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ASSESSMENT OF RELATIONSHIPS AND VARIABILITY OF MORPHO-PHYSIOLOGICAL CHARACTERS IN BREAD WHEAT (*TRITICUM AESTIVUM* L.) UNDER DROUGHT STRESS AND IRRIGATED CONDITIONS

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ABSTRACT
Thirty nine genotypes of bread wheat were evaluated under two conditions (drought stress and irrigated) to study the variability, correlation and path coefficient analysis based on sixteen morpho-physiological traits *viz*, days to fifty per cent flowering, days to maturity, spike length, plant height, chlorophyll content, flag leaf area, canopy temperature, relative water content (RWC), number of tillers per plant, number of grains per spike, grain yield per plant, 1000 grain weight, harvest index (HI), drought susceptibility index (DSI), germination percentage and seed vigour index (SVI). Analysis of variance revealed highly significant variation among the genotypes for all the characters under studied in both conditions. The variability study indicated high to moderate phenotypic and genotypic coefficient of variation accompanied by high heritability and genetic advance as per cent of mean for traits like number of tillers per plant, grain yield per plant, 1000 grain weight, flag leaf area, chlorophyll content and harvest index indicating their importance in selection for yield improvement under both conditions. Correlation studies indicated that number of tillers per plant, 1000 grain weight, harvest index, number of grains per spike, flag leaf area, chlorophyll content, relative water content and seed vigour index showed significant positive association with grain yield per plant as well as among themselves at phenotypic and genotypic level under both environments. However, grain yield per plant showed negative significant correlation with canopy temperature in both conditions. Further, path coefficient analysis revealed that under rainfed condition highest positive direct effect was exhibited by number of tillers per plant and flag leaf area, while under irrigated condition number of grains per spike, 1000 grain weight and number of tillers per plant had highest positive direct effect. Thus, these traits may be used as selection criteria for respective environments for further improvement. The highest negative direct effect was showed by canopy temperature on grain yield under both conditions (drought stress and irrigated).

INTRODUCTION

Drought is a world-wide problem seriously influencing global crop production and it will become progressively important due to the global climate change (Akbarian *et al*., 2011). Drought is the most common environmental stress affecting about 32% of 99 million hectares under wheat cultivation in developing countries and at least 60 million hectares under wheat cultivation in developed countries (Shamsi *et al*., 2011). Therefore, most of the countries of the world are facing the problem of drought. The insufficiency of water is the principal environmental stress that causes heavy damage of agricultural products in many parts of the world. Drought stress can reduce grain yield, therefore, it has been estimated that average yield loss of 17 to 70% in grain yield is due to drought stress (Ahmadizadeh *et al.,* 2011).

Morphological and agronomic traits of wheat have a special role in determining the importance of each trait in increasing yield, so these traits were used in breeding programs which at least led to improving yield and introducing commercial varieties that can withstand seasonal drought stress condition. The most important criteria in any crop improvement programme is the selection of genotypes with all possible desirable yield contributing traits. Variability in genotypes for grain yield and yield components traits forms the basic factor to be considered while making selection. Heritability and genetic advance are other important selection parameters. The estimates of heritability and genetic advance as per cent of mean help the plant breeder in determining the character for which selection would be rewarding.

The knowledge about the extent and nature of inter relationship among yield components provide a better understanding in improving yield through selection. Grain yield, being a complex character, is highly influenced by environment; therefore, direct selection for yield would not give better results. Indirect selection in such a situation is more effective. The path coefficient analysis facilitates the partitioning of the correlation coefficients into different components of direct and indirect effects. Thus, study on association among different character is very essential for developing effective selection criteria (Singh *et al.,* 2009). The present study was undertaken with objective to assess the selection criteria for identifying drought tolerance in bread wheat genotypes, so that suitable genotypes can be selected based on drought tolerant traits.

MATERIALS AND METHODS

The present investigation was carried out in the fields located at Wheat Breeding section, RAU, Pusa, Samastipur, Bihar during *rabi* 2011-2012. The experimental site is located at 25.98°N latitude and 85.67°E longitudes and has altitude of 52.0m above mean sea level. The experimental materials of the study comprised of 39 diverse bread wheat (*Triticum aestivum* L.) genotypes. 39 genotypes were grown under two environments viz., drought stress (rainfed) and irrigated (well watered). The experiment in each environment was laid out in Randomized Block Design (RBD) with three replications. In each replication each genotype was grown in a plot of 6 rows of 2 meter length each with a spacing of 22.5 cm between rows and 10 cm between plants (within rows) in both sets of experiment i.e. drought stress and irrigated conditions. Genotypes were sown in field when adequate moisture was available. After sowing of experiments, three irrigations were applied to the irrigated experiment at crown root initiation stage (CRI stage), late jointing stage and milking stage during the growing season. Whereas the drought stress experiment entirely depended on natural precipitation and no surface irrigation was applied. However, it received 58.7 mm of rainfall during December 2011 to April 2012, out of that about 49 mm rainfall was received during 20-25 days of sowing. Normal agronomic practices like fertilizer application and weed control were applied to both experiments. Five plants were selected randomly from each plot for recording observations on traits viz., days to fifty per cent flowering, days to maturity, plant height, spike length, flag leaf area, relative water content (RWC), chlorophyll content, canopy temperature**,** number of tillers per plant, number of grains per spike, 1000 grain weight, harvest index and grain yield per plant. Germination percentage and seed vigour index (SVI) were recorded in laboratory condition. Flag leaf length and width of five randomly selected plants were taken by measuring scale and flag leaf area was calculated by following formula (Muller, 1991)

Flag leaf area (cm^2) = flag leaf length (cm) x flag leaf width (cm) x correction factor

Where,

Correction factor = 0.74

Relative water content was calculated by the formula given by Barr and Weatherley (1962)**.**

$$RWC = \frac{F.W. - D.W.}{T.W. - D.W} X\ 100$$

Where, F.W. = Fresh weight of flag leaf

D.W. = Dry weight

T.W. = Turgid weight

Seed Vigour Index (SVI) was calculated from the following formula (Chatterjee and Nagarajan, 2006)

Seed Vigour Index = Germination % x Seedling dry weight

Drought Susceptibility Index (DSI) was determined by following formula (Fischer and Maurer, 1978). The formula is

$$DSI = \frac{1 - Yr/ Yi}{1 - Xr/ Xi}$$

Where,

Yr = Yield under drought stress condition

Yi = Yield under irrigated condition

Xr = Mean yield of all cultivars under drought stress condition

Xi = Mean yield of all cultivars under irrigated condition

The data were analyzed using WINDOSTAT version 8.6 software for computation of analysis of variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in broad sense (h^2_b), correlation coefficients and path coefficient analysis.

RESULTS AND DISCUSSION

Variability

In the present investigation, 39 diverse genotype of breed wheat were studied to assess their drought tolerance in terms of traits implicated in drought, yield and yield related traits. The analysis of variance or estimates of MSS (table- 1) clearly indicated that there was highly significant variation among the genotypes for all the traits studied under both the environments. This in turn indicated that there was sufficient variability present in the material studied under both irrigated and drought stress conditions, which could be utilized in further breeding programme. In other words further analysis of drought tolerance is meaningful as indicated by significant mean sum of squares under drought stress condition *i.e.,* rainfed condition. Interestingly, the magnitude of MSS of many traits were more under drought stress condition than irrigated, which indicated directly that the amount of variation for these traits was more desirable under stress condition. More variation under rainfed condition is expected as different genotypes respond differentially under drought (stress condition). Many earlier workers Ahmadizadeh *et al.* (2011), Farshadfar *et al.* (2011) and Lonbani and Arzani (2011) reported high variability for different traits in wheat.

The phenotypic variances for all the traits under studied were higher than the genotypic variances (El-Kareem and El-Saidy, 2011).This may be due to the non-genetic factor which played an important role in the manifestation of these characters. Wide ranges of variance (phenotypic & genotypic) were observed in the experimental material for all the characters under investigation in both environments (Table 2). The maximum phenotypic and genotypic variance exhibited by the traits plant height, harvest index (HI), 1000 grain weight, number of grains per spike and days to fifty per cent flowering under both environments. These findings were in accordance of Gupta *et al.* (2005), who also observed high variance for yield and yield component traits among wheat genotypes. Seed Vigour Index (SVI) also showed the high phenotypic and genotypic variance. The relative water content (RWC) and Chlorophyll content exhibited high genotypic and phenotypic variance in rainfed condition indicating importance of these characters in stress condition for further improvement. Similar

Table 1: Analysis of variance for different quantitative characters in bread wheat under both conditions

No.	Characters	Mean sum of squares					
		Replication		Treatments		Error	
		IR	DS	IR	DS	IR	DS
1	Days to 50 % flowering	0.368	2.573	66.324**	84.507**	1.113	1.099
2	Days to maturity	3.496	7.547	43.805**	53.898**	2.364	3.503
3	Plant height (cm)	0.555	0.558	141.907**	143.239**	12.334	15.308
4	Spike length (cm)	0.090	0.017	4.451**	2.903**	0.237	0.283
5	Flag leaf Area (cm²)	1.345	0.185	44.756**	41.575**	1.745	16.792
6	Chlorophyll content (SPAD)	2.623	1.934	63.471**	65.777**	4.310	4.496
7	Canopy Temperature (°C)	0.176	0.044	3.722**	6.455**	0.232	0.284
8	RWC (%)	1.874	0.413	53.951**	93.987**	5.851	6.685
9	Number of Tillers/Plant	0.102	0.521	9.342**	8.178**	0.334	0.301
10	Number of Grains/ Spike	0.201	0.248	114.957**	44.976**	5.454	5.946
11	1000 Grain Weight (gm)	1.739	0.351	118.176**	104.667**	3.525	4.521
12	Harvest Index (%)	0.518	0.667	130.506**	89.495**	4.189	4.494
13	Grain Yield/ Plant (gm)	0.165	0.298	40.214**	15.046**	0.974	0.937
14	Drought Susceptibility Index		0.012		0.865**		0.053
		Seedling Characters Implicated in Drought Tolerance					
15	Germination percentage		1.547		16.771**		2.301
16	Seed Vigour Index		247.091		186496.406**		1276.213

**: Significance at 1 % level IR- Irrigated condition, DS- Drought stress condition

Table 2: Genetic parameters of various characters in bread wheat under both conditions

No.	Characters	σ^2_g		σ^2_p		GCV		PCV		h^2 (Broad sense) %		GA as % of Mean	
		IR	DS	IR	DS	IR	DS	IR	DS	IR	DS	IR	DS
1	Days to 50 % Flowering	21.74	27.80	22.85	28.90	6.54	7.60	6.70	7.75	95.13	96.26	13.13	15.35
2	Days to Maturity	13.81	16.80	16.18	20.30	3.22	3.76	3.48	4.14	85.39	82.74	6.13	7.05
3	Plant Height (cm)	43.19	42.64	55.53	57.95	7.57	8.13	8.59	9.47	77.79	73.59	13.76	14.36
4	Spike Length (cm)	1.40	0.87	1.64	1.16	11.30	9.49	12.22	10.92	85.58	75.53	21.53	16.99
5	Flag Leaf Area (cm²)	14.34	13.03	16.08	15.51	16.02	17.40	16.97	18.98	89.15	84.04	31.17	32.86
6	Chlorophyll Content (SPAD)	19.72	20.43	24.03	24.92	12.04	13.17	13.29	14.55	82.06	81.96	22.46	24.56
7	Canopy Temperature (°C)	1.16	2.06	1.40	2.34	5.87	6.98	6.43	7.45	83.38	87.88	11.05	13.48
8	RWC (%)	16.03	29.10	21.88	35.79	4.71	7.00	5.50	7.77	73.26	81.32	8.30	13.01
9	Number of Tillers/ Plant	3.00	2.63	3.34	2.93	19.48	24.36	20.54	25.72	90.00	89.71	38.07	47.53
10	Number of Grains/ Spike	36.50	13.01	41.95	18.96	13.17	8.89	14.12	10.73	87.00	68.63	25.31	15.17
11	1000 Grain Weight (gm)	38.22	33.38	41.74	37.90	13.87	14.69	14.50	15.66	91.56	88.07	27.34	28.41
12	Harvest Index (%)	42.11	28.33	46.29	32.83	14.12	13.02	14.81	14.02	90.95	86.31	27.74	24.93
13	Grain Yield/ Plant (gm)	13.08	4.70	14.05	5.64	22.57	17.85	23.39	19.55	93.07	83.39	44.85	33.58
14	Drought Susceptibility Index		0.27		0.32		56.63		61.88		83.76		106.78
		Seedling characters implicated to drought tolerance											
15	Germination %		4.82		7.12		2.35		2.86		67.70		3.99
16	Seed Vigour Index		61740.06		63016.28		14.69		14.84		97.97		29.96

IR- Irrigated condition, DS- Drought stress condition

results were obtained by Lonbani and Arzani (2011).

The assessment of heritable and non-heritable components in the total variability observed is indispensable in adopting suitable breeding procedure. In the present investigation, the genotypic and phenotypic coefficient of variation (Table 2) for number of tillers per plant was found high in both environments, whereas grain yield per plant showed high GCV and PCV in irrigated condition and moderate GCV and PCV in rainfed condition. These results are in agreement with Mondal and Kour (2004) for number of tillers per plant and Shukla *et al*. (2000) for grain yield per plant. The results showed that drought susceptibility index (DSI) exhibited very high GCV and PCV, indicating the importance of this trait in evaluation for drought tolerance and selecting the genotypes for drought tolerance. In this study, the phenotypic and genotypic coefficient of variance was found to be moderate for flag leaf area , HI , 1000 grain weight and number of grains per spike under both environments (irrigated and drought stress). Seed vigour index recorded moderate GCV and PCV. Similar results were also reported by Shukla *et al*. (2000) for harvest index and 1000 grain weight; Mondal and Kour (2004) for number of tillers per plant and 1000 grain weight. They found high GCV and PCV for respective traits. These findings were clearly indicated that selecting genotypes through these traits will be effective for drought tolerance. It is interesting to note that the differences between GCV and PCV values were minimum implying least influence of environment and maximum additive gene effects indicating genotypes can be improved and selected for these characters under stress condition for improvement of drought tolerance.

In this study, heritability in broad sense for all the characters (Table 2) namely yield per plant, number of tillers per plant, days to fifty per cent flowering, days to maturity, plant height, spike length, flag leaf area, chlorophyll content, canopy

Table 3: Genotypic and phenotypic correlation coefficient for sixteen characters in bread wheat under drought stress condition

Sl. no.	Characters		DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI	DSI
1	DFF		1														
2	DM	P	0.789**	1													
		G	0.863	1													
3	PH	P	0.179	0.132	1												
		G	0.239	0.158	1												
4	SL	P	0.174	0.120	-0.072	1											
		G	0.183	0.173	-0.021	1											
5	FLA	P	-0.469**	-0.302**	-0.018	0.166	1										
		G	-0.524	-0.330	0.034	0.227	1										
6	CHL	P	0.141	0.171	-0.238**	0.459**	-0.015	1									
		G	0.152	0.192	-0.263	0.535	-0.012	1									
7	CT	P	0.16	0.136	-0.050	-0.208*	-0.325**	-0.241**	1								
		G	0.197	0.178	-0.056	-0.249	-0.400	-0.318	1								
8	RWC	P	-0.145	-0.099	-0.155	0.416**	0.526**	0.498**	-0.655**	1							
		G	-0.171	-0.115	-0.167	0.577	0.637	0.557	-0.775	1							
9	TPP	P	-0.128	-0.129	-0.130	0.389**	0.485**	0.422**	-0.601**	0.730**	1						
		G	-0.138	-0.145	-0.138	0.450	0.567	0.468	-0.665	0.834	1						
10	GPS	P	0.102	0.114	-0.160	0.478**	0.354**	0.318**	-0.210*	0.512**	0.502**	1					
		G	0.136	0.164	-0.307	0.744	0.463	0.399	-0.319	0.637	0.654	1					
11	TGW	P	-0.327**	-0.162	0.116	0.404**	0.515**	0.365**	-0.466**	0.604**	0.520**	0.126	1				
		G	-0.371	-0.210	0.142	0.474	0.631	0.381	-0.506	0.679	0.552	0.169	1				
12	HI	P	-0.100	-0.076	-0.164	0.450**	0.390**	0.507**	-0.580**	0.759**	0.664**	0.405**	0.558**	1			
		G	-0.103	-0.100	-0.177	0.562	0.471	0.638	-0.645	0.904	0.763	0.559	0.637	1			
13	GP	P	-0.141	-0.200*	0.096	0.036	0.103	0.140	-0.273**	0.192*	0.305**	-0.010	0.136	0.301**	1		
		G	-0.154	-0.253	0.168	0.058	0.150	0.159	-0.404	0.279	0.382	-0.069	0.204	0.397	1		
14	SVI	P	-0.240**	-0.142	-0.300**	0.492**	0.460**	0.340**	-0.371**	0.636**	0.517**	0.545**	0.360**	0.543**	0.081	1	
		G	-0.245	-0.150	-0.363	0.577	0.522	0.381	-0.407	0.709	0.557	0.655	0.393	0.592	0.037	1	
15	DSI	P	0.211*	0.244**	-0.105	0.352**	-0.232*	0.225*	0.440**	-0.112	-0.215*	0.148	-0.039	-0.058	-0.110	0.181	1
		G	0.238	0.302	-0.130	0.477	-0.266	0.255	0.497	-0.141	-0.253	0.193	-0.058	-0.041	-0.157	0.203	1
16	GY	P	-0.186*	-0.093	-0.151	0.472**	0.528**	0.467**	-0.673**	0.768**	0.805**	0.498**	0.605**	0.765**	0.204*	0.600**	-0.177
		G	-0.209	-0.113	-0.221	0.585	0.593	0.604	-0.760	0.949	0.940	0.696	0.714	0.854	0.355	0.671	-0.104

** Significant at 1 % level = 0.237 *Significant at 5 % level = 0.182 P- Phenotypic correlation, G- Genotypic correlation

Abbreviations: CHL- chlorophyll content, CT- canopy temperature, DFF- days to fifty per cent flowering, DM- days to maturity, DSI- drought susceptibility index, FLA- flag leaf area, GP- germination percentage, GPS-number of grains per spike, GY- grain yield per plant, HI- harvest index, PH- plant height, RWC- relative water content, SL- spike length, SVI- seed vigour index, TGW- 1000 grain weight, TPP- number of tillers per plant.

Table 4: Genotypic and phenotypic correlation coefficient for fifteen characters in bread wheat under irrigated condition

Sl no	Characters		DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI
1	DFF		1													
2	DM	P	0.546**	1												
		G	0.610	1												
3	PH	P	0.082	0.071	1											
		G	0.124	0.071	1											
4	SL	P	0.214*	0.021	-0.024	1										
		G	0.235	0.021	-0.044	1										
5	FLA	P	-0.316**	-0.080	-0.110	0.388**	1									
		G	-0.345	-0.114	-0.126	0.456	1									
6	CHL	P	0.188*	-0.041	-0.027	0.620**	0.180	1								
		G	0.219	-0.072	-0.005	0.755	0.191	1								
7	CT	P	-0.019	-0.035	0.234*	-0.645**	-0.438**	-0.514**	1							
		G	-0.032	-0.005	0.294	-0.770	-0.514	-0.654	1							
8	RWC	P	-0.053	-0.020	-0.251**	0.557**	0.369**	0.495**	-0.756**	1						
		G	-0.063	-0.039	-0.322	0.727	0.483	0.677	-0.935	1						
9	TPP	P	0.034	0.053	-0.102	0.582**	0.415**	0.457**	-0.585**	0.569**	1					
		G	0.019	0.062	-0.133	0.676	0.495	0.573	-0.687	0.647	1					
10	GPS	P	0.171	0.020	-0.088	0.619**	0.376**	0.525**	-0.558**	0.499**	0.672**	1				
		G	0.185	0.034	-0.085	0.714	0.434	0.617	-0.646	0.657	0.748	1				
11	TGW	P	-0.246**	-0.117	0.044	0.489**	0.516**	0.611**	-0.520**	0.510**	0.403**	0.373**	1			
		G	-0.252	-0.137	0.051	0.558	0.558	0.660	-0.578	0.644	0.468	0.426	1			
12	HI	P	0.084	0.001	-0.044	0.707**	0.366**	0.687**	-0.702**	0.745**	0.632**	0.644**	0.632**	1		
		G	0.096	-0.011	-0.071	0.780	0.406	0.780	-0.826	0.869	0.709	0.735	0.687	1		
13	GP	P	-0.140	-0.065	0.121	0.028	0.012	0.094	-0.196*	0.226*	0.115	-0.040	0.184*	0.249**	1	
		G	-0.213	-0.141	0.166	0.031	-0.023	0.192	-0.249	0.265	0.134	-0.062	0.250	0.293	1	
14	SVI	P	-0.132	-0.024	-0.335**	0.495**	0.614**	0.324**	-0.583**	0.583**	0.517**	0.502**	0.340**	0.509**	0.081	1
		G	-0.141	-0.037	-0.386	0.532	0.652	0.384	-0.641	0.667	0.545	0.535	0.366	0.539	0.037	1
15	GY	P	0.058	-0.012	-0.128	0.749**	0.473**	0.668**	-0.784**	0.680**	0.791**	0.788**	0.643**	0.797**	0.093	0.586**
		G	0.069	0.027	-0.165	0.822	0.542	0.777	-0.873	0.846	0.861	0.870	0.701	0.877	0.164	0.619

** Significant at 1 % level = 0.237 *Significant at 5 % level = 0.182 P- Phenotypic correlation, G- Genotypic correlation

Table 5A: Phenotypic path coefficient analysis of fifteen characters on grain yield in bread wheat under drought stress condition

Sl. No.	Characters	DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI	DSI
1	DFF	-0.126	-0.100	-0.023	-0.022	0.059	-0.018	-0.021	0.018	0.016	-0.013	0.041	0.013	0.018	0.030	-0.027
2	DM	0.091	0.115	0.015	0.014	-0.035	0.020	0.016	-0.011	-0.015	0.013	-0.019	-0.009	-0.023	-0.016	0.028
3	PH	-0.005	-0.004	-0.030	0.002	0.001	0.007	0.002	0.005	0.004	0.005	-0.003	0.005	-0.003	0.009	0.003
4	SL	0.017	0.012	-0.007	0.097	0.016	0.045	-0.020	0.041	0.038	0.047	0.039	0.044	0.004	0.048	0.034
5	FLA	-0.043	-0.028	-0.002	0.015	0.091	-0.001	-0.030	0.048	0.044	0.032	0.047	0.036	0.009	0.042	-0.021
6	CHL	0.011	0.014	-0.019	0.036	-0.001	0.079	-0.019	0.039	0.033	0.025	0.029	0.040	0.011	0.027	0.018
7	CT	-0.034	-0.028	0.010	0.043	0.067	0.050	-0.206	0.135	0.124	0.043	0.096	0.119	0.056	0.076	-0.091
8	RWC	0.007	0.005	0.008	-0.021	-0.026	-0.025	0.033	-0.050	-0.037	-0.026	-0.030	-0.038	-0.010	-0.032	0.006
9	TPP	-0.043	-0.043	-0.044	0.130	0.162	0.141	-0.201	0.244	0.334	0.168	0.174	0.222	0.102	0.173	-0.072
10	GPS	0.007	0.008	-0.011	0.033	0.025	0.022	-0.015	0.036	0.035	0.070	0.009	0.028	-0.001	0.038	0.010
11	TGW	-0.022	-0.011	0.008	0.027	0.035	0.025	-0.031	0.041	0.035	0.009	0.067	0.038	0.009	0.024	-0.003
12	HI	-0.025	-0.019	-0.040	0.110	0.096	0.124	-0.142	0.186	0.163	0.099	0.137	0.245	0.074	0.133	-0.014
13	GP	0.008	0.011	-0.005	-0.002	-0.006	-0.008	0.015	-0.011	-0.017	0.001	-0.007	-0.017	-0.055	-0.005	0.006
14	SVI	-0.016	-0.009	-0.019	0.032	0.030	0.022	-0.024	0.041	0.033	0.035	0.023	0.035	0.005	0.064	0.012
15	DSI	-0.014	-0.016	0.007	-0.023	0.015	-0.015	-0.029	0.007	0.014	-0.010	0.003	0.004	0.007	-0.012	-0.066
16	GY	-0.186*	-0.093	-0.151	0.472**	0.528**	0.467**	-0.673**	0.768**	0.805**	0.498**	0.605**	0.765**	0.204*	0.600**	-0.177

Residual effect = 0.4249

Table 5B: Genotypic path coefficient analysis of fifteen characters on grain yield in bread wheat under drought stress condition

Sl. No.	Characters	DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI	DSI
1	DFF	0.055	0.048	0.013	0.010	-0.029	0.008	0.011	-0.010	-0.008	0.008	-0.021	-0.006	-0.009	-0.014	0.013
2	DM	0.032	0.037	0.006	0.006	-0.012	0.007	0.007	-0.004	-0.005	0.006	-0.008	-0.004	-0.009	-0.006	0.011
3	PH	-0.061	-0.040	-0.253	0.005	-0.009	0.067	0.014	0.042	0.035	0.078	-0.036	0.045	-0.043	0.092	0.033
4	SL	0.031	0.029	-0.004	0.168	0.038	0.090	-0.042	0.097	0.076	0.125	0.080	0.095	0.010	0.097	0.080
5	FLA	-0.187	-0.118	0.012	0.081	0.356	-0.004	-0.142	0.227	0.202	0.165	0.225	0.168	0.054	0.186	-0.095
6	CHL	0.016	0.021	-0.028	0.058	-0.001	0.108	-0.034	0.060	0.050	0.043	0.041	0.069	0.017	0.041	0.027
7	CT	-0.106	-0.096	0.031	0.134	0.216	0.172	-0.540	0.419	0.359	0.172	0.273	0.348	0.218	0.220	-0.268
8	RWC	0.029	0.020	0.029	-0.099	-0.109	-0.096	0.133	-0.172	-0.143	-0.109	-0.117	-0.155	-0.048	-0.122	0.024
9	TPP	-0.091	-0.096	-0.091	0.298	0.374	0.309	-0.439	0.551	0.661	0.432	0.365	0.504	0.253	0.368	-0.167
10	GPS	-0.028	-0.033	0.062	-0.151	-0.094	-0.081	0.065	-0.130	-0.133	-0.203	-0.034	-0.114	0.014	-0.133	-0.039
11	TGW	-0.010	-0.006	0.004	0.012	0.016	0.010	-0.013	0.018	0.014	0.004	0.026	0.017	0.005	0.010	-0.002
12	HI	0.001	0.001	0.001	-0.005	-0.004	-0.005	0.005	-0.007	-0.006	-0.005	-0.005	-0.008	-0.003	-0.005	0.000
13	GP	0.008	0.013	-0.009	-0.003	-0.008	-0.008	0.021	-0.015	-0.020	0.004	-0.011	-0.021	-0.053	-0.002	0.008
14	SVI	0.030	0.018	0.044	-0.070	-0.063	-0.046	0.049	-0.086	-0.068	-0.079	-0.048	-0.072	-0.005	-0.121	-0.025
15	DSI	0.070	0.089	-0.038	0.140	-0.078	0.075	0.146	-0.041	-0.074	0.057	-0.017	-0.012	-0.046	0.060	0.294
16	GY	-0.209	-0.113	-0.221	0.585	0.593	0.604	-0.760	0.949	0.940	0.696	0.714	0.854	0.355	0.671	-0.104

Residual effect = 0.1487

temperature, RWC, number of grains per spike, 1000 grain weight and harvest index were found high in both environments. The seedling characters viz., germination percentage and SVI also exhibited high heritability. High heritability value for these traits indicated that the variation observed was mainly under genetic control and was less influenced by environment. So, these traits may be used as a selection criteria under stress and improved for drought tolerance in confirmation with the result of Esmail *et al*. (2008) who also noticed high heritability value for days to fifty per cent flowering, flag leaf area, number of grains per spike, 1000 grains weight and grain yield per plant. Farshadfar *et al*. (2011) reported high heritability for RWC; Sharma and Kumar (2010) recorded high heritability for number of grains per spike and grain yield per plant. Lush (1949) pointed out that when heritability was high, relevance should be mainly on mass selection or as heritability become lower, more emphasis should be placed on pedigree selection method.

Heritability estimates are useful in deciding the character to be considered while making selection, but selection based on this factor alone may limit the progress, as it is prone for changes with environment, material etc., (Johnson *et al*., 1955; Athwal and Gain Singh.1966). In other words, estimates of heritability have a role to play in determining the effectiveness of selection for a character, provided they are considered in conjugation with the genetic advance as per cent of mean as suggested by Johnson *et al*. (1955). In the present investigation, the characters, namely grain yield per plant, number of tillers per plant, flag leaf area, chlorophyll content, 1000 grain weight and HI had showed high heritability coupled with high genetic advance as per cent of mean under both environments (Table 2). Hence, direct selection can be done through these characters for future improvement of genotypes under drought stress condition (rainfed condition) for improvement of drought tolerance and under irrigated condition for higher grain yield. Similar results were also reported by earlier workers Mondal and Kour (2004) for flag leaf area, number of tillers per plant and grain yield; Gupta *et al*. (2005) for 1000 grain weight grain yield and flag leaf area; El-Kareem and El-Saidy (2011) for grain yield per plant, 1000 grain weight and HI. The SVI and DSI depicted high heritability coupled with high genetic advance as per cent of mean. The high heritability associated with high genetic advance indicated, the variation was mostly due to additive gene effects. It indicates that if these characters are subjected to any selection scheme for exploiting fixable genetic variance, a wide adopted genotype can be developed.

The number of grains per spike and spike length revealed high heritability with high genetic advance as per cent of mean under irrigated condition, whereas high heritability with medium genetic advance as per cent of mean in drought condition. RWC exhibited high heritability with low genetic advance as per cent of mean in irrigated condition , whereas high heritability with medium genetic advance as per cent of mean under rainfed condition suggesting future improvement of genotypes for these characters for further selection and subsequent use in drought related breeding programme. High heritability coupled with moderate genetic advance as per cent of mean were observed for traits viz., days to fifty per cent flowering, plant height and canopy temperature under both environments (Drought stress and Irrigated). These traits indicated that their manifestation is governed by both additive and non-additive genetic effects and therefore, selection should be practiced in later segregating generations i.e. by hybridization programme to exploit heritability. Other traits viz., days to maturity and germination percentage exhibited high heritability along with low genetic advance, indicating greater role of non-fixable genetic effects on the expression of these characters. Therefore, direct selection based on these characters would be less effective.

Association analysis

The results of association analysis (Table 3) between the traits indicate that grain yield per plant was negatively correlation with days to fifty per cent flowering and days to maturity at genotypic and phenotypic level under stress condition. It indicated that earliness enabled the cultivars to escape drought at the end of the growing season (Yazdi-Samadi and Hosseini, 2002) under stress condition. Thus, early maturing genotypes preferred as indicated by negative correlation of days to fifty per cent flowering and days to maturity as water is limited. The correlation of all the characters under drought stress and irrigated conditions were tabulated in Table 3 and Table 4, respectively. Grain yield per plant exhibited significant positive association with number of tillers per plant, relative water content (RWC), 1000 grain weight, number of grains per spike and flag leaf area in both environments. These results were in accordance with the findings of Muhammad *et al*. (2007) and Saleh (2011). El- Mohsen *et al*. (2012) and El-Ameen *et al*. (2013) reported significant positive correlation of grain yield with spike length, number of grains per spike and 1000 grain weight. Guendouz *et al*. (2013) observed strong positive correlation of number of grains per spike with grain yield per plant. Grain yield per plant also recorded strong positive association with seed vigour index (SVI), chlorophyll content and harvest index, while strong negative associated with canopy temperature in both environments. Bahar *et al*. (2011) observed also negative correlation of grain yield with canopy temperature in contrast to Naroui-Rad *et al*. (2010), who reported the positive association of grain yield with canopy temperature.

Spike length exhibited significant positive association with number of grains per spike, 1000 grains weight and HI in both environments (Irrigated and Rainfed). Similar result was obtained by Singh *et al*. (2001). El-Ameen *et al*. (2013) also reported strong positive association among spike length, 1000 grain weight and number of grains per spike. Spike length also depicted positive correlation with chlorophyll content and RWC, whereas negatively correlated with canopy temperature. Flag leaf area depicted strong positive association with 1000 grain weight, number of tillers per plant and HI, although it showed negative correlation with the traits canopy temperature in both environments. Chlorophyll content also exhibited strong positive association with HI, number of grains per spike and 1000 grain weight, whereas it also showed negative correlation with canopy temperature in both conditions. Similar result was also reported by Bhutta (2006) for number of tillers per plant. It is clear that genotypes with larger flag leaf area can maintain high transpiration and photosynthetic rate

Table 6A: Phenotypic path coefficient analysis of fourteen characters on grain yield in bread wheat under irrigated condition

Sl. No.	Characters	DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI
1	DFF	0.027	0.015	0.002	0.006	-0.009	0.005	-0.001	-0.001	0.001	0.005	-0.007	0.002	-0.004	-0.004
2	DM	-0.019	-0.035	-0.003	-0.001	0.003	0.001	0.001	0.001	-0.002	-0.001	0.004	0.000	0.002	0.001
3	PH	-0.001	-0.001	-0.017	0.000	0.002	0.001	-0.004	0.004	0.002	0.002	-0.001	0.001	-0.002	0.006
4	SL	0.018	0.002	-0.002	0.086	0.034	0.053	-0.056	0.048	0.050	0.053	0.042	0.061	0.002	0.043
5	FLA	0.015	0.004	0.005	-0.018	-0.046	-0.008	0.020	-0.017	-0.019	-0.017	-0.024	-0.017	-0.001	-0.028
6	CHL	0.008	-0.002	-0.001	0.025	0.007	0.041	-0.021	0.020	0.019	0.022	0.025	0.028	0.004	0.013
7	CT	0.005	0.009	-0.063	0.174	0.118	0.138	-0.269	0.204	0.158	0.150	0.140	0.189	0.053	0.157
8	RWC	0.003	0.001	0.015	-0.032	-0.021	-0.029	0.044	-0.058	-0.033	-0.029	-0.030	-0.043	-0.013	-0.034
9	TPP	0.010	0.015	-0.029	0.168	0.120	0.132	-0.169	0.164	0.288	0.194	0.116	0.182	0.033	0.149
10	GPS	0.044	0.005	-0.022	0.158	0.096	0.134	-0.142	0.127	0.171	0.255	0.095	0.164	-0.010	0.128
11	TGW	-0.056	-0.026	0.010	0.111	0.117	0.138	-0.118	0.115	0.091	0.084	0.226	0.143	0.042	0.077
12	HI	0.006	0.000	-0.003	0.052	0.027	0.050	-0.051	0.055	0.046	0.047	0.046	0.073	0.018	0.037
13	GP	0.005	0.002	-0.004	-0.001	0.000	-0.003	0.007	-0.008	-0.004	0.001	-0.006	-0.009	-0.035	-0.003
14	SVI	-0.006	-0.001	-0.015	0.022	0.027	0.014	-0.026	0.026	0.023	0.022	0.015	0.022	0.004	0.044
15	GY	0.058	-0.012	-0.128	0.749**	0.473**	0.668**	-0.784**	0.680**	0.791**	0.788**	0.643**	0.797**	0.093	0.586**

Residual effect = 0.3142

Table 6B: Genotypic path coefficient analysis of fourteen characters on grain yield in bread wheat under irrigated condition

Sl. No.	Characters	DFF	DM	PH	SL	FLA	CHL	CT	RWC	TPP	GPS	TGW	HI	GP	SVI
1	DFF	-0.015	-0.009	-0.002	-0.004	0.005	-0.003	0.001	0.001	0.000	-0.003	0.004	-0.001	0.003	0.002
2	DM	0.027	0.045	0.003	0.001	-0.005	-0.003	0.000	-0.002	0.003	0.002	-0.006	-0.001	-0.006	-0.002
3	PH	-0.008	-0.005	-0.065	0.003	0.008	0.000	-0.019	0.021	0.009	0.006	-0.003	0.005	-0.011	0.025
4	SL	0.002	0.000	0.000	0.010	0.005	0.008	-0.008	0.008	0.007	0.007	0.006	0.008	0.000	0.006
5	FLA	0.027	0.009	0.010	-0.036	-0.079	-0.015	0.041	-0.038	-0.039	-0.034	-0.044	-0.032	0.002	-0.052
6	CHL	0.015	-0.005	0.000	0.051	0.013	0.068	-0.044	0.046	0.039	0.042	0.045	0.053	0.013	0.026
7	CT	0.015	0.002	-0.141	0.371	0.247	0.315	-0.481	0.450	0.331	0.311	0.278	0.398	0.120	0.308
8	RWC	0.017	0.010	0.087	-0.197	-0.131	-0.183	0.253	-0.271	-0.175	-0.178	-0.175	-0.235	-0.072	-0.181
9	TPP	0.004	0.013	-0.029	0.147	0.108	0.125	-0.150	0.141	0.218	0.163	0.102	0.155	0.029	0.119
10	GPS	0.079	0.015	-0.036	0.305	0.186	0.264	-0.276	0.281	0.320	0.428	0.182	0.314	-0.026	0.229
11	TGW	-0.078	-0.042	0.016	0.172	0.172	0.204	-0.178	0.199	0.144	0.131	0.308	0.212	0.077	0.113
12	HI	-0.003	0.000	0.002	-0.025	-0.013	-0.025	0.026	-0.027	-0.022	-0.023	-0.022	-0.031	-0.009	-0.017
13	GP	-0.009	-0.006	0.007	0.001	-0.001	0.008	-0.011	0.011	0.006	-0.003	0.011	0.013	0.043	0.002
14	SVI	-0.006	-0.002	-0.016	0.022	0.027	0.016	-0.027	0.028	0.023	0.022	0.015	0.022	0.002	0.041
15	GY	0.069	0.027	-0.165	0.822	0.542	0.777	-0.873	0.846	0.861	0.870	0.701	0.877	0.164	0.619

Residual effect = 0.0224

as well as produce a high yield under both moisture-stress and irrigated conditions.

Under stress condition, canopy temperature revealed strong negative association with grain yield per plant and RWC, whereas it showed significant positive correlation with drought susceptibility index (DSI). It indicated that elevated canopy temperature accompanied yield reduction under water stress condition; apparently because plants could not maintain adequate transpiration rates and transpiration cooling was reduced. These findings were in agreement of Talebi (2011). Canopy temperature also exhibited negative association with 1000 grain weight, HI and SVI in both environments. Blum *et al*. (1989) used canopy temperatures in drought stresses wheat genotypes to characterize yield stability under various moisture conditions. RWC was one of useful traits under water stress condition that showed maximum positive correlation with grain yield per plant and it also recorded significant positive association with HI, 1000 grain weight, number of grains per spike and number of tillers per plant. Similarly, Zarei *et al*. (2013) also recorded positive correlation of RWC with HI, number of tillers per plant, number of grains per spike and 1000 grain weight. It also recorded positive and significant correlation with chlorophyll content. It revealed that varieties with higher RWC under stress condition are more droughts tolerant and produce higher yield than others. The finding of present study supports the possibility that RWC could be used as indicator of drought resistance. Similar direction of association of RWC was recorded with other traits in irrigated condition also, only extent of association varied in both conditions. Number of tillers per plant depicted positive association with grain yield per plant, HI and number of grains per spike. It also exhibited positive association with flag leaf area, spike length and chlorophyll content. Spike length expressed higher number of grains per spike resulted in increase in grain yield per plant. It was noteworthy that increase in number of grains per spike was correspondingly related with decrease in plant height which helps in acquiring high harvest index. 1000 grain weight exhibited strong positive correlation with flag leaf area and chlorophyll content in both environments. As increase in flag leaf areas as well as chlorophyll content help in more photosynthesis and so accumulation of energy which might be diverted towards bold grain formation. 1000 grain weight was also positively correlated with HI, number of tillers per plant, RWC and flag leaf area while negatively correlated with canopy temperature in both moisture-stress and irrigated condition. Shahryari *et al*. (2008) also found significant positive association of 1000 grain weight with number of tillers per plant and grain yield.

SVI revealed maximum positive correlation with RWC, number of grains per spike and grain yield per plant, whereas it depicted significant negative association with canopy temperature. It also showed positive association with spike length, flag leaf area, chlorophyll content, 1000 grain weight and number of tillers per plant. This indicated that SVI may be an important trait for predicting grain yield and yield attributing characters of genotypes in early stages for water stress condition. Rauf *et al*. (2007) reported that seed germination and seedling growth characters are extremely important factors in determining yield**.** Dhanda *et al*. (2004) indicated that seed vigour index and shoot length are among the most sensitive to drought stress, followed by root length and coleoptiles length. DSI exhibited positive association with canopy temperature, spike length, days to maturity, chlorophyll content and days to fifty per cent flowering. However, it showed negative correlation with RWC, number of tillers per plant, grain yield per plant and flag leaf area contrasting to the Nouri *et al*. (2011) who recorded positive association of these traits with DSI. Bahar and Yildirim (2010) observed negative association of DSI with grain yield. This indicated that genotypes with short duration which can maintain high RWC and lower down the canopy temperature will be preferred under water stress condition.

Thus, it is clear from the discussion of association analysis under both environments (Drought stress and Irrigated), in general, the direction of association is same in both environments for almost all the traits, only extent (degree) of association varied in both environments for that pair of traits. Therefore, it could be concluded from above discussion, grain yield per plant had positive and significant association with number of tillers per plant, harvest index, relative water content, number of grains per spike, 1000 grain weight, spike length, flag leaf area, chlorophyll content and seed vigour index and also positive significant inter correlation among themselves under both environments. Hence, selection for any one of these characters would bring in simultaneous improvement of other characters and also finally improvement in grain yield in both environments.

Path coefficient analysis

The correlation coefficient indicated the relationship existing between pair of characters. But dependent character is an interaction of product of many mutually associated component characters and change in any one component character will disturb whole network of cause and effect system. The success of breeding programme depends upon contribution of individual component characters on polygenic traits like grain yield. Path coefficient analysis (phenotypic and genotypic) of studied characters on grain yield under drought stress and irrigated conditions are tabulated in Table 5 (5.A and 5.B) and 6 (6.A and 6.B), respectively.

Under rainfed condition, high positive direct effect at genotypic level was exhibited by the characters number of tillers per plant and flag leaf area, whereas moderate positive direct effect was recorded by DSI. At phenotypic level number of tillers per plant showed highest positive direct effect on grain yield per plant, whereas HI depicted moderate positive direct effect (Sarkar *et al*., 2002). Canopy temperature exhibited highest negative direct effect on grain yield at both genotypic and phenotypic level. These results were in accordance of Bhutta (2006) who recorded high positive direct effect of number of tillers per plant and flag leaf area on grain yield. Mondal and Khajuria (2001); Mondal and Kour (2004) found high positive direct effect of number of tillers per plant on grain yield. Saleh (2011) reported high direct effect of flag leaf area on grain yield. Ahmadizadeh *et al*. (2011) observed high positive direct effect of HI on grain yield under rainfed condition. Correlation coefficient of these traits (number of tillers per plant and flag leaf area) was also high and in the same direction with grain yield indicating their true relationship with grain yield. So these traits may be directly used for selection under drought stress condition (rainfed) and subjected for improvement of drought tolerance. Canopy temperature showed negative direct effect and also strong negative correlation with grain yield. Hence, this trait may also be used as indirect selection criteria in rainfed condition. Relative water content exhibited very high positive correlation (genotypic and phenotypic) with grain yield under drought stress condition, whereas its direct effect was negative. It showed high positive indirect effect via number of tillers per plant, canopy temperature and flag leaf area and ultimately resulted in very high positive association with grain yield per plant. Number of grains per spike (Shamsi *et al.,* 2011), RWC, HI, flag leaf area, 1000 grain weight, chlorophyll content and SVI had high positive indirect effect on grain yield per plant via number of tillers per plant. RWC, number of tillers per plant and HI had high and positive indirect effect on grain yield per plant through canopy temperature, whereas flag leaf area, 1000 grain weight and SVI exhibited moderate and positive indirect effect via canopy temperature. However, RWC, number of tillers per plant and 1000 grain weight had moderate and positive indirect effect on grain yield per plant through flag leaf area at genotypic level. Almost all characters showed moderate indirect effect towards grain yield via harvest index at phenotypic level. Ahmadizadeh *et al*. (2011) recorded high indirect effect of HI in rainfed condition. Therefore, it implicated from above discussion that the traits viz., number of tillers per plant and flag leaf area have to be given importance in selection process for improvement in yield, since they had positive correlation with grain yield, positive inter correlation among themselves, high direct effect towards grain yield and also almost all other characters contributed indirectly towards grain yield via these characters. Hence, selection based on these characters would be more effective for yield improvement in bread wheat under drought stress condition.

Under irrigated condition, number of grains per spike and 1000 grain weight had high and positive direct effect, whereas canopy temperature had high and negative direct effect on grain yield at genotypic level. However, number of tillers per plant showed moderate and positive direct effect at both genotypic and phenotypic level; and number of grains per spike and 1000 grain weight showed moderate and positive direct effect on grain yield at phenotypic level. Therefore, number of grains per spike, 1000 grain weight and number of tillers per plant should be given due weightage to increase the grain yield in bread wheat, since correlation coefficient of these traits were also high and in same direction with grain yield indicating their true relationship with grain yield. However, canopy temperature may also be used for screening genotypes in irrigated condition as its strong negative correlation with grain yield was due to its high negative direct effect towards grain yield. These findings were in accordance of Guendouz *et al*. (2013) who also reported that 1000- kernels weight and number of grains per spike had high positive direct effect on grain yield. Similarly, high positive direct effect was noticed by Mondal and Khajuria (2001) for number of effective tillers per plant and 1000 grain weight. El- Mohsen *et al*. (2012) observed high direct effect of 1000- kernels weight and number of grains per spike and number of tillers per plant. Similar to stress condition, relative water content recorded high positive association with grain yield under irrigated condition, although it showed high negative indirect effect on grain yield. The high positive correlation was build-up by the contribution of its high indirect effect via canopy temperature, number of grains per spike, 1000 grain weight and number of tillers per plant on grain yield. Number of tillers per plant (El- Mohsen *et al.*, 2012), HI and spike length had high and positive indirect effect through number of grains per spike, whereas RWC, chlorophyll content and SVI had moderate and positive indirect effect on grain yield per plant via number of grains per spike. RWC, HI, spike length, number of tillers per plant, chlorophyll content, number of grains per spike and SVI had high and positive indirect effect on grain yield per plant through canopy temperature. However, chlorophyll content and HI had moderate and positive indirect effect on grain yield via 1000 grain weight at genotypic level. Similar results were reported by Ahmadizadeh *et al*. (2011) who observed harvest index showed high positive indirect effect on grain yield under well watered condition. Hence, from above discussion it could be concluded that based on these traits viz., number of grains per spike, 1000 grain weight and number of tillers per plant would be effective and reliable in irrigated environments, since they had high positive correlation with grain yield, positive inter correlation among themselves and high indirect effect of most of the characters via these traits on grain yield. Similar to drought stress condition, canopy temperature had high negative association with grain yield per plant due to its high negative direct and most of the traits showed high indirect effect via this trait, suggesting importance of this character in selection breeding programme under drought stress as well as irrigated condition.

The genotypic residual effect for grain yield was 0.1487 and 0.0224 in drought stress and irrigated environments, respectively reflected that the characters studied in this investigation accounted for 85.13 and 97.76 per cent variability and remaining 14.87 and 2.24 per cent of variability in yield in respective environments was due to unknown factors.

CONCLUSION

Yield and yield-related traits under drought stress conditions were independent of yield and yield-related traits under irrigated condition. Among the characters, number of tillers per plant, flag leaf area and canopy temperature should be given priority while making selections under drought stress condition, whereas number of tillers per plant, 1000 grain weight, number of grains per spike and canopy temperature should be given due weightage while making selection under irrigated condition because of its remarkable consistency in maintaining significantly high correlation with grain yield as well as high direct effect on grain yield. The genotypes with high relative water content and lower canopy temperature would be preferred under drought stress condition.

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