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Research Article

Investigation and selection index for drought stress in durum wheat (*Triticum durum* Desf.) under Mediterranean condition

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Abstract

Drought is a wide-spread problem seriously influencing durum wheat (*Triticum durum* Desf.) 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 tolerant cultivars under varying environmental conditions. Ten durum wheat cultivars were evaluated under both moisture stress and non-stress field environments using a randomized complete block design for each of the environment. Six drought tolerance indices including stress susceptibility index (SSI), stress tolerance index (STI), yield stability index (YSI), mean productivity (MP), harmonic mean (HMP) and geometric mean productivity (GMP) were used. The indices were adjusted based on grain yield under drought and normal conditions. Yields in the normal condition were not correlated with yields in the stress condition, better stress susceptibility index (SSI) was associated with low yield under normal conditions, and therefore this index could not identify cultivars with good performance in both stress and non-stress condition. The significant and positive correlation of GYp and MP, GMP and STI showed that these indices were more effective in identifying high yielding cultivars under different moisture conditions. Stress tolerance index (STI) gave identical cultivar classification with the geometric mean (GMP), both being better than SSI in identifying top yielders in contrasting water availability conditions. The results of calculated gain from indirect selection from moisture stress environment would improve yield in moisture stress environment than selection from non moisture stress environment. Wheat breeders should, therefore, take into account the stress severity of the environment in choosing an index.

Key words
Durum wheat, drought, tolerance index, stress tolerance index, stress intensity.

Introduction

Durum wheat (*Triticum durum* Desf.) is one of the more widely cultivated crops in the Mediterranean basin, where drought is the main abiotic stress limiting its production (Royo *et al.*, 1998), it's mostly grown under rain-fed conditions, where drought and heat stress usually constrain yield potential during the grain filling period (Simane *et al.*, 1993). Drought stress at the grain filling period dramatically reduces grain yield. Visible syndromes of plant exposure to drought in the vegetative phase are leaf wilting, a decrease in plant height, number and area of leaves, and delay in accuracy of buds and flowers (Boyer, 1982; Passioura *et al.*, 1993). The negative effect of drought stress on yield performance has been well documented as a major problem in many developed and developing countries of the world (Guo, 2004; Passioura, 2007). Amongst the crop plants, wheat cultivation inadvertently faces drought conditions under arid and semi arid regions. It is widely consumed by humans in producer countries and other countries where wheat cannot be grown. About 95% of the wheat grown worldwide is bread wheat (Dixon et al., 2009), but durum wheat (*Triticum durum* Desf.) with a global production of 30 million tons, is an important adapted crop under drought conditions, particularly in the Mediterranean region where 75% of the world's durum grain is produced (Araus *et al*, 2002; Condon *et al*, 2004). Recently Siddique *et al.* (2000) has suggested that one important strategy for crop production, yield improvement, and yield stability is to develop drought tolerant crop varieties under water deficit conditions. Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes can be evaluated efficiently (Ramirez and Kelly, 1998). Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders while progress in yield gain has been much higher in favorable environments (Richards *et al*, 2002). Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992). Drought resistance is defined by Hall (1993) 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 (Blum, 1988) whilst the values are confounded with differential yield potential of genotypes (Ramirez and Kelly, 1998). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (GYs) and non-stress (GYp) environments and mean productivity (MP) as the average yield of GYs and GYp. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992) 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. Other yield based estimates of drought resistance are geometric mean (GM). The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (Ramirez and Kelly, 1998). Clark *et al*. (1992) used SSI for evaluation of drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and their ranking pattern. In spring wheat cultivars, Guttieri *et al*. (2001) using SSI criterion suggested that SSI more than 1 indicated above-average susceptibility to drought stress. Golabadi *et al*. (2006) and Sio-Se Mardeh *et al*. (2006) suggested that selection for drought tolerance in wheat could be conducted for high MP, GMP and STI under stressed and non-stressed environments. Fernandez (1992) had divided genotypes reaction on the basis of their yields into 4 categories under stressed and non-stressed conditions: group A are genotypes which have high yield in both conditions; group B are genotypes which have a high yield under non-stressed conditions; group C including genotypes which have a good yield under stressed conditions and finally group D are genotypes which have a low yield in both conditions. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting the genetic variations to improve the stress-tolerant cultivars (Clark *et al*., 1984). The present study was undertaken to assess the selection criteria for identifying drought tolerance in durum wheat genotypes, so that suitable genotypes can be recommended for cultivation in the drought area of Algeria.

Material and methods

Ten durum wheat cultivars (*Triticum durum* Desf.) were chosen for the study based on their differences in yield performance under irrigated and non-irrigated conditions (Table 1). These cultivars were planted on 30th November 2010, in the experimental fields of ITGC, Setif, Algeria (5°20'E, 36°8'N, 958 m above sea level). Genotypes were grown in randomized block design with four replicates. Plots were 2.5 m × 6 rows with 0.20 m row spacing and sowing density was adjusted to 300 g m^{-2}. The soil at the experimental site is a rendzin, mollisol (Calcixeroll USDA) up to 0.6 m in depth, containing low organic matter. SULFAZOT (26% N, 12% S) was applied at 120 Kg/ha at tillage on all plots. Weeds were removed chemically by TOPIC (0.75L/ha) and GRANSTA (15g/ha). Irrigated plots were watered at elongation and flowering stage. Non-irrigated plots were grown under rain-fed conditions. The total dry weight and grain yield (Qx /h) were measured by harvesting each plot at crop maturity. Six plants were randomly chosen from each plot to measure the number of grains per spike (grain/spike), plant height and spike length. Drought resistance indices were calculated using the following relationships:

1. Harmonic mean (HM) (Kristin *et al.*, 1997):

$$HM = 2\,(GYp * GYs) / (GYp + GYs)$$

GYp and GYs were the yield of each cultivars, non-stressed and stressed, respectively.

2. Stress susceptibility index (SSI) (Fisher and Maurer, 1978):

$$SSI = 1 - (GYs / GYp) / SI$$

while $SI = 1 - (G\hat{Y}s / G\hat{Y}p)$ whereas SI is stress intensity and $G\hat{Y}s$ and $G\hat{Y}p$ are the means of all genotypes under stress and well watered conditions, respectively.

3. Geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992; Kristin *et al*., 1997):

$$GMP = (GYp * GYs)^{½} \quad STI = (GYp * GYs) / (G\hat{Y}p)^2$$

4. Yield Stability Index (YSI) (Bouslama and Schapaugh, 1984):

$$YSI = GYs / GYp$$

5. Mean productivity (MP) (Hossain *et al*., 1990):

$$(GYp + GYs) / 2$$

Data were analyzed using SAS for analysis of variance and Fisher’s LSD multiple range test was employed for the mean comparisons.

Results and Discussion

In this study, the stress intensity (SI) was 14.72 %. It is essential to say that this index is just to measure drought stress intensity in experiment and it has no efficiency to measure stress intensity in varieties (Fisher and Maurer, 1978). Achieved results from calculation of drought tolerance and drought sensitive indices (Table 2) shows that the higher value of MP, GMP and STI indicated stress tolerance. Entries Waha, Dukem and Sooty yielded 6.46, 6.39 and 6.31 tons/ha respectively as stress adaptive genotypes. Genotype Sooty with yield of 6.31 tons/ha under stressed condition and 7.55 tons/ha under non stressed condition is identified as a tolerant variety. These indices had identified Oued Zenati and Polonicum with yields 5.22 and 5.64 tons/ha, respectively as the most sensitive genotypes under drought stress conditions. Stress sensitive index (SSI) value with less than one indicated high tolerance of variety to stress (Choukan *et al*., 2006), SSI indices, which indicate in lower amounts with relative tolerance to stress, identified Waha and Hoggar (with yields 6.43 and 6.00 tons/ha, respectively) as tolerant genotypes, as well as they identified Kucuk and Bousselem (with yields 5.39 and 5.50 tons/ha, respectively) as drought sensitive genotypes. Evaluation of genotypes by SSI, had divided experimental material on the basis of stress tolerance and stress sensitive, that helps to determine tolerant and sensitive genotypes regardless of their yield potential by this index (Naderi *et al*., 2000). Stress sensitive index is evaluated on the basis of proportion of each variety yield under stressed to non-stressed condition in comparison with this proportion to total varieties. Thus, varieties with low/high yield can have equal SSI rate in both conditions, so selection process on the basis of this index can cause mistake (Naeimi *et al*., 2006). The best index to select varieties, is stress tolerance index (STI), as it can separate varieties which has high yield in both stressed and non-stressed conditions (group A) from two groups of varieties which have just relatively batter yield under non- stressed (group B) or stressed (group C) conditions (Fernandez, 1992). Results from correlation between drought tolerance and yield indices (Table 3) can be applied to select the best genotypes and indices as a suitable standard. Yield in normal condition show positive and significant correlation with mean productivity (MP) (r = 0.88***), geometric mean (GMP) (r = 0.86**), stress tolerance index (STI) (r = 0.86**) and harmonic mean (HM) (r = 0.78*) in probability level of 0.1%, 1% and 5% respectively. These results are compatible with Roiselle and Hamblin (1981). They show that in a majority of comparative experiments, the correlation of yield between MP and GYp and also MP and GYs is positive. Yield under stressed conditions show positive and significant correlation with mean productivity (MP) (r = 0.77**), geometric mean (GMP) (r = 0.79**), stress tolerance index (STI) (r = 0.79**) and harmonic mean (HM) (r = 0.79**) in probability level of 1%; but it shows negative and significant correlation with stress sensitive (SSI) (r = -0.64*) in probability level of 5%. Choukan *et al.* (2006), Khalilzade and Karbalaei Khiavi (2002) and Farshadfar *et al.* (2001) believed that the best suitable index to select stress tolerance varieties, is index in which there is relatively high correlation with grain yield in both stressed and non-stressed conditions. Therefore, by evaluation of correlation rate between grain yield and stress tolerance in both conditions, it can be possible to identify most suitable index. Since mean productivity (MP), geometry mean of productivity (GMP), harmonic mean (HM) and Fernandez index show high correlation in both normal irrigation and drought stress conditions, introduced as major indices. Farshadfar *et al.* (2001) in a research about pea reported that all of indices show positive and significant correlation with yield under non-stressed condition. Fernandez (1992) in a three years study in normal and low-water stress conditions realized that there was a significant and negative correlation between grain yield and stress sensitive indices. They reported that there is positive and significant correlation between STI and GMP indices with wheat yield. Shafazade *et al.* (2004) in a study of wheat genotypes, reported positive and significant correlation between yield in non-stressed condition and MP, GMP and STI and also they expressed that there is positive and significant correlation between yield in non-stressed condition and all drought tolerance and drought sensitive indices. They suggested that existence of positive and significant correlation between indices and yield in both conditions (stressed and non-stressed) means these indices are suitable to evaluate drought tolerance of genotypes. Bahmaram *et al.* (2006) in their reports about evaluation of drought tolerance of spring varieties expressed that STI can be better applied to evaluate drought tolerance of varieties than SSI. Results of this research are compatible with Taghizade *et al.* (2002). They realized that among the indices, MP, GMP and STI indices have a positive and significant correlation with yield in both conditions, while evaluation of drought tolerance references in lentil genotypes in a research, realized that there is no relation between stress sensitive index (SSI) and grain yield (Fernandez, 1992). Choukan *et al.* (2006) by evaluation of some drought tolerance indices in some genotypes of spring barley, reported significant correlation between with MP and GMP in both stressed and non-stressed conditions. Rosielle and Hamblin (1981) showed that in a majority of comparative experiments, the correlation of yield between MP and GYp, and MP and GYs are positive. According to their reports, selection on the basis of MP generally cause to increasing yield in both normal and stressed conditions. Fernandez (1992) declared that sensitivity of GMP index is less than different amounts of GYp and GYs, while MP index which is on the basis of computation mean, has up-curve, as there is relatively high difference between GYp and GYs, thus GMP has the highest capability to separate major genotypes in comparison with MP. Correlation between drought tolerance and yield indices (Table 3) can be applied as a suitable standard to select better genotypes and indices. As STI, GMP and MP were able to identify cultivars producing high yield in both conditions. When the stress was severe, TOL, YSI and SSI were found to be more useful indices discriminating resistant cultivars, although none of the indicators could clearly identify cultivars with high yield under both stress and non-stress conditions (group A cultivars). It is concluded that the effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress conditions, potential yield greatly influences yield under stress (Blum, 1996; Panthuwan *et al*., 2002). In order to grouping genotypes, we used from ear analysis by the Ward way on the basis of standardized mean of evaluated drought tolerance indices during both stressed and normal conditions and 10 under-study genotypes were placed on two groups (Figure. 1). First group including genotypes like Waha, Dukem and Sooty; second group including genotypes like Oued Zenati, Altar, Polonicum, Mexicali, Kucuk, Hoggar and Bousselem. Principal component analysis (PCA) revealed that the first PCAs explained 66.14 % of the variation with GYs, GYp, HM, GMP, STI and MP (Figure 2). Thus, the first dimension can be named as the yield potential and drought tolerance. Considering the high value of this biplot, genotypes that have high values of these indices will be high yielding under stress and non-stress environments. The second PCA explained 32.51 % of the total variability and correlated positively with YSI and negatively with SSI. Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from non-stress tolerant ones. Thus, selection of genotypes that have high PCA1 and low PCA2 are suitable for both stress and non-stress environments. Therefore, genotypes Waha, Dukem and Sooty were superior genotypes for both environments with high PC1 and low PC2. Genotypes Oued Zenati, Altar, Polonicum, Mexicali, Kucuk, Hoggar and Bousselem with high PC2 were more suitable for non-moisture stress than for moisture-stress environment. Farshadfar and Sutka (2003), Sio-Se Mardeh *et al*. (2006) and Golabadi *et al*. (2006) obtained similar trends in multivariate analysis of drought tolerance in different crops. First and second main components had justified 98.65 % of total variations (Table 4). In stressed and non-stressed conditions and by charting of 3D (3-dimension) diagram about yield of varieties in both conditions, as well as about STI and GMP indices, it was obvious that genotypes which are located in group A, had high STI and GMP and introduced these two indices as the best. The biplot diagram had divided into four quadrants named A, B, C and D on the basis of two first components and genotypes which are placed on A region, have the high yield under drought stress and normal irrigation and also drought tolerance conditions. On the other hand, genotypes which are placed on D region have the lowest yield in both conditions and also they are sensitive. Indices that have a high correlation with yield under drought stress and normal irrigation conditions, emerged as major indices, in addition they placed on between yield under drought stress and normal irrigation conditions.

Conclusions

Over all, drought stress reduced significantly the yield of some genotypes and some of them revealed tolerance to drought, which suggested the genetic variability for drought tolerance in this material. In our study, Waha, Dukem and Sooty revealed a high tolerance to drought. Therefore, based on this limited sample and environments, testing and selection under non-stress and stress conditions alone may not be the most effective approach for increasing yield under drought stress. The significant and positive correlation of GYp and MP, GMP and STI showed that these criteria indices were more effective in identifying high yielding cultivars under different moisture conditions. The results of calculated gain from indirect selection in moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Wheat breeders should, therefore, take into account the stress severity of the environment when choosing an index for identifying drought adaptive genotypes.

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Table 1. Origin of the ten genotypes used in the study

Cultivar	Name	Origin	Cultivar	Name	Origin
1	Bousselem	Algeria	6	Altar	Mexico
2	Hoggar	Algeria	7	Dukem	Mexico
3	Oued Zenati	Algeria	8	Kucuk	Mexico
4	Polonicum	Algeria	9	Mexicali	Mexico
5	Waha	Algeria	10	Sooty	Mexico

Table 2. Estimation of sensitivity rate of 10 durum wheat genotypes by different drought tolerance indices under normal and stressed conditions

	GYs	GYp	HM	SSI	YSI	STI	GMP	MP
Oued Zenati	5.22d	5.74b	5.60ef	0.995abc	0.865ab	0.671e	5.46e	5.48e
Altar	5.59bcd	6.91ab	6.15cd	1.13abc	0.825ab	0.87bcd	6.20bcd	6.25bcd
Sooty	6.31abc	7.55a	6.82a	0.994abc	0.843ab	1.065a	6.88a	6.93a
Polonucum	5.64abcd	6.01ab	5.51f	0.775bc	0.87ab	0.758de	5.79de	5.83de
Waha	6.46a	6.59ab	6.67abc	0.4213c	0.938a	0.955abc	6.52abc	6.52abc
Dukem	6.39ab	7.27ab	6.74ab	0.855bc	0.875a	1.039ab	6.80ab	6.83ab
Mexicali	5.96abcd	6.34ab	6.27bcd	0.779bc	0.901a	0.849cd	6.14cd	6.15cd
Kucuk	5.39d	7.35a	6.20bc	1.758a	0.742b	0.891abcd	6.29abcd	6.37abcd
Hoggar	6.00abcd	6.23a	5.93def	0.528bc	0.916a	0.828cde	6.05cde	6.12cde
Bousselem	5.50cd	6.77ab	6.06de	1.38ab	0.813b	0.833cde	6.09cd	6.13cd
Mean	5.85	6.68	6.19	0.961	0.859	0.876	6.22	6.26
Min	5.22	5.74	5.51	0.421	0.742	0.671	5.46	5.48
Max	6.46	7.55	6.82	1.758	0.938	1.065	6.88	6.93
LSD $_{(5\%)}$	0.815	0.977	0.549	0.889	0.137	0.175	0.632	0.651

Means followed by the same latter are not significantly different at $p<0.05$; GYs: Yield under stress condition (tons/ha), GYp: Yield under non-stress condition (tons/ha), HM: Harmonic mean, SSI: Stress susceptibility index, YSI: Yield Stability Index, STI: Stress tolerance index, GMP: Geometrie mean productivity and MP: Mean productivity

Table 3. Correlation between grain yield under non-stress, stress conditions and drought tolerance indices

	GYs	GYp	HM	SSI	YSI	STI	GMP	MP
GYs	1							
GYp	0.37	1						
HM	0.79**	0.78*	1					
SSI	-0.64*	0.46	-0.09	1				
YSI	0.6	-0.5	0.08	-0.98***	1			
STI	0.79**	0.86**	0.95***	-0.05	-0.00	1		
GMP	0.79**	0.86**	0.96***	-0.04	-0.00	1.00***	1	
MP	0.77**	0.88***	0.94***	-0.01	-0.04	1.00***	1.00***	1

*; ** and *** significantly at $p < 0.05$, < 0.01 and < 0.001, respectively. GYs: Yield under stress condition (tons/ha), GYp: Yield under non-stress condition (tons/ha), HM: Harmonic mean, SSI: Stress susceptibility index, YSI: Yield Stability Index, STI: Stress tolerance index, GMP: Geometric mean productivity and MP: Mean productivity

Table 4. Principal component loadings for the measured traits

Component	Proportion of total variation (%)	Variables GYs	GYp	HM	SSI	YSI	STI	GMP	MP
Factor 1	66,14	-0.814	-0.839	-0.968	0.083	-0.041	-0.998	-0.998	-0.994
Factor 2	32.51	0.574	-0.538	0.027	-0.99	0.995	-0.04	-0.044	-0.081
Factor 3	1.11	-0.056	-0.055	0.249	0.087	0.074	-0.045	-0.034	-0.066

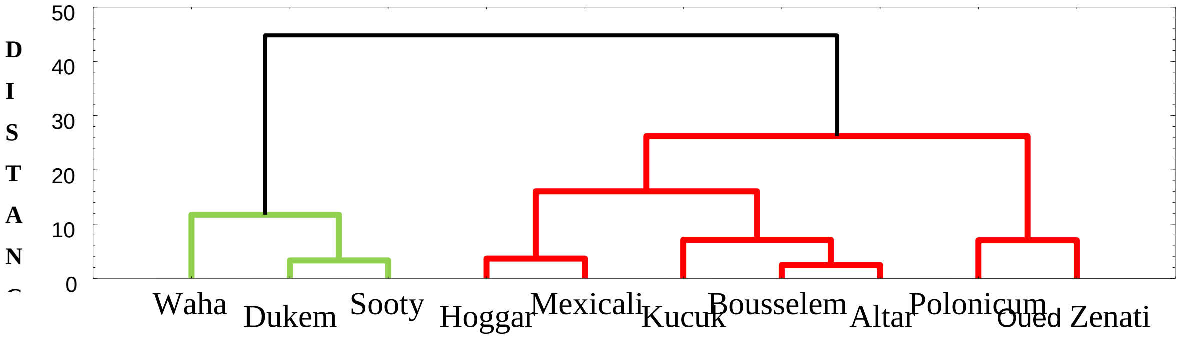

Figure 1. Achieved dendrogram form ear analysis by the minimum variance of ward way on the basis of drought tolerance indices of 10 wheat genotypes under normal irrigation and drought stress conditions

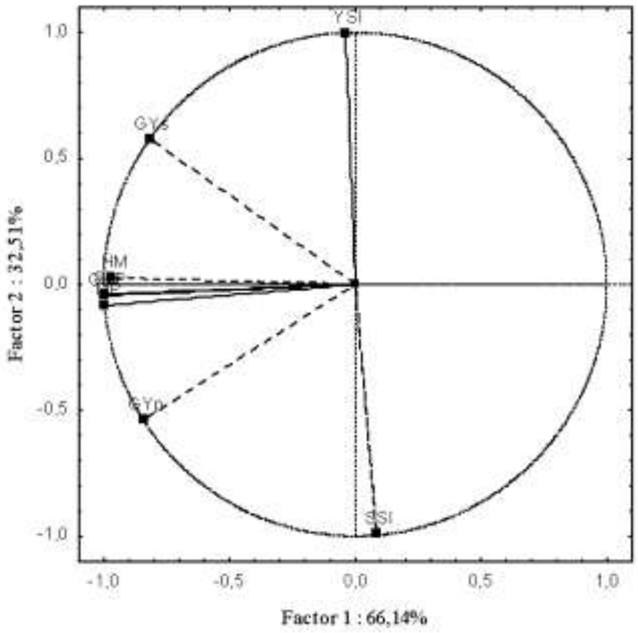

Figure 2. Principal component analysis of drought resistance indices