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Study relationship of drought tolerance indices in wheat (*Triticum aestivum*) genotypes

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Abstract

Drought is a wide-spread problem seriously influencing wheat (*Triticum aestivum*) production and quality, but development of resistant cultivars is hampered by the lack of effective selection criteria. The objective of this study was to evaluate the ability of several selection indices to identify drought resistance cultivars under drought stress conditions. Eight wheat cultivars (*Triticum aestivum*) were chosen for the study based on randomized complete block design with three replications in the greenhouse. The resulting of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment; GMP, HARM, MP and STI were suggested as useful indicators for wheat breeding and on basis of this index genotypes 2022, Alvand and 2021 introduced as tolerant genotypes. The best indices for selecting tolerant species were GMP, HARM, MP and STI. Therefore genotypes which had higher amount of these indices identified as the most tolerant genotypes.

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Introduction

Wheat is the most important crop in the world and it is cultivating in about 228 million hectare around the world. Iranian farmers cultivate on an average 6.6 million hectares of wheat each year of which about 4.2 million hectares under rain fed (drought stressed) and the remaining of total wheat areas is irrigated or under irrigation (Shahryari and Mollasadeghi, 2011). Also, wheat is one of the agricultural plants which are cultivated in the large scale semi-arid areas; in these areas the rainfall is varying in different years. Considering the low heritability of drought tolerance and lack of efficient selection strategies, production of drought tolerance cultivars is difficult (Kirigiwi *et al.*, 2004). Wheat production in Mediterranean region is often limited by sub-optimal moisture conditions. Visible syndromes of plant exposure to drought in the vegetative phase are leaf wilting, decrease in plant height, number and area of leaves, and delay in accuracy of buds and flowers (Talebi *et al.*, 2009).

Due to occurrence of different forms of stress, especially drought stress in different stages of wheat growth, the average yield which was obtained in such areas every year, is 30 percent of the maximum yield which can be harvested (Denge *et al.*, 2005). Drought tolerance improvement has become a breeder's major aim in dry areas. Nevertheless, drought tolerance is a complex trait resulting from the contribution of numerous factors (Sadeghzadeh Ahari *et al.*, 2009). Breeding for drought tolerance by selecting solely for grain yield is difficult, because the heritability of yield under drought conditions is low, due to small genotypic variance or to large genotype-environment interaction variances (Naroui Rad *et al.*, 2010).

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 unpredictable rain-fed conditions. There is some agreement that a high yield potential is advantageous under mild stress, while genotypes with low yielding potential and high drought tolerance may be useful when stress is severe (Mohammadi *et al.*, 2010). To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions (Sadeghzadeh Ahari *et al*, 2009).

Tolerance (TOL) (Clarke *et al.*, 1992), mean productivity (MP) (Rosielle and Hamblin, 1981), stress susceptibility index (SSI) (Fischer and Maurer, 1978), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) have all been employed under various conditions. Fischer and Maurer (1978) explained that genotypes with an SSI of less than a unit are drought resistant, since their yield reduction in drought condition is smaller than the mean yield reduction of all genotypes. Yield stability index (YSI) also was computed as suggested by Bouslama and Schapaugh (1984). This parameter was calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions. The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions (Mohammadi *et al.*, 2010). Kaya *et al.*, (2002) in their study concluded that genotypes with large PC1 and small PC2 have higher yield in both stressed and non-stressed conditions (stable) and genotypes with large PC1 and small PC2 have lower yield (unstable).

The objective this study is to identify drought tolerant genotypes under drought stress condition. Using and comparison drought stress indices also group genotypes base on these indices, so that suitable genotypes can be recommended for cultivation in the drought prone area of Iran.

Materials and methods

Plant materials

Eight wheat cultivars (*Triticum aestivum*) were chosen for the study based on their reputed differences in yield performance under irrigated and drought stress conditions (Table 1). The experiment was carried in the greenhouse based on randomized complete block design with three replications.

Drought tolerance indices were calculated by using the following equations:

$STI = (Ypi \times Ysi)/Yp^2$ Fernandez, (1992);

$TOL = (Ypi - Ysi)$ Rosielle and Hamblin, (1981);

$HARM = 2(Ypi \times Ysi) / (Ypi + Ysi)$ Jafari *et al.*, (2009);

$GMP = \sqrt{Ypi \times Ysi}$ Fernandez, (1992);

$MP = (YPi + YSi) / 2$ Rosielle and Hamblin, (1981);

$SSI = (1 - (Ysi/Ypi)) / SI$; $SI = 1 - (Ys/Yp)$ Fischer and Maurer, (1978);

Yield stability index $(YSI) = Ysi/Ypi$ Bouslama and Schapaugh, (1984).

Where in these equations Y_{si} and Y_{Pi} are yields of a given genotype under stress and optimum condition, respectively. Y_s and Y_p are average yield of all genotypes under stress and optimal conditions, respectively. Data were analyzed using SPSS21 and Minitab16 software's.

Results and Discussion

Drought tolerance indices

Genotypes 2022, Alvand and 2021 had the highest grain yield and genotypes 2025 and Gascogen had the lowest yield in normal condition, respectively. Also, genotypes 2022, Alvand and 2021 had the most grain yield and genotypes 2071 and Gascogen had the lowest yield in stress condition, respectively (Table 2). Stress intensity (SI) has been given in stress susceptibility index (SSI) formula that it can be at most 1. In this study, stress intensity was calculated SI=0.385. The smaller the amount of SSI, the less stress susceptibility index (SSI) and the more relative tolerance of genotype to drought stress will be. In the other hand, the closer of YS to YP from quantitative point of view, the less the sensitivity of that genotype to drought will be. Genotypes Alvand, 2022 and 2021 were more tolerant genotypes based on SSI. Among the genotypes, genotype 2022 had the highest yield in stress condition (Table 2). Genotypes Tous, Alvand and 2025 were more tolerant genotypes based on TOL and genotypes 2071 and Sardari had the lowest tolerant based on TOL, respectively, which low quantity of TOL and SSI identified tolerant genotypes (Table 2). Among these genotypes, genotype Alvand had a high yield in both stress and normal conditions. Therefore, it seems that TOL and SSI had succeeded in selecting genotypes with high yield under both environments and if a given genotypes has high yields under both stress and normal conditions. SSI had a negative and significant correlation with yield in drought stress condition, but its correlation with yield in normal condition wasn't significant. Jabbari *et al.* (2008) and Ghafari (2008) reported that genotype evaluation through SSI, categorizes experimental materials according to tolerance and stress sensitivity. Through this index, tolerant and sensitive genotypes can be specified without regarding their performance potential.

Table 1. Name of genotypes used for drought tolerance assessment.

No	Name
1	Sardari
2	2021
3	Alvand
4	2022
5	2071
6	Tous
7	Gascogene
8	2025

Genotypes 2022, Alvand and 2021 had the highest MP (Table 2). So, MP index leads to selection towards more efficient genotypes in both stress and non-stress conditions. The results of this study correspond to the results of, Moghaddam and Hadizadeh (2002) and Shirinzadeh *et al.* (2008) reported that Mp index had important role in selecting stress tolerant genotypes compared to SSI and TOL. The highest YSI was in genotypes Alvand, 2022 and 2021, respectively (Table 2). In drought stress condition, YSI had a positive and significant correlation with grain yield in stress condition (YS) while it had non-significant correlation with grain yield in normal condition (YP). Genotypes 2022, Alvand and 2021, respectively had the highest stress tolerance index (STI) and genotypes Gascogen and 2071 had the lowest stress tolerance index (STI), respectively, the high amount of STI in these genotypes indicated the high drought tolerance and high potential yield. Genotypes 2022, Alvand and 2021 had the highest GMP. In addition, Genotypes 2022, Alvand and 2021 had the most Harm (Table 2). STI had specified the more tolerant genotypes in stress condition and GMP index was able to identify the genotypes which have the higher yield in stress and non-stress conditions (Fernandez, 1992). The observed relations were in consistence with those reported by Fernandez (1992) in mung bean, Talebi *et al.*, (2009), Mohammadi *et al.*, (2010) in durum wheat.

Table 2. Drought tolerance indices of 8 wheat genotypes under stress and normal conditions

Genotypes	Yp	Ys	STI	TOL	HARM	GMP	MP	SSI	YSI
Sardari	3.980 (4)	1.978 (5)	0.454 (5)	2.002 (7)	2.642 (5)	2.805 (5)	2.979 (5)	1.306 (7)	0.496 (7)
2021	4.740 (3)	3.330 (3)	0.912 (3)	1.410 (4)	3.911 (3)	3.972 (3)	4.035 (3)	0.772 (3)	0.702 (3)
Alvand	4.988 (2)	3.770 (2)	1.087 (2)	1.218 (2)	4.294 (2)	4.336 (2)	4.379 (2)	0.634 (1)	0.755 (1)
2022	5.433 (1)	3.900 (1)	1.224 (1)	1.533 (5)	4.540 (1)	4.603 (1)	4.666 (1)	0.732 (2)	0.717 (2)
2071	3.954 (5)	1.430 (8)	0.326 (7)	2.524 (8)	2.100 (8)	2.377 (7)	2.692 (6)	1.657 (8)	0.361 (8)
Tous	3.607 (6)	2.522 (4)	0.525 (4)	1.084 (1)	2.968 (4)	3.016 (4)	3.064 (4)	0.781 (4)	0.699 (4)
Gascogene	3.361 (7)	1.676 (7)	0.325 (8)	1.684 (6)	2.237 (7)	2.373 (8)	2.518 (8)	1.301 (6)	0.498 (6)
2025	3.212 (8)	1.854 (6)	0.344 (6)	1.357 (3)	2.351 (6)	2.440 (6)	2.533 (7)	1.097 (5)	0.577 (5)

The numbers in the parentheses are the genotype ranks for each index.

Table 3. Correlation coefficients between Ys, Yp and drought tolerance indices.

	Ys	Yp	STI	TOL	HARM	GMP	MP	SSI	YSI
Ys	1								
Yp	0.881**	1							
STI	0.984**	0.946**	1						
TOL	-0.578	-0.124	-0.433	1					
HARM	0.997**	0.915**	0.994**	-0.512	1				
GMP	0.990**	0.939**	0.998**	-0.458	0.998**	1			
MP	0.976**	0.964**	0.996**	-0.385	0.990**	0.997**	1		
SSI	-0.892**	-0.575	-0.799*	0.880**	-0.853**	-0.820*	-0.772*	1	
YSI	0.892**	0.575	0.799*	-0.880**	0.853**	0.820*	0.772*	-1.000**	1

* $p<0.05$, ** $p<0.01$

To determine the most desirable drought tolerance criteria, correlation coefficients between Ys, Yp and other quantitative indices of drought tolerance were calculated (Table 3). Consider to results of correlation coefficients of different indices and grain yield in two drought stress and normal conditions, we observed that indices STI, MP, GMP and HARM had the above-mentioned characteristic. These indices had positive and significant correlation with grain yield of genotypes at probability level of 1% in two drought stress and normal conditions (Table 3). Therefore genotypes which had higher amount of these indices identified as the most tolerant genotypes. Shafa Zadeh *et al*., (2004) in evaluation of wheat genotypes reported that there was positive and highly significant correlation between yield in stressed environment and indices MP, GMP and STI and also stated that there were positive and significant correlation between yield in non-stressed environment and all drought tolerance. Nazari and Pakniyat, (2010) with study on barley genotypes reported that there were significant differences for all criteria among the genotypes. The correlation coefficients indicated that STI, MP and GMP were the best criteria for selection of high yielding genotypes under stress and non-stress conditions.

Table 4. Principal components analysis for yield in stress and normal condition and drought tolerance indices.

Components	Ys	Yp	STI	TOL	HARM	GMP	MP	SSI	YSI	Cumulative %
PC1	0.362	0.312	0.354	-0.222	0.360	0.357	0.350	-0.330	0.330	84.5
PC2	-0.035	-0.432	-0.179	-0.672	-0.102	-0.154	-0.221	-0.351	0.351	15.4
										99.9

Table 5. Mean and difference percentage of Ys, Yp and drought tolerance indices of wheat genotypes grouping from cluster analysis.

	Group		Ys	Yp	STI	TOL	HARM	GMP	MP	SSI	YSI
1	Gascogene, 2025, Sardari, 2071, Tous	Mean	1.8923	3.623	0.396	1.731	2.46	2.603	2.758	1.2287	0.5268
		difference %	-35.16	-14.81	-64.4	7.442	-27.27	-24.51	-21.8	15.76463	-14.085
2	Alvand, 2022, 2021	Mean	3.485	4.049	0.564	3.767	3.715	3.74	0.657	0.753	0.879
		difference %	30.245	17.697	39.49	-15.5	26.31	24.7	22.97	-45.1206	17.13774
	Total	Mean	2.5577	4.1596	0.65	1.602	3.131	3.241	3.359	1.0354	0.6013

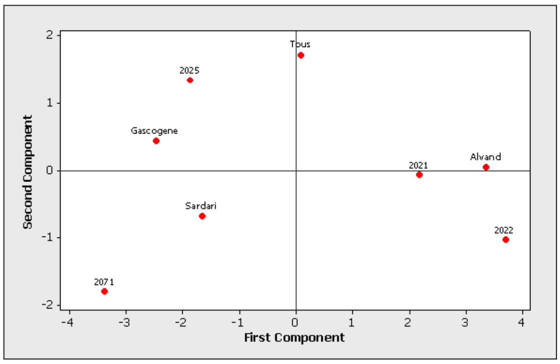

Fig. 1. Biplot of heat genotypes and drought tolerant indices based on first and second components.

Genotypes and drought tolerant indices

In order to further evaluation of relations between genotypes and drought tolerance indices, principal components analysis was performed. Table 3 showed latent roots and special vector of under-study genotypes for two first components, the most variations between data expressed by two components (99.00%). The first vector showed 84.5 percent of variations and showed that indices GMP, MP, HARM, Ys and STI in the formation of this component had the highest positive coefficient, since high amounts of these indices was optimal, and considering the positive relation of the first component with these indices, if we selected the top level, the genotypes were selected which had high and stable yield in different environments (drought stress, non-stress). So this component was named as drought tolerant component (Farshadfar *et al.*, 2001 and Pouresmael *et al.*, 2009). The second component had 15.4 percent of these variations. This component had high and negative correlation with the Yp, SSI and TOL, also had positive correlation with YSI.

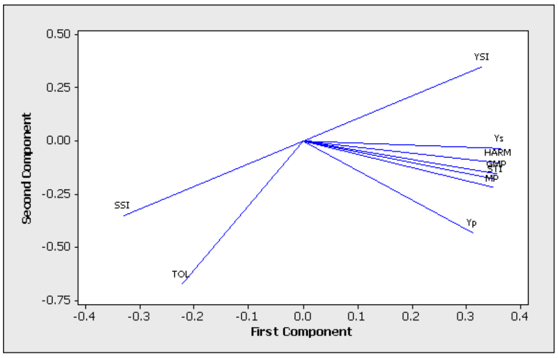

Fig. 2. Biplot of drought tolerant indices based on first and second components.

After principal components analysis was drawn to reviewing relationships between variables based on biplot first and second components (Figure 1 and 2), so that the horizontal axis was related to first component and the vertical axis was related to the second component. Based on component values, the location of genotypes and their grouping were determined in top of biplot. Biplot had been used by many researchers in comparing different genotypes. Kaya *et al.*, (2002) and Abdolshahi *et al.*, (2010) were able to reveal that bread wheat genotypes with larger PCA1 and lower PCA2 scores gave high yields (stable genotypes) and genotypes with lower PCA1 and larger PCA2 scores had low yields (unstable genotypes) (Table 4). The angle between them is less than 90 degree, this represents a positive correlation, and if the angle between the lines is more than 90 degree, this indicated the correlation was negative. The correlation coefficient between two indices was almost angle cosine of their vectors (Yan and Rajcan, 2002). Naroui-Rad *et al.*, (2010) in evaluation of lentil genotypes reported that STI and GMP had positive and significant correlation in %1 level with yield in drought and normal condition and principal components analysis showed two components explained 82.94% variation.

Principal components analysis results

According to the biplot (Figure 2) there was positive correlation between indices MP, GMP, HARM and STI and yield in two environments, and this confirming the correlation. Accordingly, these mentioned three indices were the most appropriate indices to screening genotypes. Two indices GMP and STI had similar value, since they were close to each other. The results of this study were compatible with Gol-Abadi *et al.*, (2006) and Kaya *et al.*, (2002). According to Biplot (Figure 1), genotypes 2022, Alvand and 2021 had stable and higher yield, these genotypes had large PC1 and its PC2 was almost small, so those were superior as compared to other genotypes. Shahryari and Mollasadeghi, (2011) with study on wheat genotypes under end seasonal drought reported that correlation analysis between indices and mean of yield in both conditions showed that the most suitable indices to screen genotypes in drought stress condition were MP, STI, GMP and HARM. According to stress tolerance indices, principal component analysis had been divided genotypes into two groups (drought tolerant and drought susceptible).

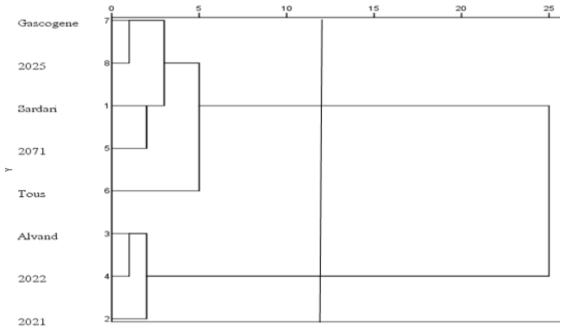

Fig. 3. Clustering of wheat genotypes based on Yp, Ys and drought tolerance indices.

Cluster analysis has been widely used for description of genetic diversity and grouping based on similar characteristics (Golestani *et al.*, 2007 and Malek shahi *et al.*, 2009). Separate cluster analysis (using Average Linkage between groups method) based on Yp, Ys and other quantitative indices of drought tolerance were performed for wheat genotypes (Table 5). Using the discriminate function analysis allowed the highest differences among groups when genotypes were categorized into two groups (Figure 3). Mean values of wheat genotypes groups in cluster analysis were presented in table 4. Group (II) Ys and majority of the drought tolerance showed maximum deviance of total means and this group may recommend as superior groups

(Figure 2). Also cluster analysis supported the results of principal component analysis because genotypes 2022, Alvand and 2021 were in this group. Mohammadi *et al*., (2011) in evaluation of bread wheat genotypes under dry-land and supplemental irrigation conditions indicated bi-plot display and cluster analysis cleared superiority of these genotypes in both years. Their results showed that MP, GMP and STI indices were more effective in identifying high yielding cultivars in diverse water scarcity.

Conclusion

The resulting of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment; GMP, HARM, MP and STI were suggested as useful indicators for wheat breeding and on basis of this index genotypes 2022, Alvand and 2021 introduced as tolerant genotypes. Also drawing bi-plot graph, and studied the correlation between grain yield in drought stress condition showed that the best indices for selecting tolerant species were GMP, HARM, MP and STI. Therefore genotypes which had higher amount of these indices identified as the most tolerant genotypes. They showed considerable potential to improve drought tolerance in wheat breeding programs.

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