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GENETIC ANALYSIS OF AGRONOMIC TRAITS OF WHEAT UNDER TERMINAL DROUGHT STRESS

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ABSTRACT

Seven wheat genotypes (Sirvan, Zarin, Pishgam, Karim, Baran, Heidary, and Rizhav) were crossed in diallel mating to develop 42 F₁'s hybrids. The resultant hybrids along with parents were evaluated during cropping season 2015-16 at agriculture and natural resources Pardis of Tehran University, Iran, using RCB design with 3 replications under drought stress and normal field conditions from the booting stage till physiological maturity. General combining ability (GCA) and specific combining ability (SCA) for agronomic traits were determined. The main objective of the research was the identification and proper selection of best-performing wheat parental genotypes and best F₁'s hybrids, based on GCA and SCA estimates. Significant differences were observed among the wheat genotypes for all the reported traits in this article. Results for combining ability analysis indicated that mean squares of GCA and SCA effects were significantly high for most of the traits. The estimates of σ^2_{gca} and σ^2_{sca} and its ratio ($\sigma^2_{gca}/\sigma^2_{sca}$) indicated that non-additive genetic expression was dominant for most of the traits studied, then the heterosis breeding is a useful program, however selection on superior hybrids should be postponed to the next generation for these traits in recombination program. It is concluded that Zarin, and Baran are recommended as the best general combiners for a future wheat breeding program. The maximum values of SCA observed in flag leaf length in normal and peduncle length in drought condition related to crosses of Rizhav with other parents. So, it is suggested these series of crosses can be down to improve these traits at the mentioned condition.

Keywords: GCA, SCA, Wheat genotypes, Drought stress, Diallel.

INTRODUCTION

Drought is one of the most devastating environmental stresses which limiting the productivity of agricultural crops (Zhu *et al.*, 2010; Mollasadeghi *et al.*, 2011). Reduction of crop yield under water deficit conditions is the primary concern of plant breeders (Nazari *et al.*, 2010). The reaction of plants to drought stress depends on several factors such as developmental stage, severity and duration of importance, and genotype (Passioura, 2007). Among the crops, common wheat (*Triticum aestivum* L.) is the main food of most people in the world (Kawaura *et al.*, 2008). According to USDA reports (2018), the total area under wheat cultivation in the worldwide is estimated at 46.0 million acres in the 2017-18. In wheat, germination, tillering and reproductive stages are considered as most sensitive traits to drought stress (Passioura, 2007). Katerji *et al.* (2009) reported

that imposition of drought stress during ear formation and flowering stages of wheat reduced 37% and 18% in grain yield and straw yield.

Drought tolerance is one of the leading components of yield stability (Nazari *et al.*, 2010). One effort to improve wheat tolerance to drought stress is through a breeding program. Before setting the breeding and selection methods breeders need to correct the character of genetic information. One way to obtain genetic information is Diallel cross analysis. Diallel analysis can be done using different methods such as Griffing (1956). In this method, the general combining ability (GCA) and the specific combining ability (SCA) can be conducted by using the appropriate statistical model to the estimation of components of variance; then, these variances can be used to predict genetic components such as additive and dominant effects of a population based on special

assumptions.

This study was made to find appropriate parents for hybridization process of desirable plant traits under study as well as sorting of superior cross combinations for development of new cultivars with desirable attributes and future varietal development program.

MATERIALS AND METHODS

Genetic Material and Field Procedure: The studies were carried out at the Agricultural Research Station of Agriculture and Natural Resources Pardis of Tehran University in Karaj, Mohamad Shahr (35.56°N and 50.58°E), Iran. The soil is classified as Loamy and characterized by pH 7.9 and EC 1.74 (ds.m⁻¹). Average of annual rainfall at the experiment site is 243 (mm. year⁻¹). Average of rainfall and temperature ranged from 77.4 mm and 19.4 °C in November 2015 to 3.7mm and 24.2 °C in June 2016 while those ranged from 3.7 mm and 13.1 °C in November 2016 to 53.9mm and 25.8 °C in June 2017, respectively, according to thirty years data of Alborz meteorological organization (Statistical data of Alborz meteorological center, 2018).

Seven genotypes (Baran, Haidari, Sirvan, Rijave, Karim, Zarinssss and Pishgam) between Thirty genotypes of wheat were chosen by agronomic and morphologic traits obtained from the previous cropping season (2015-16) and the other researcher's data about these genotypes under drought stress. Land preparation was done by ploughing and disking the soil at appropriate intervals and the sowing was done by hand. The selected genotypes were sown at three different dates to achieve proper synchronization of flowering between parents. A compound fertilizer in the form of NPK was applied before planting then four months later. Weeds control was carried out manually 4 times during the growing period by 2,4-D herbicide and Weeding. Cross-pollination was done using all possible combinations to give a total of 49 crosses. The set of forty-two F₁'s and their seven parents were grown alike last year cultivation in November 2016. Each trial had three replications, each of 2 rows 1 m in length and 0.2 m in width for each plot.

Experimental layout: The experiment was done using three replicates in a randomized complete block design (RCBD). The plant materials were grown under two moisture regimes of irrigation; the drought stress and well-watered (non-stress) experiments in reproductive stages. The amount of irrigation water given to each plot was estimated using the information of the evaporation pan and the data was obtained from a meteorological

station located in the site. The irrigation rotations were calculated at the drought stress and normal field conditions by the cumulative evaporation after the first irrigation in spring. Irrigation levels were exerted at 90 mm cumulative evaporation for normal field condition and at 120 mm cumulative evaporation for drought stress level. The moisture treatments were applied from the booting stage (Zadoks 45) till physiological maturity (Zadoks 92). In order to better control of water entry, the valve was installed at the entrance of all blocks.

Data collection and analysis: Observations were made on five random plants of the two middle rows in each plot, their average was used. Yield components and agronomic traits including plant height (PL), ripening date (RD), spike length (SL), awn length (AK), flag leaf length (FLL), peduncle length (PeL), number of spikelet per spike (NSpS), main spike weight (MSW), number of spikes per plant (NSP), total weight of spikes per plant (TWSP), biological yield (BY), stem diameter (SD), grain weight of main spike (GWMS), harvest index (HI), kernel weight (actual weight of 1000 grains at 14% moisture content) (KW), total leaf chlorophyll content (TLC), and yield of single plant (YSP) were evaluated.

The parents were selected based on performance, then data were analyzed using analysis of variance (ANOVA) with wheat genotypes for each irrigation rate (environments: Normal (E1) and drought stress (E2)). Data were subjected to analysis of variance using Statistical Analysis Software (SAS) Version 9.1 for Windows (SAS, 2000) by proc GLM. The significant genotypic variance of each trait was further partitioned to GCA, SCA and experimental error. Combining ability analysis and genetic component of measured traits was performed according to method 2, model I (fixed model) Griffing (1956) using Excel (2016) by programming. This method was calculated by following model:

$$X_{ij} = u + g_i + g_j + s_{ij} + \frac{1}{b} \sum_k e_{ijk}$$

Where, u = the population mean, g_i = the general combining ability effect of the ith parent, g_j = the general combining ability effect of the jth parent, s_{ij} = the specific combining ability effect of the cross between ith and jth parents such that s_{ij} = s_{ji} and e_{ijk} the environmental effect associated with ijkth observation. Comparing combining abilities of the used parents in the diallel crosses and identifying superior hybrid combinations is interested with this model.

RESULTS

ANOVA: Diallel crosses were carried out in form of the full diallel cross in the field, while traits studied analysed according to method II of Griffing, given that, there were no difference among F₁'s and reciprocals according to t-test analysis (alpha=0.01%) (Results of t-test has not been reported).

Means observed of parents for traits under study under

non-stress and drought stress conditions are presented in Table 1 (Top parents were shown with grey colour cells). Top parents mean or mean of two parents existed in crosses can be used for heterosis calculations for each F₁'s hybrid. The result of the analysis of variance for wheat traits under consideration under the drought stress and well-watered experiments is presented in Table 2.

Table 1. means observed of parents (P1: Sirvan, P2: Zarin, P3: Pishgam, P4: Karim, P5: Baran, P6: Heidary, and P7: Rizhav) for traits under consideration under non-stress and drought stress conditions. Top parents were shown with grey colour cells.

Traits		PL (cm)		SL (cm)		PeL (cm)		NSpS		MSW (g)	
		Env.	E1	E2	E1	E2	E1	E2	E1	E2	E1
Parents	p1	99.00	91.19	12.61	11.81	36.78	32.11	21.67	19.74	3.36	3.77
	p2	101.33	101.00	10.39	10.06	38.33	37.56	18.00	17.78	3.02	2.55
	p3	95.00	93.78	11.44	9.28	32.00	33.33	20.56	18.22	3.36	2.73
	p4	94.89	102.22	11.78	10.56	31.89	35.44	20.33	19.56	3.57	3.00
	p5	95.22	91.89	11.00	9.83	31.44	30.00	21.78	20.89	4.07	3.83
	p6	85.39	85.11	10.08	10.50	31.48	33.11	20.76	21.56	3.85	3.93
	p7	108.67	110.83	11.78	9.25	39.78	41.28	18.89	16.89	3.64	2.37
Traits		SD (cm)		GWMS (g)		FLL (cm)	NSP	TWSP (cm)	KW (g)	RD	
		Env.	E1	E2	E1	E2	E1	E1	E1	E1	E2
Parents	p1	4.49	4.38	1.97	2.75	25.22	14.67	40.13	3.83	218.33	
	p2	4.11	3.90	2.23	1.87	25.11	14.22	31.52	3.79	217.67	
	p3	4.44	3.82	2.27	1.91	23.78	12.44	29.21	4.07	220.33	
	p4	4.46	3.77	2.07	2.12	24.33	15.78	41.16	3.72	222.67	
	p5	4.64	4.46	2.88	2.75	23.22	18.22	44.81	3.45	220.67	
	p6	4.53	4.44	2.34	2.43	22.81	14.50	40.99	3.89	218.00	
	p7	4.52	3.60	2.65	1.64	29.89	11.67	25.86	4.28	219.00	

PH: Plant height; SL: Spike length; PeL: Peduncle length; NSpS: Number of spikelets per spike; MSW: Main spike weight; SD: Stem diameter; GWMS: Grain weight of main spike; FLL: Fag leaf length; NSP: Number of spikes per plant; TWSP: Total weight of spikes per plant; KW: Kernel weight; RD: ripening date; Env.: Environments; E1: Normal field environment; E2: Drought stress environment;

The effects of genotypes were highly significant for PH, SL, PeL, NSpS, MSW, SD, and GWMS traits in E1 and E2, RD in E2, FLL, NSP, TWSP, and KW in E1, indicated enough genetic variation in selected wheat genotypes while this effect was nonsignificant for other traits studied (Data has not been reported). According to results, variation among selected parents was observed for most of the traits; except FLL, NSP, KW and TWSP in E1 and RD in E2 that indicate these traits are varying in the mentioned environment.

Genetic components: Analysis of variances of genetic components for wheat traits under study under the drought stress and well-watered experiments is presented in Table 3. The effect of GCA was significant for PH, SL, PeL, NSpS, and GWMS traits in E1 and E2, FLL, NSP, and TWSP in E1 and RD in E2, while this effect was nonsignificant for MSW, SD in E1 and E2 and KW in E1. The effect of SCA was significant for all traits studied in E1 and E2. The genetic component of variances is assessed through the estimates of GCA and SCA variances (Table 3).

Table 2. Analysis of variance of wheat traits under non-stress and drought stress conditions (method II Griffing).

Sources of variation		MS _{Block}	MS _{Genotypes}	MS _{Error}	Coefficient of variation (%)
Traits	Df Env.	5	27	m*	-
PL	E1	366.125	342.003 **	79.6194	9.9345
	E2	95.00965	447.01 **	78.1194	10.9429
SL	E1	1.156543	1.94328 **	0.48313	6.08062
	E2	0.370795	1.84095 **	0.78021	8.25747
PeL	E1	28.85693	58.4585 **	10.1723	9.41499
	E2	13.50762	70.4375 **	10.265	10.1468
NSpS	E1	1.986081	7.50883 **	2.07021	7.24551
	E2	1.4178	6.92919 *	4.03253	10.7301
MSW	E1	2.237974	2.55802 **	1.30365	25.9646
	E2	0.570165	1.72436 **	0.63456	19.0956
SD	E1	0.005948	0.31927 **	0.09998	6.78316
	E2	0.096947	0.43586 **	0.14332	8.48497
GWMS	E1	88.53825	123.363 **	50.1862	66.0943
	E2	11.16178	84.4665 **	12.9984	29.5618
FLL		15.65709	11.6203 **	5.89598	10.1696
NSP	E1	66.67766	16.9574 *	9.10608	20.1715
TWSP		937.0474	176.771 *	98.7398	23.0026
KW		0.149892	0.44284 **	0.1485	9.12163
RD	E2	3.092939	20.7167 **	7.80766	1.25603

MS: Mean of the square; Df.: Degree of freedom; m*: Df_e= 96 (for all traits in Stress level and RD in E1), Df_e= 94 (for SD trait in E1), and Df_e=95 (for others).

*: F-test significant at 0.05% probability level.

**: F-test significant at 0.01% probability level.

ns: Non-significant at 0.05%.

Note: For other abbreviations see Table 1.

The σ_A^2 is additive variance and σ_D^2 is dominance variance. According to results, the genetic component's magnitudes showed that the components of dominance variances were higher compared to additive components of variances for all characters. All characters showed less than unity values for GCA/SCA ratio. The highest ratio was observed in TWSP in E1 (0.128), while the lowest GCA/SCA ratio (0.004) was obtained from SD in E1.

General combining ability effects: It is primarily a function of additive genetic variance; it helps in the selection of suitable good general combining parents for hybridization. Data on GCA effects of wheat parent

characters under tested environments are presented in Table 3. GCA effects was significant for most of the traits studied (except grey cells). It was noticed that among parents, no parent was proved as good general combiner simultaneously for all traits and selected parents were not same in different conditions except P3 and P6 for NSpS either, P2 and P3 for GWMS. Genotypes with high and positive GCA have a major influence on the increase of trait. The significantly negative estimate of GCA indicated that these genotypes possess additive genes that reduce the trait. The genotypes shown by "a" have got higher and positive GCA for every trait under normal and drought stress conditions.

Table 3. Combination analysis of variance and Genetic components of wheat traits under non-stress and drought stress conditions (method II, model 1 Griffing).

Sources of variation	Df Env.	MS σ_{GCA}^2	MS σ_{SCA}^2	MS Error	$\frac{\sigma_{gca}^2}{\sigma_{sca}^2}$	σ_A^2	σ_g^2	σ_D^2
		6	21	m*				
PH	E1	159.035***	90.105***	0.14	0.115	35.310	17.655	89.965
	E2	94.55***	137.55***	0.136	0.114	20.982	10.491	137.418
SL	E1	0.54*	135.7***	0.000848	0.009	0.122	0.061	135.742
	E2	0.86***	0.55***	0.001355	0.011	0.190	0.095	0.554
PeL	E1	28.7***	11.53***	0.02	0.041	6.377	3.188	11.510
	E2	22.9***	14.57***	0.018	0.041	5.105	2.552	14.558
NSpS	E1	1.98***	1.64***	0.0036	0.019	0.440	0.220	1.636
	E2	2.38***	1.79***	0.007	0.026	0.528	0.264	1.791
MSW	E1	0.22 ns	0.34***	0.002	0.015	0.049	0.025	0.334
	E2	0.34 ns	0.58***	0.001	0.010	0.076	0.038	0.578
SD	E1	0.055 ns	0.09*	0.0002	0.004	0.012	0.006	0.100
	E2	0.038 ns	0.15***	0.0002	0.005	0.009	0.004	0.146
GWMS	E1	2.37***	38.64***	0.09	0.092	0.507	0.254	38.558
	E2	3.74***	37.46***	0.023	0.046	0.828	0.414	37.435
FLL		3.25***	3.27***	0.01	0.031	0.720	0.360	3.263
NSP	E1	6.33***	2.96***	0.016	0.039	1.403	0.702	2.948
TWSP		9.94***	50.36***	0.17	0.128	2.171	1.085	50.192
KW		0.12 ns	0.128*	0.0003	0.005	0.026	0.013	0.128
RD	E2	1.97***	6.23***	0.014	0.036	0.434	0.217	6.217

MS σ_{GCA}^2 : Mean of the square of general combining ability; MS σ_{SCA}^2 : Mean of the square of specific combining ability; σ_A^2 : Additive variance; σ_g^2 : Genotypic variance; σ_D^2 : Dominant variance

***: F-test significant at 0.001% probability level.

Note: For other abbreviations see Table 1 and 2.

Specific combining ability effects: Sprague and Tatum (1942) indicated that estimates of GCA and SCA may be interpreted in terms of genes and gene action. GCA is an indication of genes with primarily additive effects while SCA is an indication of genes with dominance or epistatic effects. Therefore, Estimates of GCA and SCA can provide valuable information about the parents used. The estimation of SCA given in Table 5 revealed that F₁'s hybrids had significant SCA effect for all traits thereby, indicating good specific combinations for traits with SCA positive. Altogether, the maximum values of SCA observed in FLL in E1 and PeL in E2 related to cross P7 with other parents.

DISCUSSION

The ratio of $\sigma_{gca}^2 / \sigma_{sca}^2$ often used by plant breeders as an indication of the primary type of gene effects for the trait of interest. A large $\sigma_{gca}^2 / \sigma_{sca}^2$ ratio implies primarily additive gene effects, whereas a low ratio implies dominant and/or epistatic gene effects are important (Griffing, 1956a; Bhullar *et al.*, 1979). All of the

traits under consideration were controlled by non-additive components. In such cases, hybrids would be ideal, however, the selection on superior hybrid should be postponed to the next generation for these traits in recombination breeding. Muhammad (2009) reported the non-additive genetic effects for yield traits and stated that magnitude and direction of combining ability effects provide a guideline about efficient utilization of wheat parents in hybridization programs.

In wheat, significant differences were found for relative water content (RWC), leaf water potential (LWP), proline content (PC) and non-stressed yield (Y_p) in irrigated condition, while relative water loss (RWL), RWC and stressed yield (Y_s) exhibited significant differences in stress condition indicating the presence of genetic variation and consequently the possibility of genetic analysis and combining ability analysis revealed significant differences among the parents for RWC in the irrigated and CMS, PC and Y_s in the non-irrigated conditions indicating the involvement of additive and non-additive gene action in their inheritance (Farshadfar and *et al.*, 2014).

Table 4. Estimation of general combining ability (gi) of 7 parents (P1: Sirvan, P2: Zarin, P3: Pishgam, P4: Karim, P5: Baran, P6: Heidary, and P7: Rizhav) for various traits in wheat under non-stress and drought stress conditions. All gi es are significant according to t-test (alpha=0.05%) except grey cells.

		Traits																			
		PH		SL		PeL		NSpS		MSW		SD		GWMS		FLL	NSP	TWSP	KW	RD	
		env.	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E1	E1	E1	E2
parents	p1	2.415 a	1.100	0.030	0.345 a	0.531	-0.739	-0.227	0.169	-0.315	0.038	-0.107	-0.029	-0.880	-0.099	0.030	1.055 a	0.502	0.030	-0.722	
	p2	2.038 a	3.207 a	0.837 a	0.287 a	0.687	1.478 a	-0.012	0.098	0.081	-0.006	-0.104	-0.037	0.346 a	0.716 a	0.837 a	-0.406	-0.774	-0.089	-0.389	
	p3	-0.599	-1.131	0.265	-0.436	-0.705	-0.209	0.720 a	0.250 a	0.180 a	0.200 a	0.079 a	0.080 a	0.749 a	0.475 a	0.265	-1.481	-1.878	0.073 a	-0.111	
	p4	-3.797	-0.765	-0.826	-0.042	-1.940	-1.069	0.133	-0.093	0.027	-0.094	0.056	-0.102	-0.266	-0.139	-0.826	-0.043	0.647	-0.029	0.722 a	
	p5	6.449 a	3.267 a	-0.470	0.266	2.653 a	1.924 a	-0.304	-0.186	0.074 a	0.031	-0.016	-0.001	0.141	0.154	-0.470	0.864 a	0.744 a	0.033	0.185	
	p6	-6.294	-6.222	-0.407	-0.115	-2.393	-2.529	0.390 a	0.723 a	0.017	0.201 a	0.029	0.083 a	-0.169	0.186	-0.407	-0.013	1.083 a	-0.186	0.259 a	
	p7	-0.212	0.544	0.571 a	-0.305	1.167 a	1.145	-0.699	-0.960	-0.066	-0.369	0.063 a	0.005	0.079	-1.293	0.571 a	0.025	-0.325	0.168 a	0.056	

" a " are the highest positive values of GCA.

Note: For other abbreviations see Table 1 and 2.

Table5. Estimation of specific combining ability effects (Sij) of 21 F1's hybrids for various traits in wheat under non-stress and drought stress conditions. All Sij s are significant according to t-test (alpha=0.05%) and the highest positive values of GCA for each trait in each Environment was shown with grey cells.

		Traits																		
		PH		SL		PeL		NSpS		MSW		SD		GWMS		FLL	NSP	TWSP	KW	RD
Env.	F1's hybrids	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E1	E1	E1	E2
P1 x P2	11.475	6.415	1.893	-17.749	1.357	1.055	0.370	0.870	0.470	0.073	-0.493	-0.080	-0.711	3.389	-24.670	-0.950	-1.684	0.265	-0.306	
P1 x P3	12.229	2.200	0.279	-6.202	1.044	-3.378	-0.059	1.011	-0.322	0.161	-0.499	-0.064	-3.164	1.758	0.867	1.971	0.868	0.501	-0.972	
P1 x P4	8.203	-0.125	-0.48	-17.199	6.088	5.013	-2.991	-1.552	-0.422	0.436	0.031	0.144	0.245	3.858	-26.352	4.074	3.751	0.013	-0.361	
P1 x P5	-12.29	-8.189	-1.19	-18.206	-3.099	-0.974	-2.118	-1.366	-0.516	0.186	0.175	-0.058	-0.570	3.271	-27.892	2.259	3.556	-0.110	0.713	
P1 x P6	4.358	-0.700	-0.24	201.883	-0.157	0.388	-0.920	-2.691	-0.008	-0.245	-0.057	-0.412	0.133	2.026	1004.527	1.228	-0.334	0.119	2.398	
P1 x P7	-11.09	-8.217	-3.54	1408.346	-3.441	-3.402	-0.266	1.555	-0.043	0.874	0.267	0.297	12.821	4.375	7161.940	1.585	1.049	-0.071	1.306	
P2 x P3	-10.54	-14.82	0.135	-7.018	-2.598	-3.687	2.216	0.245	1.046	1.032	0.874	0.479	9.289	2.813	0.722	-2.385	1.621	-0.042	2.694	
P2 x P4	17.595	13.294	2.194	-14.982	8.782	10.816	-0.999	0.526	0.389	1.025	-0.370	0.304	6.371	5.177	-23.677	-1.960	-5.235	0.441	-1.194	
P2 x P5	-2.899	5.231	1.482	-15.990	-0.405	4.829	-0.127	0.712	0.295	0.775	-0.225	0.103	5.556	4.590	-25.217	-3.775	-5.430	0.318	-0.120	
P2 x P6	2.830	4.633	1.746	203.193	1.946	1.502	-0.464	-0.605	0.233	0.022	-0.019	-0.085	0.610	3.330	1006.515	-0.528	-1.276	-0.019	4.731	
P2 x P7	-4.654	-5.690	-0.55	1408.576	-3.893	-1.955	1.647	1.894	0.443	0.909	0.004	0.272	0.124	6.514	7164.934	1.571	8.266	-0.154	-1.194	
P3 x P4	15.158	0.130	1.685	-17.317	8.655	6.127	-1.149	-0.768	0.699	0.518	0.128	0.315	2.725	4.836	-24.185	-0.999	-0.771	0.444	0.639	

P3 x P5	-5.335	-7.933	0.973	-18.325	-0.532	0.140	-0.277	-0.583	0.605	0.268	0.272	0.113	1.910	4.250	-25.726	-2.814	-0.965	0.321	1.713
P3 x P6	4.872	1.191	1.905	201.522	2.488	1.519	1.386	-0.688	0.469	0.681	0.039	0.502	6.885	5.119	1006.674	-2.536	-1.291	0.246	-0.602
P3 x P7	-6.199	-7.001	-0.47	1408.318	-3.015	-1.847	1.847	2.611	0.689	1.288	0.210	0.549	1.973	2.561	7165.014	-0.062	10.872	0.039	0.806
P4 x P5	-0.115	0.647	0.915	-17.623	0.045	0.496	0.840	-0.388	0.276	-0.029	0.003	-0.081	5.860	3.255	-25.784	-1.375	2.565	0.551	0.546
P4 x P6	1.141	-7.367	0.071	202.099	0.127	-4.370	-0.984	-2.391	0.255	-0.416	0.255	-0.383	3.494	1.984	1004.840	-0.900	-5.549	0.191	2.065
P4 x P7	-16.88	-14.27	-4.91	1408.262	-6.970	-5.091	-0.241	-0.384	-0.161	0.304	-0.164	0.381	-3.538	1.502	7160.578	-0.418	-1.951	-0.436	2.472
P5 x P6	17.522	16.766	0.430	203.386	6.813	6.660	-1.373	-0.688	-0.392	-0.382	-0.234	-0.130	1.063	1.586	1005.199	-0.161	-5.692	0.256	-1.935
P5 x P7	16.901	-8.506	-1.77	1408.307	8.391	-2.014	-0.519	-1.723	0.128	-0.029	-0.350	-0.240	-0.064	2.147	7163.717	0.055	-0.729	0.264	1.472
P6 x P7	-10.02	-12.44	-2.17	1408.122	-5.131	-7.236	1.520	2.602	0.227	1.100	-0.073	0.322	2.333	5.735	7163.311	3.655	15.430	-0.289	1.139

P1: Sirvan, P2: Zarin, P3: Pishgam, P4: Karim, P5: Baran, P6: Heidary, and P7: Rizhav.

Note: For others, abbreviations see Tables 1, 2 and 3.

As well as, Farshadfar and *et al.*, (2011) reported significant differences for grain yield, RWC, cell membrane stability, PC, and leaf chlorophyll content, and non-additive gene action in their inheritance according to combining ability analysis under drought stress in wheat. These results are general agreement with Muhammad (2009), Farshadfar and *et al.*, (2011), and Farshadfar and *et al.*, (2014).

Genotypes with high and positive GCA can be used in the development of high yielding genotypes through the pedigree selection and progeny selection or mass selection in later generations in generations in wheat. Present finding are in confirmation with Kandil *et al.*, (2016). Altogether, P2 and P5 registered best good general combiner for most of the traits under two environments while P4 registered poor general combiner.

In self-pollinated crops like wheat, SCA effects are not much important as they are mostly related to non-additive gene effects excluding those of arising from complementary gene action or linkage effects they

cannot be fixed in pure lines. Further superiority of the hybrids might not indicate their ability to yield transgressive segregates; rather SCA would provide satisfactory criteria (Jink and Jones, 1958). However, if a cross combination exhibiting high SCA as well as high performance having at least one parent as good general combiner for a specific trait, it is expected to throw desirable transgressive segregates in later generations (Singh Rajput and Kandalkar, 2018). The crosses with higher SCA indicated by grey cells in Table 5, for example, P2 x P4, P5 x P6 and P5 x P7 registered best good specific combiner for PH in E1 were the result of good x poor general combiner. There is a high probability that the offspring of these crosses will produce a higher plant in normal condition. In addition, four crosses (P4 x P7, P1 x P5, P6 x P7, and P2 x P3) had negative SCA effects, associated with low values of this trait in the progeny. In wheat, the exploitation of heterosis is still in its infancy. Ideally, in such situations, recurrent selection as proposed by Joshi, diallel selective mating as

proposed by Jensen or the use of multiple crosses and biparental mating might be effective alternate approaches (Jain and Sastry, 2012).

Finally, Drought tolerance is a multigenic trait that expresses at different levels of the organization and different stages of development. Selection for drought tolerance, therefore, must involve molecular biological, biochemical and physiological approaches (László *et al.*, 2002).

CONCLUSIONS

Results for combining ability analysis indicated that mean squares of GCA and SCA effects were significantly high for most of the traits. Diallel analysis demonstrated that non-additive effects played the major role in determining most of the characters studied. Therefore, both additive and non-additive gene actions were found to play an important role in controlling for drought resistance and other yield related characters with non-additive being more important. Thus, the heterosis breeding is a useful

program, however selection on superior hybrids should be postponed to the next generation for these traits in recombination program.

It is concluded that Zarin, and Baran are recommended as the best general combiners for a future wheat breeding program. The maximum values of SCA observed in flag leaf length in normal and peduncle length in drought condition related to crosses of Rizhav with other parents. So, it is suggested these series of crosses can be down to improve these traits at the mentioned condition.

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