy 2013	2.16**	1.54**	0.98**	0.72**
2511	0.76**	0.98**	-0.33	-0.07
Lasani 2008	-2.92**	-2.51**	-0.65	-0.65**

Estimation of specific combining ability (SCA)

SCA results of crosses are reflected in *Table 5a-d*. Crosses Chakwal 86 × Lasani 2008, Chakwal 50 × Galaxy 2013, GA 2002 × Lasani 2008, ESWYT P 117 × Lasani

2008 and B 215 B 1103 × Galaxy 2013 exhibited positive and significant SCA effects for plant height under both conditions. Crosses Chakwal 86 × Galaxy 2013, BARS 2009 × 2511, GA 2002 × Galaxy 2013, ESWYT P 117 × 2511, ESWYT P 117 × Lasani 2008 and B 215 B 1103 × Lasani 2008 were best specific combiners under normal condition environment whereas for water stress condition, best combiners were Chakwal 86 × Galaxy 2013, GA 2002 × Galaxy 2013, ESWYT P 117 × 2511 and B 215 B 1103 × Lasani 2008 for flag leaf area. The same findings were reported by Srivastava et al. (2012), Singh and Kumar (2014) and Sattar et al. (2018). Under normal condition, crosses like Chakwal 86 × Lasani 2008, Chakwal 50 × Lasani 2008, GA 2002 × 2511, ESWYT P 117 × 2511 and B 215 B 1103 × Galaxy 2013 displayed significant and favorable SCA effects and proved to be good combiners for tillers plant⁻¹. Likewise, under water stress condition, for tillers plant⁻¹, the crosses Chakwal 86 × 2511, BARS 2009 × Lasani 2008, Chakwal 50 × 2511 and B 215 B 1103 × Galaxy 2013 proved to be good specific combiners. Jain and Sastry (2012), Hammad et al. (2013), Singh and Kumar (2014), Muneer et al. (2016), and Kumar et al. (2018) also reported similar results in their experiments for tillers plant⁻¹. Two crosses ESWYT P 117 × Lasani 2008 and B 215 B 1103 × Galaxy 2013 under normal condition and three crosses GA 2002 × 2511, ESWYT P 117 × Lasani 2008 and B 215 B 1103 × Galaxy 2013 under water stress condition had significantly positive SCA effects for spike length. For grains spike⁻¹, all cross combinations under both conditions showed non-significant results except GA 2002 × 2511. Similar results were shown by Shabbir et al. (2012) and Bibi et al. (2013) for this trait. Positive and favorable SCA effects for 1000 grain weight were witnessed for six crosses like Chakwal 86 × Lasani 2008, Chakwal 50 × Lasani 2008, GA 2002 × Lasani 2008, ESWYT P 117 × Galaxy 2013, B 215 B 1103 × Galaxy 2013 and B 215 B 1103 × 2511 under water stress condition while no cross had significantly positive SCA effects under normal condition. Out of these six crosses under water stress condition, the best three in order of merit were Chakwal 86 × Lasani 2008, Chakwal 50 × Lasani 2008 and B 215 B 1103 × 2511. Similar findings were given by Ahmad et al. (2011), Majeed et al. (2011), Hammad et al. (2013) and Muneer et al. (2016). Under both conditions, six cross combinations Chakwal 86 × Galaxy 2013, BARS 2009 × Galaxy 2013, Chakwal 50 × Lasani 2008, GA 2002 × Lasani 2008, ESWYT P 117 × Lasani 2008 and B 215 B 1103 × Galaxy 2013 reflected positive and significant SCA effects for biological yield plant⁻¹. However, B 215 B 1103 × Galaxy 2013 and Chakwal 86 × Galaxy 2013 were the best combiners. Crosses with desired and significant SCA effects under normal condition for grain yield plant⁻¹ were GA 2002 × 2511 and B 215 B 1103 × Galaxy whereas under water stress condition, the positive and significant results were obtained for Chakwal 86 × Lasani 2008, GA 2002 × 2511, ESWYT P 117 × 2511 and B 215 B 1103 × Galaxy 2013. Similarly, under both conditions, the best combiners were GA 2002 × 2511 and B 215 B 1103 × Galaxy 2013 for grain yield plant⁻¹. These results are in confirmation with Majeed et al. (2011), Bibi et al. (2013), Fellahi et al. (2013), Muneer et al. (2016) and Sattar et al. (2018).

Heritability

Genotypic variance (V_g), Phenotypic variance (V_p), Environmental variance (V_e) and Heritability (H^2) estimates for studied traits evaluated under both environmental conditions are presented in *Table 8*. The characters like plant height, flag leaf area, tillers plant⁻¹, grains spike⁻¹ and biological yield plant⁻¹ under both environments showed high heritability. However, under water stress environments, all traits reflected

moderate to high heritability. Similarly, spike length, 1000-grain weight and grain yield plant⁻¹ reflected medium to high heritability.

Table 5a. SCA effects of crosses under normal and water stress conditions

Crosses	Plant height		Flag leaf area	
	Normal	Water stress	Normal	Water stress
Chakwal 86 x Galaxy 2013	2.31**	3.70**	-3.77**	-3.00**
Chakwal 86 x 2511	-0.38	0.76	-0.35	-0.21
Chakwal 86 x Lasani 2008	-1.93**	-4.46**	4.12**	3.21**
BARS 2009 x Galaxy 2013	0.75	-0.06	0.10	-0.07
BARS 2009 x 2511	-2.45**	-1.36	-1.13**	-0.49
BARS 2009 x Lasani 2008	1.70**	1.43	1.03**	0.56
Chakwal 50 x Galaxy 2013	-6.38**	-5.69**	0.08	-0.51
Chakwal 50 x 2511	-0.26	-2.45**	0.86	0.58
Chakwal 50 x Lasani 2008	6.64**	8.14**	-0.94	-0.07
GA 2002 x Galaxy 2013	3.52**	3.86**	-1.13**	-2.66**
GA 2002 x 2511	0.39	-0.05	-0.09	-0.32
GA 2002 x Lasani 2008	-3.91**	-3.81**	1.22**	2.97**
ESWYT P 117 x Galaxy 2013	5.54**	1.82	3.08**	2.32**
ESWYT P 117 x 2511	-0.97	0.36	-1.64**	-1.69**
ESWYT P 117 x Lasani 2008	-4.57**	-2.18**	-1.44**	-0.64
B 215 B 1103 x Galaxy 2013	-5.74**	-3.63**	1.65**	3.91**
B 215 B 1103 x 2511	3.66**	2.74**	2.35**	2.12**
B 215 B 1103 x Lasani 2008	2.08**	0.89	-4.00**	-6.03**

Table 5b. SCA effects of crosses under normal and water stress conditions

Crosses	Tillers plant ⁻¹		Spike length	
	Normal	Water stress	Normal	Water stress
Chakwal 86 x Galaxy 2013	-0.61	-1.30**	0.14	0.01
Chakwal 86 x 2511	-0.99**	1.24**	-0.04	0.13
Chakwal 86 x Lasani 2008	1.60**	0.06	-0.09	-0.14
BARS 2009 x Galaxy 2013	-0.65	0.50	-0.33	-0.22
BARS 2009 x 2511	0.37	-0.16	0.36	0.24
BARS 2009 x Lasani 2008	0.27	0.66**	-0.03	-0.03
Chakwal 50 x Galaxy 2013	-0.88**	-1.27**	0.06	0.04
Chakwal 50 x 2511	-0.52	1.44**	0.19	0.14
Chakwal 50 x Lasani 2008	1.40**	-0.17	-0.25	-0.18
GA 2002 x Galaxy 2013	-0.39	0.12	-0.32	-0.29
GA 2002 x 2511	0.88**	-0.15	0.46	0.34**
GA 2002 x Lasani 2008	-0.49	0.02	-0.14	-0.05
ESWYT P 117 x Galaxy 2013	0.06	0.37	-0.71**	-0.62**
ESWYT P 117 x 2511	1.34**	-0.82**	-0.11	-0.27
ESWYT P 117 x Lasani 2008	-1.40**	0.44	0.82**	0.89**
B 215 B 1103 x Galaxy 2013	2.47**	2.57**	1.16**	1.08**
B 215 B 1103 x 2511	-1.09**	-1.56**	-0.85**	-0.58**
B 215 B 1103 x Lasani 2008	-1.38**	-1.01**	-0.31	-0.49**

Table 5c. SCA effects of crosses under normal and water stress conditions

Crosses	Grains spike ⁻¹		1000-grain weight	
	Normal	Water stress	Normal	Water stress
Chakwal 86 x Galaxy 2013	0.68	0.61	-0.76	-0.92**
Chakwal 86 x 2511	-1.31	-0.86	-1.05	-1.73**
Chakwal 86 x Lasani 2008	0.62	0.25	1.81	2.65**
BARS 2009 x Galaxy 2013	0.90	-0.45	-0.12	-0.09
BARS 2009 x 2511	-1.32	-0.32	-0.41	0.01
BARS 2009 x Lasani 2008	0.42	0.77	0.53	0.09
Chakwal 50 x Galaxy 2013	0.12	0.50	-0.68	-1.00**
Chakwal 50 x 2511	0.07	-0.09	-0.64	-1.32**
Chakwal 50 x Lasani 2008	-0.19	-0.41	1.32	2.32**
GA 2002 x Galaxy 2013	-1.79**	-1.09	-0.78	-1.49**
GA 2002 x 2511	1.66**	1.22**	-0.41	0.57
GA 2002 x Lasani 2008	0.14	-0.13	1.18	0.93**
ESWYT P 117 x Galaxy 2013	-1.02	-0.65	1.63	1.67**
ESWYT P 117 x 2511	0.76	0.04	1.06	0.41
ESWYT P 117 x Lasani 2008	0.25	0.62	-2.69**	-2.07**
B 215 B 1103 x Galaxy 2013	1.10	1.08	0.71	1.84**
B 215 B 1103 x 2511	0.14	0.01	1.45	2.07**
B 215 B 1103 x Lasani 2008	-1.24	-1.09	-2.16	-3.91**

Table 5d. SCA effects of crosses under normal and water stress conditions

Crosses	Biological yield plant ⁻¹		Grain yield plant ⁻¹	
	Normal	Water stress	Normal	Water stress
Chakwal 86 x Galaxy 2013	2.73**	1.67**	-1.74**	-1.59**
Chakwal 86 x 2511	-1.61**	-1.17	0.13	0.33
Chakwal 86 x Lasani 2008	-1.11	-0.50	1.61	1.25**
BARS 2009 x Galaxy 2013	2.06**	2.80**	0.05	0.37
BARS 2009 x 2511	0.56	-1.06	-0.87	-1.07**
BARS 2009 x Lasani 2008	-2.62**	-1.74**	0.82	0.69
Chakwal 50 x Galaxy 2013	-1.75**	-0.54	-1.43	-0.21
Chakwal 50 x 2511	0.21	0.38	-0.15	-0.66
Chakwal 50 x Lasani 2008	1.53**	0.16	1.58	0.87
GA 2002 x Galaxy 2013	-3.72**	-5.87**	-2.04**	-1.08**
GA 2002 x 2511	1.02	0.80	1.72**	1.19**
GA 2002 x Lasani 2008	2.70**	5.06**	0.32	-0.10
ESWYT P 117 x Galaxy 2013	-2.56**	-2.12**	-1.73**	-1.69**
ESWYT P 117 x 2511	0.09	-0.92	1.24	0.99**
ESWYT P 117 x Lasani 2008	2.47**	3.05**	0.49	0.71
B 215 B 1103 x Galaxy 2013	3.24**	4.06**	6.90**	4.20**
B 215 B 1103 x 2511	-0.26	1.97**	-2.08**	-0.78
B 215 B 1103 x Lasani 2008	-2.98**	-6.03**	-4.82**	-3.42**

Component of variance and proportional contribution of parents and crosses

Genetic component of variance i.e. variance due to GCA (σ^2_g) and variance due to SCA (σ^2_s) were worked out from analysis of variance for combining ability under both conditions and are presented in *Table 6*. The ratio between σ^2_g/σ^2_s was calculated to determine the relative role of gene action. The ratio between σ^2_g/σ^2_s greater than 1 reflected additive type of gene action and the ratio less than one indicated non-additive (dominance) type of gene action. Variance due to GCA greater than SCA variance showed additive types of gene action but variance due to SCA greater than GCA variance indicated non-additive type of gene action. Variance due to GCA equal to the SCA variance reflected the epistasis (non-allelic interaction).

In the present studies, the estimated values of genetic components of variance due to σ^2_g and σ^2_s revealed the predominance of SCA indicating the role of non-additive (dominance) type of gene action in the expression of characters in both conditions except grains spike⁻¹ which shows the additive type of gene action under both conditions. Dominance and additive type of gene actions were studied for various yield related traits under normal and water stress conditions. Non-additive gene action for plant height, flag leaf area, tillers per plant⁻¹, spike length, 1000-grain weight, biological yield plant⁻¹ and grain yield plant⁻¹ was observed. These results are in accordance with Srivastava et al. (2012) and Sattar et al. (2018) who observed non-additive type of gene action for plant height, flag leaf area, tillers plant⁻¹, 1000-grain weight and grain yield plant⁻¹. Additive type of gene action for spike length and grain weight per spike has been reported earlier by Ahmad et al. (2011) and Hammad et al. (2013).

Proportional contribution of lines, testers and line × tester interaction to the total variance for different plant characters is presented in *Table 7*. While observing the proportional contribution of lines, testers and their hybrids to the total variance of eight studied traits, lines were more prominent for the characters like plant height, grains spike⁻¹ and biological yield plant⁻¹ under both conditions. The contribution of testers was very low in proportion in most of the studied traits under both conditions. Line × tester interaction contributed predominantly to flag leaf area, tillers plant⁻¹, spike length, 1000-grain weight and grain yield plant⁻¹ under both conditions. Similar findings were reported by Shabbir et al. (2012) and Fellahi et al. (2013) and Sattar et al. (2018).

Table 6. Variances due to GCA, SCA under normal and water stress conditions

Traits	σ^2 GCA		σ^2 SCA		σ^2 GCA/ σ^2 SCA	
	N	WS	N	WS	N	WS
Plant height	2.477	0.617	22.914	19.202	0.108	0.032
Flag leaf area	0.058	-0.087	7.399	9.891	0.008	-0.009
Tillers plant ⁻¹	0.072	0.040	2.061	1.788	0.035	0.023
Spike length	-0.003	-0.002	0.322	0.316	-0.009	-0.007
Grains spike ⁻¹	4.644	2.823	0.986	0.534	4.712	5.283
1000-grain weight	0.100	0.038	1.256	5.122	0.080	0.007
Biological yield plant ⁻¹	1.925	0.773	7.669	14.523	0.251	0.053
Grain yield plant ⁻¹	-0.151	-0.068	9.185	4.206	-0.016	-0.016

N = normal, WS = water stress, L×T = line × tester

Table 7. Gene action, contribution of parents and their crosses under normal and water stress conditions

Traits	Gene action				Contribution of parents and their crosses					
	Additive		Dominance		Line		Tester		L×T	
	N	WS	N	WS	N	WS	N	WS	N	WS
Plant height	4.95	1.23	22.91	19.20	66.91	48.16	6.04	7.94	27.05	43.90
Flag leaf area	0.12	-0.17	7.40	9.89	31.33	24.23	14.40	10.77	54.26	65.00
Tillers plant ⁻¹	0.14	0.08	2.06	1.79	32.16	32.37	24.80	20.13	43.04	47.50
Spike length	-0.01	-0.005	0.32	0.32	35.54	34.59	0.50	1.72	63.96	63.69
Grains spike ⁻¹	9.29	5.65	0.99	0.53	97.25	97.33	1.01	1.15	1.74	1.53
1000-grain wt.	0.20	0.08	1.26	5.12	39.95	31.24	17.78	14.28	42.27	54.49
Biological yield plant ⁻¹	3.85	1.55	7.67	14.52	67.23	48.23	16.41	14.48	16.35	37.29
Grain yield plant ⁻¹	-0.30	-0.14	9.18	4.21	22.72	19.88	6.45	9.16	70.83	70.96

Table 8. Genotypic variance (V_g), phenotypic variance (V_p), environmental variance (V_e) and heritability (H^2) estimates for studied traits evaluated under normal and water stress conditions

Traits	Environmental variance		Genotypic variance		Phenotypic variance		Heritability (b.s)	
	N	WS	N	WS	N	WS	N	WS
Plant height	1.60	2.91	43.82	22.99	45.42	25.90	96.48	88.78
Flag leaf area	0.75	0.71	9.33	9.57	10.08	10.28	92.52	93.05
Tillers plant ⁻¹	0.33	0.26	2.62	2.08	2.95	2.34	88.91	88.78
Spike length	0.12	0.19	0.33	0.36	0.45	0.55	73.33	65.45
Grains spike ⁻¹	1.78	0.90	42.22	25.63	44.00	26.53	95.95	96.59
1000-grain weight	0.68	1.11	3.38	1.88	4.06	2.99	83.25	62.87
Biological yield plant ⁻¹	1.72	1.08	35.27	22.61	36.99	23.69	95.35	95.43
Grain yield plant ⁻¹	2.08	2.06	8.31	8.32	10.39	10.38	80.07	80.15

Conclusion

The parent Chakwal 86 and Galaxy 2013 possessed highest general combining ability for number of tillers plant⁻¹, biological yield plant⁻¹ and grain yield plant⁻¹ under both environments. Crosses B 215 B 1103 × Galaxy 2013, GA 2002 × 2511 and ESWYT P 117 × Lasani 2008 were the ideal specific combiners for flag leaf area, tillers plant⁻¹, spike length, and biological yield plant⁻¹ under both environments. Similarly, High heritability (H^2) under normal and water stress environments was observed for plant height, flag leaf area, tillers plant⁻¹, grains spike⁻¹ and biological yield plant⁻¹.

Keeping in view the overall results of the study, it is recommended that parents Chakwal 86 and Galaxy 2013 having highest general combining ability for various traits under normal and water stress conditions. Similarly crosses B 215 B 1103 × Galaxy 2013, GA 2002 × 2511 and ESWYT P 117 × Lasani 2008 being best specific combiners under both conditions can be safely employed for future breeding programs to explore high yielding wheat genotypes under water stress conditions.

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