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GENETIC ANALYSIS OF PAKISTANI WHEAT GERMPLASM FOR YIELD CONTRIBUTING TRAITS UNDER NORMAL AND HEAT STRESSED CONDITIONS

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Climate change plays a key role in wheat production. The objective of this study was to identify and select efficient parents and cross combinations based on general and specific combining ability under different climatic conditions. Analysis of combining ability was carried out by Line × Tester mating design by crossing 10 lines and 5 testers resulting in 50 F_1 hybrids. All of these 65 genotypes sown in the Randomized Complete Block Design (RCBD) in three replications during cropping season of 2015-16 in both normal and heat stress conditions. Significant genetic variation was observed for yield and related characters. The general combining ability (GCA) estimates revealed that parents naming SW89.5277, V-12103 and V-13248 showed excellent general combining ability for almost all of the traits study under both conditions. It was also found that the crosses i.e. V-13241 × Millat-11 for plant height, V-13248 × Millat-11 for spikelets per spike, V-13013 × Millat-11 for grains per spike, Shahkar-2013 × Chenab-2000 for thousand grain weight and Faisalabad-08 × V-12082 for grain yield per plant, exhibited good specific combining ability estimates under both conditions. The parents and crosses that exhibited excellent results in terms of GCA and SCA estimates may be exploited in improving the yield of crop and yield related characters against normal and heat stress conditions.
Keywords: General combining ability (GCA), Specific combining ability (SCA), spring wheat, Heat stress tolerance.

INTRODUCTION

Wheat is one of the most important cereal crops that is grown on large scale across the globe due to its widespread acceptability, consumption and its nutritious as well as economic importance (Rasaei *et al*., 2017). All around the world, it is grown on an area of 222.24 million hectares with production of 737.83 million metric tons (USDA, 2017). In Pakistan, wheat contributes 1.7% in Gross Domestic Product and 8.7% in value addition. Wheat is sown on area of 8825 thousand hectares with yield of 24.946 million tonnes (Govt. of Pakistan 2019-20).
Among different abiotic stresses, heat stress is the main constraint that damages the productivity of wheat (Shaukat *et al.*, 2018). Major threat to wheat productivity is increasing temperature and changing climate (Wang *et al*., 2015). In wheat growing areas, approximately 40% of wheat (36 million hectares) lies in temperate environment facing terminal heat stress (Reynolds *et al*., 2011). High temperature defects wheat production, as increase of each 1°C in ambient temperature can cause 4% reduction in grain weight (Acevedo *et al*., 1991). Due to heat stress, the synthesis of reactive oxygen species (ROS) occurs, that results lipid oxidation of cell membrane (Hasanuzzaman *et al*., 2013). For defense mechanism against heat stress, plants produce different compatible solutes and antioxidants to attain its proper growth in heat stressed condition (Kamal *et al*., 2017). Furthermore, Ozkan *et al*. (1998) reported different yield related traits as most efficient indicator for estimation of heat stress tolerance. Climatic change plays a crucial role in changing the pattern of crop production worldwide. Before developing material with respect to heat tolerance and any other stress plant

breeders must have complete understanding of inheritance and genetic pattern of yield related traits in adverse environmental conditions for the growth of more plant produce (Yield) varieties with new and diverse range of genetic material. For the improvement of genotypes to heat, tolerance deserve utmost priority to mitigate the production losses due to rise in temperature. According to Shpiler and Blum (1991) lowering in number of spikelets/spike along with reduction in number of kernels/spike in wheat crop under heat stress, ultimately causes reduction in grain yield/plant. Both GCA & SCA are involved in determining genetics of grain yield and its components (Singh *et al*., 2000; Muralia and Sastry, 2001). The investigations are required to find out the impact of heat stress conditions on GCA and SCA in wheat germplasm.

The main aim of this study was to investigate genetic behavior of yield and related trait in wheat genotypes under heat stress condition and identification of best parents that can be manifested in breeding programmes and further studies of cross combinations in the development of heat tolerant cultivars.

MATERIALS AND METHODS

Experimental material for current research included 15 parents and 50 crosses. Fifty crosses were generated by crossing between 10 lines viz., V-13248, MISR 1, SW89.5277, Shahkar-2013, Miraj-08, AARI-11, Faislabad-08, V-13013, V-13241 and V-12103 with 5 testers viz., V-12056, Millat-11, Chenab-2000, ND643 and V-12082. Germplasm was collected and sown in cropping season of 2015-16, Fifty F_1 hybrids with their 15 parental genotypes were sown in the RCBD with three replications at Wheat Research Institute (WRI), Ayub Agricultural Research Institute (AARI) Faisalabad under normal, and heat stressed conditions. Wheat was exposed stress when it reached its anthesis stage by wrapper the tunnel with the plastic sheet. Temperature (both inner and outer side of the tunnel) was recorded on daily basis and 5-7°C higher temperature was noticed inside the tunnel as compared to ambient temperature. Normal agronomic and cultural practices were carried out throughout the duration of experiment. At maturity, data was recorded for different traits like, plant height (cm), spikelets per spike, grains per spike, thousand-grain weight (g) and grain yield per plant (g).

The data collected for different yield and its components were analyzed to analysis of variance (ANOVA) to find out the different significance levels for all the genotypes under both environmental conditions as described by Steel *et al*. (1997). Data for further analysis were subjected to Line × Tester analysis as described by Kempthorne (1957).

RESULTS

High temperature stressed condition is one of the main concern for productivity and crop improvement. Identification of the better parents with required morphological and physiological performance is necessary in the segregating generation. Genetic differences among genotypes are useful for conduction a successful breeding program. Highly significant differences were observed for all the genotypes as shown in Table 1. The main concern for breeding material focuses on yield of the genotypes. The yield potential was analyzed by analysis of variance of yield related traits. The values of GCA for plant height were shown in Table 2. The parent SW89.5277 showed negative significant values (-5.70 and -6.63) for general combining behavior under both normal and heat stress conditions respectively. For plant height, five parents showed negative and significant effects of general combining ability under both environments. For specific combining ability, highest negative significant effects were observed in cross combination V-13241 × Millat-11 (-13.36 and -13.65) as shown in Table 3, under normal and heat stressed conditions.

Table 1. Analysis of variance for yield and related traits in *Triticum aestivum* L. involving 10×5 L × T mating design under both normal and heat stressed conditions.

SOV	DF	Plant height		Spikelets /spike		Grains /spike		1000 grain weight		Grain yield /plant	
		Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress
Rep.	2	31.49**	46.50**	0.18	19.77	301.48**	7.40	29.14**	48.53**	94.46**	43.33**
Gen.	64	140.70**	128.45**	48.66**	18.12**	68.77**	56.27**	60.75**	103.81**	31.75**	14.72**
Parents	14	49.13**	53.02**	5.56	11.46	88.23**	15.08**	89.17**	82.65**	38.48**	19.98**
Crosses	49	137.11**	140.20**	17.36**	17.68	64.23**	31.10**	51.44**	103.47**	30.35**	13.49**
P. vs Cross	1	1598.30**	609.89*	2185.9**	132.97**	18.50*	1866.0**	118.89**	417.16**	6.10	1.31
Lines	9	163.01**	184.79**	20.10**	25.12**	100.94**	52.20**	97.07**	229.43**	16.01**	13.48**
Testers	4	124.17**	97.14**	26.62	12.04	62.62**	24.04**	28.04**	81.65**	10.1**1	7.29**
L × T	36	132.07**	133.84**	15.64**	16.45**	55.23**	26.61**	42.63**	74.40**	36.19**	14.19**
Error	128	1.68	2.301	7.24	6.38	2.87	5.68	5.56	8.08	1.94	2.51

Table 2. Estimates of General Combining Ability (GCA) effects of 15 parents for yield and related traits under both normal and heat stressed conditions.

Parents	Plant height		Spikelets /spike		Grains /spike		1000 grain weight		Grain yield /plant	
	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress
V-13248	-0.48	-1.94**	-0.48	0.44	4.69**	2.95**	1.17	-1.43	0.98*	0.48
MISR 1	-1.70**	-3.71**	0.05	-0.49	2.09**	0.55	-0.84	-3.48**	-0.82*	0.16
SW89.5277	-5.70**	-6.63**	1.79**	-1.69*	-4.31**	-1.12	-1.04	2.76**	1.38**	1.31**
Shahkar-13	-1.10**	0.45	-1.15	-1.16	1.22**	-0.79	-3.03**	0.44	0.38	-1.80**
Miraj-08	-0.20	-0.26	-1.68**	-0.36	-0.31	-0.92	0.22	7.86**	0.78	0.30
AARI-11	-3.00**	-0.06	0.72	0.17	-0.71**	-2.45**	-1.10	0.36	-0.75	-0.86*
Faisalabad-08	0.77*	1.58**	-0.61	1.11	1.89**	0.81	-2.17**	-5.36**	-1.42**	-0.24
V-13013	4.26**	4.07**	-0.61	-1.56*	-1.11**	0.61	2.13**	-0.52	0.85*	1.30**
V-13241	2.14**	1.13**	0.19	2.17**	-0.51	-2.32**	-1.17	-3.81**	0.05	-0.12
V-12103	5.22**	5.36**	1.79**	1.37*	-2.91**	2.68**	5.83**	3.19**	-1.42**	-0.55
V-12056	-0.17	-0.32	0.45	-0.49	-0.41	-0.75	-0.84	-2.44**	0.68*	-0.45
Millat-11	0.03	-1.18**	0.99	-0.16	-1.31**	-0.92*	-0.97*	-0.68	-0.52	-0.48
Chenab-2000	-3.20**	-2.14**	-1.28**	-0.29	1.29**	1.05*	1.24**	1.11*	0.58*	0.70*
ND643	1.90**	2.17**	-0.68	-0.16	-1.31**	-0.19	-0.15	1.79**	-0.42	-0.01
V-12082	1.51**	1.47**	0.52	1.11*	1.75**	0.81	0.73	0.21	-0.32	0.24

Highly positive combining ability estimates are required for spikelets/spike that depicted highest positive significant general combining ability (Table 2) in V-12103 (1.79 and 1.37) under both climatic conditions. This indicated presence of genes for heat tolerance in V-12082. The values of SCA are shown in Table 3. Under normal condition, highest specific combining ability values were observed in cross combination V-13248 × V-12082 (3.48) followed by MISR 1 × ND643 (3.48), whereas for heat stressed conditions, V-13248 × Millat-11 (3.63) and V-13241 × V-12056 (3.56) showed highest SCA effects.

Only two parents (V-13248 and Chenab-2000) showed positive significant GCA effects (Table 2) for grains per spike under both environments. The highest positive significant GCA effect was observed in V-13248 (4.69 and 2.95) under normal and stress condition respectively. For specific combining ability cross combination, V-13013 × Millat-11 (9.11 and 4.12) represented relatively higher significant values for SCA under both normal and heat stress condition.

T V-12103 (5.83 and 3.19) showed maximum positive general combining ability (Table 2) under both environmental conditions. Only one parent i.e. Faisalabad-08 showed negative significant effect under normal and heat stress environment. Under both climatic conditions, highest significant specific combining ability was observed in Shahkar-2013 × Chenab-2000 (4.36 and 8.43) as revealed in Table 3.

For grain yield per plant, maximum effect of significant positive general combining ability was recorded for SW89.5277 (1.38 and 1.31) under different environment (Table 2). Genotype SW89.5277 have similar results in both normal and heat stressed environments and showed its ability to cope with heat stress. Under both normal and stress condition, highest significant positive specific combining ability effects were revealed in Faisalabad-08 × V-12082 (2.92 and 2.36), hence it is proved to be good specific combiner for grain yield per plant (Table 3).

DISCUSSION

In case of wheat, yield and yield related characters play a key role (Anwar *et al*., 2011). Heat stress causes significant reduction of plant height by rapid phase change, ultimately resulting in shortening of vegetative period and inducing early maturity (VollenWeider and Gunthardt-Goerg, 2005).

Medium to Short plant height is ideal, so it will be more responsive for fertilizer and lodging resistant. For obtaining this objective, negative GCA effects are desired. For plant height negative significant combining ability effects were recorded in this study are in accordance with previous findings (Shaukat *et al*., 2018; Noorka and Saba, 2015).

Spikelets per spike played an importance role in wheat yield improvement. It could be due to the fact that spikelets bear the grain and more spikelets produce more grain yield which ultimately giving more yield of wheat. Present study focused on positive significant general and specific combining ability effects. Results for spikelets/spike were in accordance literature (Malik *et al*., 2005; Saeed *et al*., 2001; Tosun *et al*., 1995).

Increase of grains per spike resulted in more grain yield which is ultimate breeding objective of any crop breeding. In the present research, our findings revealed that heat stress deteriorates the development of wheat spike and grain yield. The results of this study were also similar to the findings of Saini and Aspinall (1982). They also noted the decrease in number of spikelet, eventually reduction grain yield per spike under heat stress. On the other, hand heat stress induced development of spikes in wheat rapidly, as reported by Porter and Gawith (1999). Their results contradict with this study. Farooq *et al*. (2011) reported reduction in number of grains

Table 3. Estimates of Specific Combining Ability (SCA) for different yield and related traits in *Triticum aestivum* L. under normal and heat stressed conditions.

Crosses	Plant height		Spikelets /spike		Grains /spike		1000 grain weight		Grain yield /plant	
	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress	Normal	Heat Stress
V-13248×V-12056	7.76**	7.01**	1.55	-0.04	0.41	0.95	-3.22**	-1.46	-6.48**	-3.67**
V-13248×Millat-11	10.89**	-0.36	-0.99	3.63**	3.31**	0.79	4.34**	4.00**	0.72	1.32
V-13248×Chenab-2000	-6.50**	0.30	-0.72	-2.24	1.71	1.82	0.84	0.93	1.62	1.45
V-13248×ND643	-4.96**	-2.28**	-3.32**	-1.71	-2.69**	-2.61**	-1.81	-3.80**	4.62**	0.25
V-13248×V-12082	-7.19**	-4.67**	3.48**	0.36	-2.75**	-0.95	-0.15	0.33	-0.48	0.64
MISR1×V-12056	0.88	2.88**	-2.99	-1.11	-4.99**	-1.65	4.48**	6.07**	1.32	2.66**
MISR1×Millat-11	5.83**	0.74	0.48	1.23	-2.09**	-2.48	-2.39	-2.69	-0.48	-0.32
MISR1×Chenab-2000	-0.08**	1.15	0.08	-0.64	-1.69	-1.11	-1.64	-1.52	1.42	0.48
MISR1×ND643	-8.08	-10.53**	3.48**	2.56	5.91**	2.79**	-3.78**	-5.73**	0.42	0.21
MISR1×V-12082	1.45**	5.76**	-1.05	-2.04	2.85**	2.45	3.34**	3.86**	-2.68**	-3.03**
SW89.52277×V-12056	4.27**	-3.15**	-0.72	0.09	5.41**	-0.98	-4.88**	-9.74**	-1.88**	0.50
SW89.52277×Millat-11	-6.14**	-3.59**	0.75	0.43	-0.69	5.52**	0.28	5.50**	-1.68	-0.47
SW89.52277×Chenab-2000	3.91**	4.58**	0.35	-0.77	-0.29	-2.11	1.60	0.72	-0.78	0.36
SW89.52277×ND643	-2.30**	-0.55	0.41	0.43	-1.69	0.45	-1.54	4.77**	1.22	2.06**
SW89.52277×V-12082	0.25	2.71**	-0.79	-0.17	-2.75	-2.88**	4.54**	-1.26	3.12**	-2.45**
Shahkar-2013×V-12056	-8.35**	-8.58**	1.55	0.23	-0.12	-1.31	-2.89	-7.12**	6.12**	0.14
Shahkar-2013×Millat-11	-1.72**	-0.34	1.68	1.23	-2.22**	-1.81	-4.76**	-11.12**	0.32	3.64**
Shahkar-2013×Chenab-2000	-5.44**	3.23**	-2.05	-0.64	1.18	0.89	4.36**	8.43**	5.22**	0.56
Shahkar-2013×ND643	10.04**	1.72*	-0.65	-2.77	-1.22	-1.55	3.75**	5.85**	-4.78**	-1.83**
Shahkar-2013×V-12082	5.47**	3.97**	-0.52	1.96	2.38**	3.79**	-0.46	3.96**	-6.88**	-2.51**
Miraj-2008×V-12056	-2.34**	-3.5**	-3.25	1.43	-3.59**	-1.51	0.52	1.85	3.72**	0.28
Miraj-2008×Millat-11	6.36**	6.71**	1.55	-0.91	-0.69	-4.01**	0.98	0.49	-5.08**	-3.46**
Miraj-2008×Chenab-2000	2.33**	2.24**	2.48	1.89	2.71**	0.02	-2.23	-2.19	-1.18	0.36
Miraj-2008×ND643	-0.64	-0.07	2.55	0.43	0.31	5.92**	2.49	0.29	1.82**	1.00
Miraj-2008×V-12082	-5.71**	-5.37**	-3.32**	-2.84	1.25	-0.41	-1.77	-0.43	0.72	1.82
AARI-11×V-12056	-5.75**	-3.73**	2.35	-3.77**	-2.19**	-0.31	3.18**	0.66	4.59**	0.57
AARI-11×Millat-11	1.35	9.08**	-0.19	2.56	-3.29**	-2.48	1.04	2.9	0.45	1.7
AARI-11×Chenab-2000	12.61**	5.57**	1.41	2.03	3.11**	1.55	-3.96**	-4.68**	-4.65**	-3.48**
AARI-11×ND643	-2.99**	2.5**	-1.19	0.56	-2.29**	-2.55	-2.03	2.94	1.35	2.23**
AARI-11×V-12082	-5.23**	-13.43**	-2.39	-1.37	4.65**	3.79**	1.77	-1.82	-1.75	-1.02
Faisalabad-08×V-12056	8.14**	11.63**	0.35	1.29	3.21**	1.09	0.02	2.16	-4.08**	-2.95**
Faisalabad-08×Millat-11	-1.73**	0.84	1.81	-2.37	2.11**	4.25**	3.58**	4.86**	2.12**	2.08**
Faisalabad-08×Chenab-2000	-2.91**	-5.50**	-2.59	-0.91	1.51	1.29	3.82**	0.74	0.02	-0.10
Faisalabad-08×ND643	1.38	1.09	1.48	0.29	0.11	-3.48**	-4.44**	-5.84**	-0.98	-1.39
Faisalabad-08×V-12082	-4.89**	-8.05**	-1.05	1.69	-6.95**	-3.15**	-2.98**	-1.91	2.92**	2.36**
V-13013×V-12056	-6.60**	-6.79**	-2.99	1.96	5.21**	2.95**	5.30**	6.89	-2.35**	-0.49
V-13013×Millat-11	-4.10**	-3.05**	-1.52	-2.37	9.11**	4.12**	0.19	-0.10	2.19**	-0.78
V-13013×Chenab-2000	0.60	-0.10	2.08	-0.24	-6.49**	-3.51**	-3.13**	-3.00	-1.25	-0.63
V-13013×ND643	1.89**	0.59	0.81	2.29	-5.89**	0.39	3.26**	1.31	-0.25	0.07
V-13013×V-12082	8.21**	9.35**	1.61	-1.64	-1.95	-3.95**	-5.62**	-5.1**	1.65	1.83
V-13241×V-12056	5.09**	6.39**	2.88	3.56**	-2.39**	-2.45	-4.76**	-3.16	1.12	3.6**
V-13241×Millat-11	-13.36**	-13.65**	-2.32	-4.11**	-0.49	-2.61**	-0.63	-0.92	4.32**	-1.11
V-13241×Chenab-2000	0.92	-1.99**	1.28	2.03	2.91**	2.42	2.16	2.29	-1.45	-0.22
V-13241×ND643	5.92**	6.60**	-2.65	-4.11**	-2.49**	0.99	6.55**	4.61**	-4.45**	-3.51**
V-13241×V-12082	1.42**	2.66**	0.81	2.63	2.45**	1.65	-3.33**	-2.81	0.45	1.24
V-12103×V-12056	-3.10**	-2.16**	1.28	-3.64	-0.99	3.22**	2.24	3.84**	-2.08**	-0.64
V-12103×Millat-11	2.60**	3.63**	-1.25	0.69	-5.09**	-1.28	-2.63	-2.92	-2.88**	-2.61**
V-12103×Chenab-2000	-5.43**	-9.48**	-2.32	-0.51	-4.69**	-1.25	-1.84	-1.71	1.02	1.22
V-12103×ND643	-0.29	0.94	-0.92	2.03	9.91**	-0.35	-2.45	-4.39**	1.02	0.92
V-12103×V-12082	6.21**	7.07**	3.21	1.43	0.85	-0.35	4.67**	5.19**	2.92**	1.11

per spike due to heat stress on different reproductive stages in wheat that support present study. Positive significant general combining ability was also reported by Singh *et al*. (2003); Hassan *et al*. (2007), which supported the fact that heat stress at grain filling causes sever yield losses.

Thousand-grain weight reduction was noticed in this investigation so genotypes with high positive significant GCA and SCA were selected to improve this trait. Heat stress in wheat resulted in shortening of the duration of grain filling, grain weight and grain yield per plant. The results are in line with the findings of Gooding *et al*. (2002). Furthermore, our results depicted positive significant specific combining ability effects for grain weight. Such type of findings was also previously reported by Iqbal (2007). Rise in the temperature for every 1°C above 15–20°C causes reduction in wheat grain weight (~1.5 mg/day) (Streck, 2005). Heat tolerance of a genotype can be assessed if its grain weight under heat stress during grain filling maintains its integrity (Tyagi *et al*., 2003; Singha *et al*., 2006). Likewise, Wardlaw (2002) found reductions in grain weight due to high temperature during both anthesis and milky growth stages under field conditions. Grain yield per plant decreased under heat stress at both reproductive growth stages. Results of this study showed similar positive significant GCA that have impact to improve yield and our results are in agreement with earlier findings of Jatav *et al*. (2014); Koumber *et al*. (2006) who reported that general combining ability effects changes in various traits. They also highlighted that high GCA value for grain yield in parents should be used in future breeding programs to improve wheat yield. Results of highly significant Specific combining ability obtained in this experiment are in agreement with Saeed *et al*. (2001); Awan *et al*. (2005); Hassan *et al*. (2007); Iqbal (2007); Singh *et al*. (2007); Akbar *et al*. (2009). Furthermore, Wahid *et al*. (2007) reported grain yield reduction was due to heat stress during grain filling period, which affects growth and developmental processes in wheat and resulted in lower yield.

***Conclusions*:** Heat stress has significantly reduced growth and yield traits in wheat genotypes. Overall, significant genetic variations were observed for yield and yield related traits investigated in this study. The roles of significant general combining ability (GCA) and specific combining ability (SCA) were observed for all investigated characters i.e. Plant height, Spikelets per spike, Grains per spike, Thousand grain weight and Grain yield per plant. From genetically diverse parents SW89.5277, V-12103 and V-13248 depicted excellent performance for all traits under both normal and heat stressed condition. Different crosses like; V-13241 × Millat-11 for plant height, V-13248 × Millat-11 for spikelets per spike, V-13013 × Millat-11 for grains per spike, Shahkar-2013 × Chenab-2000 for thousand grain weight and Faisalabad-08 × V-12082 for grain yield per plant resulted outclass specific combining ability estimates under both normal and heat stressed conditions. These results also indicated the presence of stability in these wheat genotypes for heat tolerance in both environments.

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