SCREENING DROUGHT TOLERANCE IN BREAD WHEAT GENOTYPES (*Triticum aestivum* L.) USING DROUGHT INDICES AND MULTIVARIATE ANALYSIS

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ABSTRACT

Drought is a wide-spread problem seriously influencing wheat (*Triticum aestivum* L.) production , but development of tolerant genotypes is hampered by the lack of effective selection criteria. The objective of research study was to evaluate the efficiency of several selection indices to identify drought tolerant genotypes under drought stress conditions. Twenty seven bread wheat genotypes differing in yield performance were grown under drought stress, and normal irrigation during 2014-2015 growing season, were evaluated in split plot design with three replications Significant and high positive correlation was found between grain yield in the stress condition (Ys) and (Yp) with indices STI, GMP, YI, and Significant negative correlation was found between Ys with SSI, SI, SSPI, TOL indices. Principal component analysis (PCA) based on the Spearman's correlation matrix, indicated that first PCA (80.6%) and second PCA (18.1%) accounted for 98.7% of variations among the indices. The results of PCA revealed that the screening methods were significantly inter-correlated with each other indicating that several of the statistics probably measure similar aspects of drought tolerance. Cluster analysis classified the cultivars into four groups according to drought tolerance. The results showed that MP, GMP and STI were more effective in identifying high yielding genotypes in both drought-stressed and irrigated conditions, identifying G1 and G10 as more tolerant and G25 and G26 as more sensitive genotype to drought stress.

Key words: Drought index , Multivariate analysis, Biplot, Cluster analysis, Rank sum.

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غربلة تراكيب وراثية من حنطة الخبز (*Triticum aestivum* L.) لتحمل الجفاف باستعمال معايير الجفاف وتحليل المتغيرات المتعددة

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المستخلص

الجفاف هو المشكلة واسعة الانتشار التي تؤثر على إنتاج الحنطة (*Triticum aestivum* L.)، ان عدم وجود معايير فعالة للانتخاب يعرقل تطوير التراكيب الوراثية المتحملة للجفاف. يهدف البحث الى تقييم قدرة العديد من معايير تحمل الجفاف لانتخاب تراكيب وراثية متحملة للجفاف. تم زراعة سبعة وعشرون تركيباً وراثياً منها محلية ومدخلة ومختلفة في قابلية انتاجها تحت ظروف الري الطبيعي وتحت ظروف الاجهاد خلال موسم النمو 2014 – 2015 . استخدم تصميم الالواح المنشقة وبثلاث مكررات. اظهرت النتائج على وجود ارتباط عالي وموجب بين حاصل التراكيب الوراثية تحت الاجهاد (Ys) وتحت الري الطبيعي (Yp) و المعايير MP ,STI, GMP, YI ، وارتباط عالي سالب بين (Ys) والمعايير SSI, SI, SSPI, TOL. واظهرت نتائج تحليل المكون الرئيسي (PCA) المعتمد على معامل ارتباط بيرسن بان المكون الاساسي الاول (PC1=80.6%) ، والمكون الاساسي الثاني (PC2=18.1%) يمثل حوالي 98.7 % من التغييرات بين المعايير. كما اشارت النتائج الى وجود ارتباط فيما بين هذه المعايير، وقسم من هذه المعايير تعطي نفس النتائج في تحديد تحمل الجفاف. كما اظهرت نتائج التحليل العنقودي الى تقسيم التراكيب الوراثية الى اربعة مجاميع مختلفة تبعاً لتحملها للجفاف. وبناء على ما تقدم، بينت النتائج بان المعايير MP, GMP YI و STI معايير كفوءة في تحديد التراكيب الوراثية المنتجة في ظروف الري الطبيعي وظروف الاجهاد و المتحملة للجفا ف، وتحديد التراكيب الوراثية G1 وG10 هي التراكيب المتحملة والتراكيب الوراثية G25 وG26 حساسة للجفاف.

كلمات مفتاحية: ادلة الجفاف، تحليل المتغيرات المتعددة، تحليل المكون الرئيسئ، التحليل العنقودي، معدل الرتب.

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INTRODUCTION

Bread wheat (*Triticum aestivum* L.) considered as the most important cultivated crop in the world , and provide more than 20% of calories needed, and it is also a basic source of essential protein to the world populations(29) . Drought stress is the most limiting factor affecting growth and productivity of crop plants including wheat. (27). The insufficient soil water supply (i.e Drought) frequently occur at the same time with high temperature at the end of wheat growing season in the region of the world with a Mediterranean climate like Iraq, because rainfall is scarce, unevenly distributed and temperature are high during grain filling period. Drought tolerance is one of the key components of yield stability and its improvement, and it is of a major challenge to geneticists and plant breeders. Wheat breeding programs are designed to identify genotypes possessing improved yields adaptation to changing climatic conditions such as drought. The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for drought conditions (32). To evaluate response of plant genotypes to drought stress, some selection indices based on a mathematical relation between stress- and optimum conditions has been proposed which is called as drought or stress indices (23). These indices are either based on drought resistance or susceptibility of genotypes (13). Drought resistance is defined by Hall (18) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (4). Fernandez (13) classified plants according to their performance in stressful(Ys) and stress free environments (Yp) to four groups: genotypes with similar good performance in both environments (Group A); genotypes with good performance only in non-stress environments (Group B) or stressful environments (Group C); and genotypes with weak performance in both environments (Group D). Many researches where demonstrated the evaluation of drought tolerance in wheat cultivars based on tolerance and sensitivity indices (3, 7, 8, 22 , 25). Fischer et al. (15) suggested that relative drought index (RDI) is positive indices for indicating stress tolerance. Rosielle & Hamblin (35) defined stress tolerance (TOL) as the differences in yield between the stress (Y_s) and non-stress (Y_p) environment. Mean productivity (MP) as the average yield of Y_s and Y_p. Fischer and Maurer (14) proposed a stress susceptibility index (SSI). Among the stress tolerance indicators, a larger value of TOL and SSI represent relatively more sensitivity to stress, thus a sma-ller value of TOL and SSI are favored. Selection based on these two criteria favors genotypes with low yield potentional under non-stress conditions and high yield under stress conditions. Guttieri et al. (18) using SSI criterion suggested that SSI more than 1 indicating above-average susceptibility and SSI less than 1 indicated below-average susceptibility to drought stress. Fernandez (13) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. The geometric mean (GMP) is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (34). On the other hand, selection based on STI and GMP will be resulted in genotypes with higher stress tolerance and yield potential will be selected (13). Ramirez and Kelly (34) reported that GM and SSI as the mathematical derivations of the same yield data, selection based on a combination of both indices may provide a more desirable criterion for improving drought resistance in common bean. In wheat, SSI and grain yield were used as stability parameters and identified drought resistant genotypes (2). Blum (4) defined new indices of drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both stress and non-stress conditions. The yield index (YI) suggested by Gavuzzi *et al*.(16) and yield stability index (YSI) suggested by Bouslama and Schapaugh (5) in order to evaluation the stability of genotypes in the both stress and non-stress conditions. To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (12) which corrects the STI as a weight. Moosavi *et al.* (30) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress conditions. The objectives of this study were to (i) identify drought tolerant wheat genotypes under stress and non-stress condition in the Central Region of Iraq, (ii) determine the efficiency of tolerance indices to classify wheat genotypes into sensitive and tolerant and (iii) interpret interrelationships among the tolerance indices by biplot and cluster analysis.

MATERIALS AND METHODS

Germplasm:

The germplasm used in this study comprised of 27 wheat genotypes including 20 accessions from the CIMMITY and 7 improved local varieties (Table 1).

Table 1: Twenty seven wheat genotpes along with their codes, and origin

Code	Genotype	Origin	Code	Genotype	Origin
G1	Buhooth 10	Iraq	G15	10	CIMITY-MEXICO
G2	38	CIMITY-MEXICO	G16	21	CIMITY-MEXICO
G3	25	CIMMITY-MEXICO	G17	29	CIMITY-MEXICO
G4	18	CIMMITY-MEXICO	G18	33	CIMITY-MEXICO
G5	28	CIMMITY-MEXICO	G19	30	CIMITY-MEXICO
G6	32	CIMMITY-MEXICO	G20	Buhooth 158	IRAQ
G7	31	CIMMITY-MEXICO	G21	Buhooth 22	IRAQ
G8	Iraq	IRAQ	G22	5	CIMITY-MEXICO
G9	20	CIMMITY-MEXICO	G23	23	CIMITY-MEXICO
G10	24	CIMMITY-MEXICO	G24	27	CIMITY-MEXICO
G11	26	CIMMITY-MEXICO	G25	17	CIMITY-MEXICO
G12	36	CIMMITY-MEXICO	G26	15	CIMITY-MEXICO
G13	Tahadi	IRAQ	G27	IPA 99	IRAQ
G14	Abu-Ghraib 3	IRAQ			

Experimental design and field layout

This research was conducted during the winter season of 2013- 2014 on the fields of State Board of Agricultural Research, at Abu-Ghraib, Baghdad. A split plot in randomized complete block design was used with three replications. The two irrigation treatments (irrigation at 25% of the available water was depleted (Yp), and irrigation at 75% of the available water was depleted (Ys) were allocated to the main plot. Whereas, the 27 genotypes (G1-G27) were assigned to the subplot. The plots were fertilized with 200 kg N .ha^{-1} and 100 kg .ha^{-1} of P_2O_5 at planting and three payment in three leaves ,node on the main stem and the last in booting stage.

Data Collection :

After harvesting from the four inner rows with a net plot area of 1.6 m^2 (4 rows *0.20 m apart*2 m length) were dried, threshed and weighed for final yield data collection which was then converted into ton ha^{-1}. Analysis of variance was calculated. Besides, the most desirable drought tolerance measures, the correlation coefficient between Yp, Ys, and other quantitative indices of drought tolerance were estimated using GenStat 12 statistical software (33). Ranking for the drought indices were estimated. The lowest mean was considered maximum response while highest score was minimum response to drought tolerance. Multivariate analysis for biplot and cluster analysis were also carried out using this Genstat software and Minitab to identify and classify genotypes under both stress and non-stress conditions.

Irrigation scheduling:

Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. The available soil water was taken as the difference between root zone water storage at field capacity and permanent wilting point. The maximum allowable depletion of the available soil water were fixed at 25 % (Yp) and 75%. (Ys) Using the data of soil moisture measured by gravimetric measurements, the percentage depletion of available soil water in the effective root zone was estimated by the equation (22),

$$Depletion\ (\%) = 100 * \frac{1}{n}\sum_{1}^{n}\frac{FC_i - \theta_i}{FC_i - WP}$$

where n is the number of sub-divisions of the effective rooting depth used in the soil moisture sampling, FCi is the soil moisture at field capacity for i^{th} layer, θ_i is the soil moisture in i^{th} layer and WP is the soil moisture at permanent wilting point. The amount of water applied after the attainment of predefined MAD was calculated as:

$$V_d = \frac{MAD(\%) * (FC - WP) * R_Z * A}{100}$$

Where Vd is the volume of irrigation water, (MAD) maximum allowable depletion of available soil water, Rz is the effective rooting depth and A is the surface area of the plot (21). The surface area of each plot was 16 m^2. Each 8m x 2m plot was made to small basins, each plot was fed individually. Measured amounts of water were applied to the plot using a hosepipe and a water meters. The number of irrigations,for yp and ys are 12and4 total amount of yp and ys are 399.75 and 262 mm respectively.

Screening Methods

Drought tolerance indices were calculated using the relationships presented in table 2:

Table 2. Drought indices, codes, equations, and refrences

	Drought Index	Code	Eqation	Reference
1	Mean Productivity	MP	$MP = (Y_p + Y_s)/2$	20
2	Susceptibility Index	SI	$SI = 1-(Y_p/Y_s)$	5
3	Stress Tolerance	TOL	$TOL = Y_p - Y_s$	35
4	Stress Susceptibility Index	SSI	$SSI = [1-(Y_s/Y_p)]/1-(\bar{Y}_s/\bar{Y}_p)$	14
5	Geometric mean Productivity	GMP	$GMP = \sqrt{Y_p * Y_s}$	13
6	Stress Tolerance Index	STI	$STI = (Y_p x Y_s)/\bar{Y}_p^2$	13
7	Harmonic Mean	HM	$HM = 2(Y_p x Y_s)/(Y_p + Y_s)$	6
8	Yield Index	YI	$YI = Ys/\bar{Y}s$	16
9	Yield stability index	YSI	$YSI = Ys/Yp$	5
10	Drought Resistance Index	DI	$DI = Ys \times (Ys/Yp)/Yp$	39
11	Stress Susceptibility Percentage Index	SSPI	$SSPI = [(Yp - Ys)/2(\bar{Y}p)] * 100$	30
12	Relative drought index	RDI	$RDI = (Y_S/Y_P)/(\bar{Y}_S/\bar{Y}_P)$	14

Where, Y_P and Y_S represent yield in stress and non-stress conditions respectively; $\bar{Y}p$ and $\bar{Y}s$ are mean yield in non-stress and stress conditions respectively (for all genotypes).

RESULT AND DISCUSSION

The results were indicated significant effect of Irrigation (contribute 75.6% of the total SS), genotype (14.0%) and irrigation by genotype interaction (4.24 %) (Table 3).Mean yield of normal irrigation (Yp) was 6.192 and ranged from 7.340 (G11) to 5.117 ton ha^{-1} (G23).While, mean yield of drought stess irrigation (Ys) was 3.070 ton ha-1, and ranged from 5.080 (G10) to 1.447 ton ha1- (G26) .Thus the data indicating a reduction of yield by 50% due to water stress.

Table 3. Mean squares from the analysis of variance for grain yield of 27 wheat genotypes evaluated under normal irrigation (Yp) and drought stress (Ys) conditions

Source of Variation	df	SS	MS	Prob. Of F	%Contribution to total SS
Block	2	0.0158	0.0079		0.003
Irrigation Level	1	394.9611	394.9611	< 0.001	75.6
Error (a)	2	0.5020	0.2510		0.09
Genotypes	26	73.0964	2.8114	< 0.001	14.0
Stress * Genotypes	26	22.1338	0.8513	< 0.001	4.24
Error (b)	104	31.376	0.3017		6.01
Total	161	522.0851			

The genotypes G1,G10, G11, G20 and G6 showed higher grain yield (Yp), and genotypes G24, G26, G14, and G15 showed lower yield (Yp). Where as, genotypes G10, and G1 recorded higher grain yield under Ys and, and G24, G25,G26, and G27 showed lower yield (Table 4).The genotypes G1and G10 perform well in both irrigation levels, where as G25, G23, and G27 produce lower yield in both irrigation levels. Mean productivity (MP), Geometric mean productivity (GMP), and Stress tolerance index (STI) showed similar ranking of genotypes relative to drought tolerance (Table 4, Table 5). Based on stress tolerance index (STI), the greater the difference between the yields found in normal and stress conditions, the smaller the amount of stress tolerance index and vice versa. Thus, genotypes G10, G1, G11, and G2 were found drought tolerant with high STI and grain yield under normal irrigated and stressed conditions, while genotypes G25, G26, G23and G13 displayed the lowest amount of STI and grain yield under stressed irrigation condition. Other genotypes were identified as semi-tolerant or semi-sensitive to drought stress (Table 4). To evaluate drought tolerance genotypes using TOL index, higher value of TOL demonstrates more changes of genotype yield in stress and non-stress conditions and shows the susceptibility to non-stress condition. Fernandez (13) and Rosielli and Hamblin (1981) stated that selection based on TOL index leads to selection of genotypes which their yields in non-stress condition are low and have lower MP. The results of this experiment showed that G1, G10, G15, and G14 were the most tolerant and G26 G20, G6, G19 were the most sensitive genotypes based on TOL index to the drought. For stress susceptibility index (SSI) the higher value refer to more susceptible to drought, there for, the genotypes G26, G25, G19 and G23 were the least relative tolerant genotypes and G1,G10, G15, and G24 are more tolerant genotypes. For stress susceptibility percentage index (SSPI) resulted the same genotype ranking as TOL. Genotypes G26, G20, G6, and G19 were more sensitive, and genotypes G1, G15, G10 and G14 the most relative tolerant genotypes. Mohammadi et al. (26) showed YSI to be a more useful index to discriminate drought-tolerance from drought-susceptible genotypes. Therefore, breeders should select this index for selection of stress tolerant genotypes. Based on YSI values, the highest and lowest YSI index belong to G1 and G26 genotypes. Similar ranking were observed by RDI. Yield index (YI) can be used as a selection criterion, although it only ranks cultivars on the basis of Ys. Based on YI, G1 and G10 genotype had the highest YI and Ys, whereas G26 and G25 had the lower YI and Ys. Based on drought resistance index (DI) genotypes G1, G10, G11, and G11 were the most while genotypes G26, G25, G23 and G27 were the least relative tolerant genotypes.

Ranking Method

The estimates values of drought tolerance indicies (Table. 4) indicated that the identification of drought tolerant genotypes based on a single criterion was contradictory. Different indices introduced different genotypes as drought tolerant. To determine the most desirable drought tolerant genotype according to the all indices, mean rank of all drought tolerance criteria were calculated and based on this criteria the most desirable drought tolerant genotype were identified (Table 5). In consideration to all indices, genotype G1, G2, G10, and G11, hence they were identified as the most drought tolerant genotypes, while genotypes G13, G23, G25 ,G26 and G27as the most sensitive (Table 5).

Correlation Coefficient

To determine the most desirable drought tolerance index, the correlation coefficient between Yp, Ys and other indices of drought tolerance were calculated (Table 6). A positive correlation (r=0.54) was found between grain yield of Yp and Ys suggesting that a high yield under non-stress condition is a moderate result in improving yield under stress. Thus, indirect selection for a drought prone environment based on the results of non-stress condition will be moderately efficient. This is in agreement with findings in durum wheat (26), bread wheat (9), and barley (31) where moderate positive association was found between yields under both stressed and non-stressed conditions. High significant positive correlations were found between yield Ys and the drought indices Mp ($r=0.85^{**}$), GMP($r=0.76^{**}$), STI($r=0.75^{**}$),and negative correlation with SSI (-0.23), SI (-0.23) and HMP (-0.63). Also, high positive correlation between Ys and Mp (r=0.92**), GMP (r=0.97**), STI(r=0.97**) and negative correlation with SSI (-0.93), SI (-0.92), HMP (-0.93) and TOL-0.66). These results were in agreement with Rosielle and Hamblin (35) and Mohammadi et al. (28). However, a negative and significant correlation with SSI (r =/0.93**) and TOL (r =/0.66**). Among the drought tolerance indicators, a higher value of TOL and SSI represent higher sensitivity to drought, thus smaller values of TOL and SSI are preferable. Thus, Selection based on these two indices (TOL and SSI) favors genotypes with low yield under normal non stress conditions and high yield under drought stress conditions (17). Most of the researchers stated that

Table 4. Mean values of yield in irrigated (Yp), stressed (Ys), and in drought tolerant indices

G	Yp	Ys	SI	MP	TOL	SSI	GMP	STI	HMP	YI	YSI	DI	RDI	SSPI
G1	6.58	4.911	0.254	5.745	1.669	0.511	5.684	0.852	0.178	1.585	0.746	1.183	1.483	13.554
G2	6.565	3.59	0.453	5.077	2.975	0.912	4.855	0.622	0.215	1.158	0.547	0.633	1.086	24.16
G3	6.455	3.487	0.46	4.971	2.968	0.926	4.745	0.594	0.221	1.125	0.54	0.608	1.073	24.099
G4	6.215	3.096	0.502	4.656	3.119	1.01	4.387	0.508	0.242	0.999	0.498	0.498	0.99	25.325
G5	5.8	2.726	0.53	4.263	3.074	1.067	3.976	0.417	0.27	0.88	0.47	0.413	0.934	24.962
G6	7	3.15	0.55	5.075	3.85	1.107	4.696	0.582	0.23	1.016	0.45	0.457	0.894	31.263
G7	6.82	3.137	0.54	4.979	3.683	1.087	4.626	0.564	0.233	1.012	0.46	0.466	0.914	29.905
G8	6.38	2.807	0.56	4.594	3.573	1.127	4.232	0.472	0.256	0.906	0.44	0.399	0.874	29.012
G9	5.73	3.42	0.403	4.575	2.31	0.812	4.427	0.517	0.233	1.104	0.597	0.659	1.186	18.758
G10	7.15	5.08	0.29	6.115	2.07	0.583	6.027	0.958	0.168	1.639	0.71	1.165	1.412	16.809
G11	7.34	4.04	0.45	5.69	3.3	0.905	5.446	0.782	0.192	1.304	0.55	0.718	1.094	26.797
G12	6.22	3.28	0.473	4.75	2.94	0.952	4.517	0.538	0.233	1.058	0.527	0.558	1.048	23.874
G13	5.25	2.41	0.541	3.83	2.84	1.089	3.557	0.334	0.303	0.778	0.459	0.357	0.912	23.062
G14	5.28	3.1	0.413	4.19	2.18	0.831	4.046	0.432	0.256	1	0.587	0.587	1.167	17.702
G15	5.58	3.55	0.364	4.565	2.03	0.732	4.451	0.522	0.23	1.146	0.636	0.729	1.264	16.484
G16	5.82	3.35	0.424	4.585	2.47	0.854	4.416	0.514	0.235	1.081	0.576	0.622	1.144	20.057
G17	5.79	2.62	0.547	4.205	3.17	1.102	3.895	0.4	0.277	0.845	0.453	0.383	0.899	25.741
G18	6.219	2.555	0.589	4.387	3.664	1.186	3.986	0.419	0.276	0.824	0.411	0.339	0.816	29.749
G19	6.72	2.89	0.57	4.805	3.83	1.147	4.407	0.512	0.247	0.933	0.43	0.401	0.855	31.101
G20	7.09	2.75	0.612	4.92	4.34	1.232	4.416	0.514	0.252	0.887	0.388	0.344	0.771	35.242
G21	6.2	3.167	0.489	4.684	3.033	0.985	4.431	0.518	0.239	1.022	0.511	0.522	1.015	24.629
G22	6.49	3.57	0.45	5.03	2.92	0.906	4.813	0.611	0.217	1.152	0.55	0.634	1.093	23.711
G23	5.117	2.05	0.599	3.584	3.067	1.207	3.239	0.277	0.342	0.662	0.401	0.265	0.796	24.905
G24	5.83	3.57	0.388	4.7	2.26	0.78	4.562	0.549	0.226	1.152	0.612	0.705	1.217	18.352
G25	5.21	1.58	0.697	3.395	3.63	1.403	2.869	0.217	0.412	0.51	0.303	0.155	0.603	29.477
G26	5.833	1.447	0.752	3.64	4.386	1.514	2.905	0.223	0.431	0.467	0.248	0.116	0.493	35.616
G27	5.567	2.337	0.58	3.952	3.23	1.168	3.607	0.343	0.304	0.754	0.42	0.317	0.834	26.228
Mean	6.192	3.080	0.499	4.628	3.059	1.005	4.341	0.511	0.256	1	0.501	0.527	0.995	24.836

Table 5. Related ranks for tested drought tolerance indices

G	Yp	Ys	SI	MP	TOL	SSI	GMP	STI	HMP	YI	YSI	DI	RDI	SSPI	RANK-SUM
G1	7	2	27	2	27	27	2	2	26	2	1	1	1	27	5
G2	8	4	18	4	16	18	4	4	24	4	10	8	10	16	4
G3	10	8	17	8	17	17	6	6	22	8	11	10	11	17	8
G4	14	16	14	14	12	14	17	17	13	16	14	14	14	12	15
G5	19	20	13	20	13	13	21	21	8	20	15	17	15	13	20
G6	4	13	9	5	3	9	7	7	20	13	19	16	19	3	3
G7	5	14	12	7	5	12	8	8	18	14	16	15	16	5	6
G8	11	18	8	15	8	8	18	18	9	18	20	19	20	8	14
G9	21	9	23	17	22	23	13	13	16	9	5	6	5	22	16
G10	2	1	26	1	25	26	1	1	27	1	2	2	2	25	2
G11	1	3	20	3	9	20	3	3	25	3	8	4	8	9	1
G12	12	11	16	11	18	16	10	10	17	11	12	12	12	18	11
G13	25	23	11	24	20	11	24	24	5	23	17	21	17	20	26
G14	24	15	22	22	24	22	19	19	10	15	6	11	6	24	23
G15	22	7	25	18	26	25	11	11	19	7	3	3	3	26	17
G16	18	10	21	16	21	21	15	15	15	10	7	9	7	21	18
G17	20	21	10	21	11	10	22	22	6	21	18	20	18	11	21
G18	13	22	5	19	6	5	20	20	7	22	23	23	23	6	19
G19	6	17	7	10	4	7	16	16	12	17	21	18	21	4	10
G20	3	19	3	9	2	3	14	14	11	19	25	22	25	2	9
G21	15	12	15	13	15	15	12	12	14	12	13	13	13	15	13
G22	9	5	19	6	19	19	5	5	23	5	9	7	9	19	7
G23	27	25	4	26	14	4	25	25	3	25	24	25	24	14	27
G24	17	6	24	12	23	24	9	9	21	6	4	5	4	23	12
G25	26	26	2	27	7	2	27	27	2	26	26	26	26	7	25
G26	16	27	1	25	1	1	26	26	1	27	27	27	27	1	22
G27	23	24	6	23	10	6	23	23	4	24	22	24	22	10	24

the best suitable index for drought tolerant genotypes is an index that is highly correlated with grain yield under both stress and normal conditions. (17), Sio-Se Mardeh et al. (37), and Talebi et al. (38).Upon mentioned above, selection based on MP, GMP and STI will result in the selection of genotypes with higher drought tolerance and yield potential.

Table 6. Simple correlation coefficients of drought indices with seed yield of 27 wheat genotypes

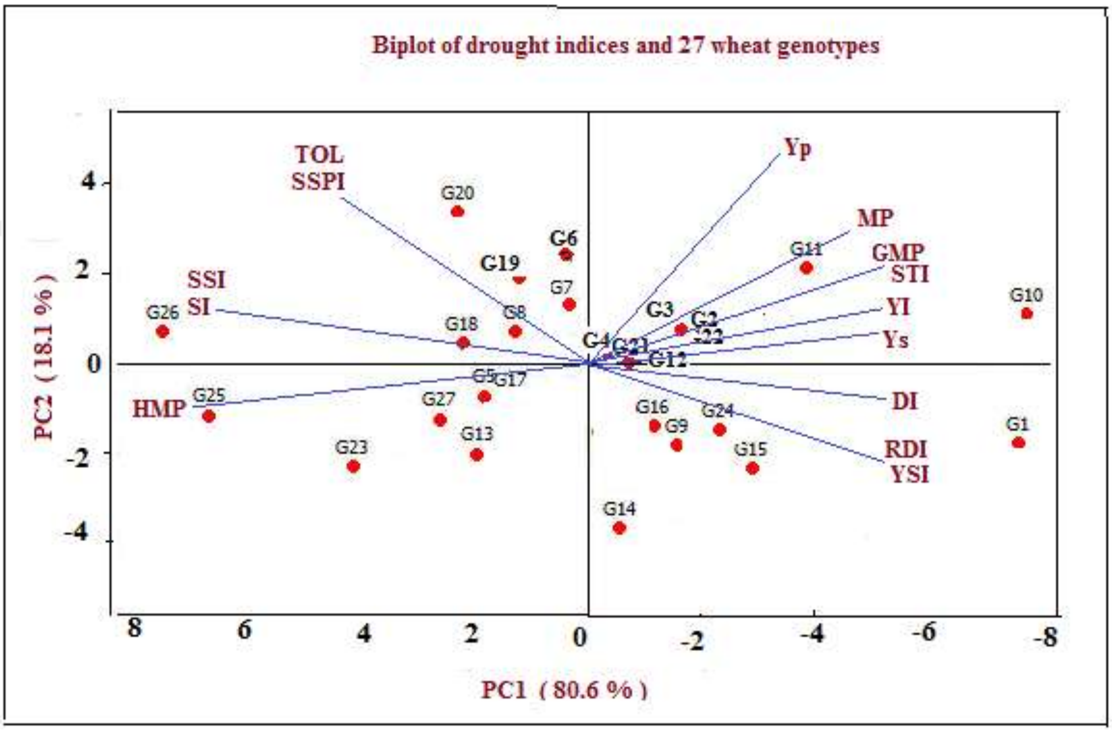
	Yp	Ys	SI	MP	TOL	SSI	GMP	STI	HMP	YI	YSI	DI	RDI
Ys	0.57												
SI	-0.23	-0.92											
MP	0.85	0.92	-0.70										
TOL	0.24	-0.66	0.89	-0.31									
SSI	-0.23	-0.93	1.00	-0.70	0.89								
GMP	0.76	0.97	-0.81	0.99	-0.45	-0.81							
STI	0.75	0.97	-0.80	0.98	-0.46	-0.80	0.99						
HMP	-0.63	-0.92	0.84	-0.89	0.52	0.84	-0.94	-0.89					
YI	0.57	1.00	-0.92	0.92	-0.66	-0.93	0.97	0.97	-0.92				
YSI	0.23	0.92	-1.00	0.70	-0.89	-1.00	0.81	0.80	-0.84	0.92			
DI	0.41	0.97	-0.96	0.82	-0.78	-0.96	0.89	0.90	-0.82	0.97	0.96		
RDI	0.23	0.93	-1.00	0.70	-0.89	-1.00	0.81	0.80	-.084	0.93	1.00	0.96	
SSPI	0.24	-0.66	0.89	-0.31	1.00	0.89	-0.45	-0.46	0.52	-0.66	-0.89	-0.78	-0.89

Biplot

In order to further investigation on relationship among genotypes and drought tolerance indices, principal component analysis were performed. This analysis is visually describing the degree of overall linear association between two indices. The correlation coefficient among any two indices is converted to a cosine of angle between two vectors (i.e r = -1.00 =cos 180^o, r=1.00=cos 0^o = 1.00, r=0 = cos 90^o=0). The Biplot is used to identify superior genotypes for both stress and non-stress environments. The first principle component (PCA 1) explained 80.6 % of the variation with Yp, Ys, MP, GMP and STI can be named as the yield potential and drought tolerance. Considering the high and positive value of this PCA on biplot, selected genotypes will be high yielding under stress and non-stress environments. The second principle component (PCA 2) explained 18.1% of the total variation and had the positive correlation with Ys and TOL can be named as stress-tolerant dimension and it separates the drought tolerant genotypes from non drought tolerant genotypes. Thus, selection of genotypes that have high PCA1 and low PCA2 are suitable for both stress and non stress environments. The biplot graph (Figure 1) revealed a strong association between YP, YS, MP, STI and GMP as indicated by acute angle between their vectors, and the biplot vectors for these indices remained between the Yp and Ys vectors, indicating that these indices are very similar for drought selection. Beside a negative association between Ys and TOL, SI, SSI, and HMP as indicated by large obtuse angle between their vectors. A high negative association between YSI and SSI indicated by Straight angle. Indices that have a high correlation with yield under drought stress and normal irrigation conditions (MP, GMP, and STI) emerged as major indices, in addition they placed on between yield under drought stress and normal irrigation conditions. The biplot demonstrate the association between drought indices and genotypes in term of productivity and drought tolerance. The genotypes G1,G10 recognized as most productive and tolerant , and genotypes G25, G26, G27, and genotypes G18 as low productive and more sensitive to drought.

Cluster Analysis

In order to classify of wheat genotypes, cluster analysis on Wards Method is used. The result of cluster analysis on all of the drought tolerance indices (Figure 2) showed that studied wheat genotypes classified in 4 classes. The numbers of genotypes in each class were 2, 12, 7 and 6 genotypes, respectively. The genotypes in each cluster evaluated together on drought indices. Also the results of cluster analysis were compared to the ranking of genotypes in the table 2 and 3. These results were completely agreement to the ranking of genotypes in table 2 and 3. At last it is cleared that the genotypes in the first cluster were high tolerant to drought. Second cluster refer to the genotypes associated with Ys. Third cluster, are referred to sensitive genotypes to the drought and associated with SSI and HMP. The fourth cluster were moderate tolerant and associated with Yp. The result of cluster analysis were in agreement to the biplot (Figure 1) and correlation coefficient (Table 6). To classify drought indices according to their similarity to assort genotypes upon drought tolerance, cluster analysis dendrogram showed similar classification to the biplot graph (Figure 1), and full agreement to the correlation coefficient between drought indices (Table 5). The results are in agreement with finding of sayyah *et al*. (36), Drikvand, *et al* (10) and Azizinia *et al*. (1).



Figuer 1. Biplot of the genotypes under study according to first and second component of principal components, over 12 drought tolerance indices of 27 wheat genotypes under normal irrigation and drought stress conditions

Conclusion

When breeder is looking for the genotype adapted for a wide range of environments, selection should be based on drought tolerant indices calculated from the grain yield under both conditions. In the present study, it was found that statistical methods including correlation between grain yield and indices, biplot analysis, and cluster analysis were identified the same genotypes as tolerant or as sensitive. We observed that mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI), yield index (YI) and rank sum are the best indices for selecting drought tolerant lines.

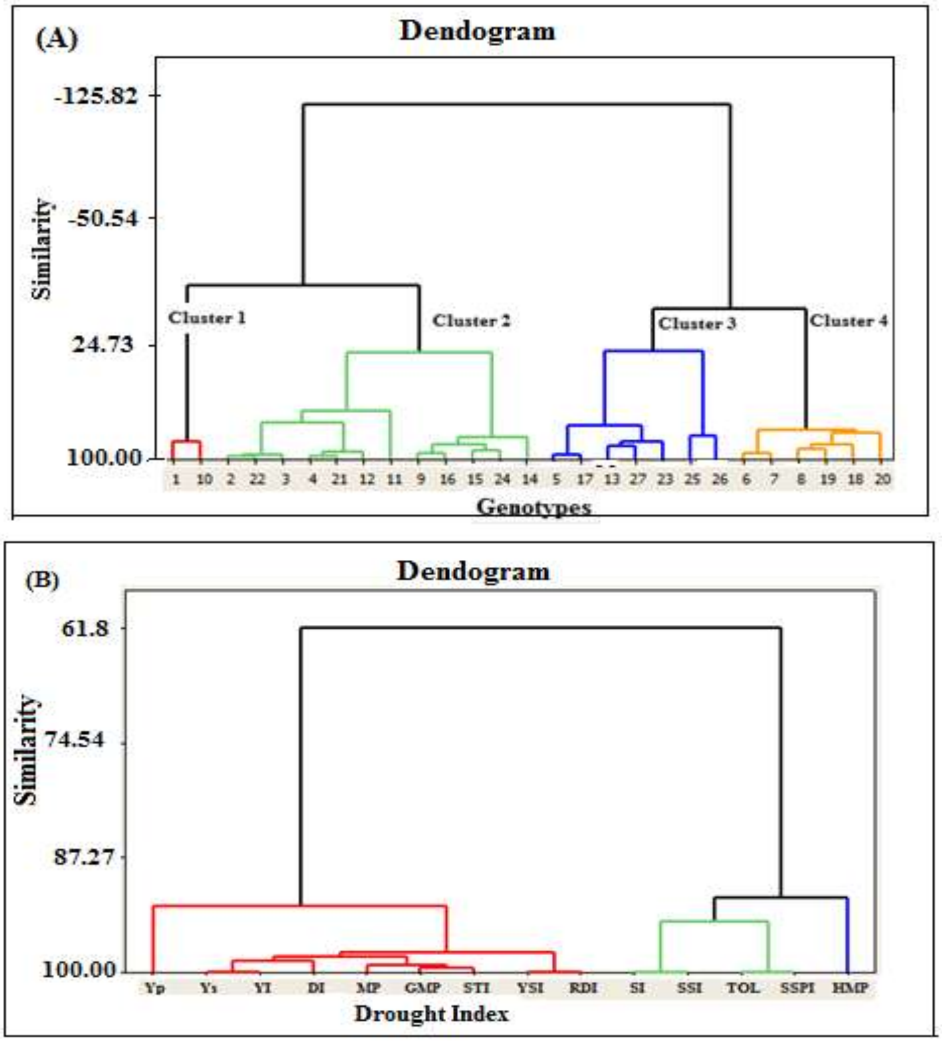


Figure 2. Dendrogram using Ward method between groups showing classification of genotypes(A) and drought indices (B) based on resistance/tolerance

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