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Evaluation of Drought Tolerance Indices for Screening Some of Corn (*Zea mays* L.) Cultivars under Environmental Conditions

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Abstract

In order to study the effect of drought stress on eight cultivars corn *(Zea mays* L.), an experiment was conducted in a factorial experimental on the basis of randomized complete block design under two irrigated conditions during 2010-2011 cropping season. Twelve drought tolerance/resistance indices including stress tolerance index (STI), stress susceptibility index (SSI), tolerance index (TOL), geometric mean production (GMP), mean production (MP), yield index (YI), yield stability index (YSI), drought resistance index (DI), relative drought index (RDI), stress susceptibility percentage index (SSPI) and modified stress tolerance (K_1STI and K_2STI) were calculated based on grain yield under drought and irrigated conditions. Yield in stress and non-stress conditions were significantly and positively correlated with STI, GMP, MP, YI, TOL, DI, RDI, YSI, SSPI, K_1STI, and K_2STI and negatively correlated with SSI. Yield in stress and non-stress conditions were significantly and positively correlated with STI, GMP, MP, YI, TOL, DI, RDI, YSI, SSPI, K_1STI, and K_2STI and negatively correlated with SSI. Screening drought tolerant cultivars using ranking method, three dimensional plots discriminated cultivars 'KSC720', KSC 710GT and 'KSC 700' as the most drought tolerant. Cluster analysis classified the cultivars into three groups i.e., tolerant, susceptible and semi-susceptible to drought conditions. In general, Results of this study showed that among drought tolerance indices STI, YI, SSPI, K_1STI, and K_2STI can be used as the most suitable indicators for screening drought tolerant cultivars and 'KSC720', KSC 710 GT and 'KSC 700' had the highest tolerance to drought in our studies condition.

Keywords: correlation analysis, drought stress, ranking method, selection indices, *Zea mays* L.

Introduction

Corn (*Zea mays* L.) is one of the most important grain crops in Iran which its grain yield is in average more than 8 ton/ha and it has the least tolerance to high plant density (Shakarami and Rafiee, 2009) and due to huge amounts of sugar, sweet corn is different from other corn varieties (Akman, 2002). After wheat and rice, maize is the third most important cereal crop in the world (Lashkari *et al.,* 2011). According to the FAO reports in Iran (annual rainfall 24 mm), the production of maize was estimated 2.8 percent of total cereals production and 1.6 million tons grain yield from 0.25 million hectare of arable and cultivated lands, however hybrid grain production is extremely low (Moradi Dezfuli *et al.,* 2008).

All the alive and non-alive stresses are the most factors to reducing production nonetheless; drought stress is the most important factor limiting crops production in agricultural systems in arid and semi-arid regions (Mollasadeghi *et al.,* 2011). Iran is located on the world's desert belt, and is considered as the arid and semiarid region. Average rainfall in the country is about 250 (mm) which this is one third of average rainfall in the world, while 1.2 percent of the world's land is allocated to Iran. On the other hand, of 18.5 million hectares of agricultural lands, 6.2 million hectares (33.5 %) is devoted to dry cultivation. About 1.2 million/ha of lands under dry cultivation, more than 400 (mm) rainfall will receive (Mohammadi *et al.,* 2006). Grain yield reduction of maize due to the drought pressure is varied between 1 to 76% depending on the severity, timing, and stage of occurrence (Song *et al.,* 2010; Mostafavi *et al.,* 2011; Zarabi *et al.,* 2011). Among different factors which affect and decline corn yield, 31 percent was belong to drought stress and thicker plant stand, using various hybrids, differences in irrigation methods and climatic conditions should be considered in corn yield reduction (Eck, 1984). Loss of yield is the main concern of plant breeders and they hence emphasize on yield performance under stress conditions. Thus, drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been used for screening drought/tolerant genotypes (Mitra, 2001). Drought tolerance selection is not easy due to the happening of strong interactions between genotypes and the environment and restricted knowledge about the function and role of tolerance mechanisms. Various researchers have used different methods to evaluate genetic differences in drought tolerance. According to Fernandez (1992) the best measure for selection in drought condition could be able to separate geno-

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types which have desirable and similar yield in stress and non-tress condition from other groups and also, the best indices are those which have high correlation with kernel yield in both conditions. On the other hand, Drought resistance is defined by Hall (1993) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Several selection criteria have been proposed to select genotypes based on their performance in stress and non-stress environments. Rosielle and Hamblin (1981) demonstrated that lower stress tolerance index (STI), hybrid yield in normal irrigation and drought condition is close to each other or plant is resistant to drought. Stress Tolerance Index (STI) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). Blum (1988) 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. So, Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Fernandez, 1992). Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Clarke *et al.* (1992) used SSI to evaluate drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and could rank their pattern. In spring wheat cultivars, Guttieri *et al.* (2001) using SSI, suggested that an SSI > 1 indicated above-average susceptibility to drought stress. The yield index (YI; suggested by Gavuzzi *et al.,* 1997) and yield stability index (YSI) suggested by Bouslama and Schapaugh (1984) in order to evaluation the stability of genotypes in the both stress and non-stress conditions. Stress Tolerance Index (STI) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which corrects the STI as a weight. Moosavi *et al.* (2008) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress conditions.

This study was carried out in order to evaluate corn cultivars reaction to drought stress and determine the best measures for increase and improvement of cultivars yield in stress and non-stress condition. Also, this study was undertaken to assess the selection criteria for identifying drought tolerance in corn cultivars, so that suitable cultivars can be recommended for cultivation in drought prone areas of Iran and it similar areas.

Materials and methods

Experimental design and plant material

This experiment was conducted on the basis of factorial experimental with completely randomized block design in 3 replications in 2010-2011, at Agricultural and Natural Resources Research Center of West Azerbaijan, Iran (latitude 36.46° N, longitude 45.43° E, Altitude 1385 m above sea level). The climate is characterized by mean annual precipitation of 330 mm, mean annual temperature of 12°C. Sowing was done by hand in plots with 40 plants in one plot. Eight cultivars in this experiment showed in Tab. 1. All plots were irrigated after sowing and subsequent irrigations in beginning in stem elongation were carried out after 50 mm (I1, as control) and 150 mm (I2, as water stress) evaporation from class A pan. Weeds were controlled by hand during crop growth and development. Fertilizers were applied prior to sowing at a rate of 200 kg ha^{-1} Ammonium Phosphate ($NH_4H_2PO_4$) and 400 kg ha^{-1} Urea ($CO(NH_2)_2$). Other normal practices for maize production were followed. At harvest time, yield potential (Yp) and stress yield (Ys) were measured.

Calculate indices

Twelve drought tolerance indices including Stress susceptibility index (SSI), Relative drought index (RDI), Stress tolerance index (STI), Geometric mean productivity (GMP), Tolerance (TOL), Mean production (MP), Yield index (YI), Drought resistance index (DI), Yield stability index (YSI), Stress susceptibility percentage (SSPI), Modified stress tolerance index (KiSTI), were calculated using the following relationships (Fischer and Maurer, 1978; Fischer *et al.,* 1998; Fernandez, 1992; Rosielle and Hamblin, 1981; Bouslama and Schapaugh, 1984; Blum, 1988; Moosavi *et al.,* 2008; Farshadfar and Sutka, 2002):

$$SSI=(1-(Y_s/Y_p))/(1-(\bar{Y}_s/\bar{Y}_p)) \quad \text{Eq. 1}$$

$$RDI=(Y_s/Y_p)/(\bar{Y}_s/\bar{Y}_p) \quad \text{Eq. 2}$$

$$STI=(Y_s\times Y_p)/(\bar{Y}_p^2) \quad \text{Eq. 3}$$

$$GMP=\sqrt{Y_s\times Y_p} \quad \text{Eq. 4}$$

$$TOL=Y_s-Y_p \quad \text{Eq. 5}$$

$$MP=(Y_s+Y_p)/2 \quad \text{Eq. 6}$$

$$YI=(Y_s)/(\bar{Y}_s) \quad \text{Eq. 7}$$

$$DI=(Y_s\times(Y_s/Y_p))/\bar{Y}_s \quad \text{Eq. 8}$$

$$YSI=Y_s/Y_p \quad \text{Eq. 9}$$

$$SSPI=(Y_p-Y_s/2(\bar{Y}_p))\times 100 \quad \text{Eq. 10}$$

$$KiSTI,\ K_1=Y_p^2/\bar{Y}_p^2 \text{ and } K_2=Y_s^2/\bar{Y}_s^2 \quad \text{Eq. 11 and 12}$$

In the above formulas, Ys, Yp, $\bar{Y}_s$ and $\bar{Y}_p$ represent yield under stress, yield non-stress for each cultivar, yield mean in stress and non-stress conditions for all cultivars, respectively.

Cultivars can be categorized into four groups based on their performance in stress and non-stress environments: cultivars express uniform superiority in both stress and non-stress conditions (Group A), cultivars perform favorably only in non-stress conditions (Group B), culti-

Tab. 1. Cultivars of canola used for drought tolerance assessment

No.	Cultivar	No.	Cultivar
1	'KSC720'	5	KSC 710 GT
2	'KSC 700'	6	KSC -Mog 84-062
3	'KSC- N84-01'	7	KSC 704
4	'KSC 708GT'	8	KSC- N84-02

vars gives relatively higher yield only in stress conditions (Group C), and cultivars perform poorly in both stress and non-stress conditions (Group D). The optimal selection criterion should distinguish Group A from the other three groups. Three-dimensional plots among YS, Yp, and STI, showed the interrelationships among these three variables to separate cultivars of Group A from other groups (Fernandez, 1992).

Statistical analysis

Correlation among indices and grain yield in two conditions and three-dimensional plots drawing were performed by SPSS ver. 16 and Statistica ver. 8 soft wares, respectively.

Results and discussion

Comparing cultivars based on the resistance/tolerance indices

To investigate suitable stress resistance indices for screening of cultivars under drought condition, grain yield of cultivars under both non-stress and stress conditions were measured for calculating different sensitivity and tolerance indices (Tab. 2). Based on the stress tolerance index (STI), MP, GMP, YI, SSPI, K1STI, K2STI and grain yield in two conditions, KSC 720, KSC 710 GT and 'KSC 700' were found drought tolerance with highest STI and grain yield under irrigation (non-stressed) condition, while KSC-N84-02 and KSC 708 GT displayed the lowest amount of for this indices under irrigation condition. Other cultivars were identified as semi-tolerance or semi-sensitive to drought stress (Tab. 2). Also, according to YSI and RDI indices selected the KSC700, 'KSC720', and KSC-N84-01 as the most relatively tolerant cultivars while for this indices the cultivars KSC- N84-02, KSC 708 GT were the least relative tolerant. So, according to SSI and TOL indices selected the 'KSC 708GT', KSC-N84-02 and KSC 704 as the most relatively tolerant cultivars while for SSI the cultivars KSC 710 GT, 'KSC 700' and for TOL the cultivars KSC 710 GT, 'KSC720' were the least relative tolerant. Tolerant indices another showed different amount for cultivars. Farshadfar *et al.* (2012a) used the tolerance indices such as, RDI, STI, YSI, SSPI, and MSTI for screening tolerance bread wheat landraces.

Correlation analysis

To determine the most desirable drought tolerant criteria, the correlation coefficients between Yp, Ys, and other quantitative indices of drought tolerance were calculated. In other words, correlation analysis between grain yield and drought tolerance indices can be a good criterion for screening the best cultivars and indices used (Tab. 3). A suitable index must have a significant correlation with grain yield under both the conditions (Mitra, 2001). The highest positive correlation was observed between MP and Yp and between YI and Ys, while highest negative correlation was recorded between SSI and yield in drought condition. Ehdaie and Shakiba (1996) in wheat found that there was no correlation between stress susceptibility and yield under optimum condition. Yield in stress condition (Ys) was significantly and positively corrected with TOL, MP, GMP, STI, RDI, YI, DI, YSI, SSPI, K_1STI, and K_2STI. Also, yield in non-stress condition (Yp) was significant and positively correlated with TOL, MP, GMP, STI, RDI, YI, DI, YSI, SSPI, K_1STI, and K_2STI indicating that these criteria were more effective in identifying high yielding cultivars under different water conditions. The results of this study indicated positive and significant correlation between MP and Yp and between YI and Ys. However, significantly and negatively correlation was recorded between SSI and yield in drought condition. Toorchi *et al.* (2012) showed that correlation between MP, GMP, Ys, and Yp was positive. Khalili *et al.* (2012) reported that GMP, MP, and STI were significantly and positively correlated with stress yield. The observed relations were consistent with those reported by Farshadfar *et al.* (2012b) in landrace wheat and Golabadi *et al.* (2006) in durum wheat. Mehrabi *et al.* (2011) suggested corn hybrids with high yield may be obtained based on GMP and STI indices. Also, İlker *et al.* (2011) concluded that MP, GMP and STI values are convenient parameters to select high yielding wheat geno-

Tab. 2. Resistance/tolerance indices of canola cultivars under stress and non-stress condition

Cultivar	Yp	Ys	TOL	MP	GMP	STI	RDI	SSI	YI	DI	YSI	SSPI	k_1STI	k_2STI
'KSC720'	649.02	122.18	526.84	385.60	281.59	0.45	0.91	1.02	1.42	0.26	0.18	63.24	1.11	0.93
'KSC 700'	518.14	96.50	421.64	307.32	223.60	0.28	0.90	1.02	1.12	0.20	0.18	50.61	0.44	0.36
'KSC- N84-01'	367.71	75.95	291.75	221.83	167.12	0.16	1.00	0.99	0.88	0.18	0.20	35.02	0.12	0.12
'KSC 708GT'	216.89	52.69	164.20	134.79	106.90	0.06	1.18	0.95	0.61	0.14	0.24	19.71	0.02	0.02
KSC 710 GT	554.53	116.66	437.86	335.59	254.35	0.37	1.02	0.99	1.36	0.28	0.21	52.56	0.66	0.69
KSC-Mog84-062	446.25	93.32	352.92	269.78	204.07	0.24	1.01	0.99	1.09	0.22	0.20	42.36	0.27	0.28
KSC 704	339.49	74.52	264.96	207.01	159.06	0.14	1.06	0.98	0.87	0.19	0.21	31.80	0.10	0.11
KSC- N84-02	239.95	52.87	187.08	146.41	112.63	0.07	1.07	0.98	0.61	0.13	0.22	22.45	0.02	0.02

types in both stress and non-stress conditions whereas relative decrease in yield. Jafari *et al.* (2009) found that STI, GMP indices which showed the highest correlation with grain yield under both optimal and stress conditions, can be used as the best indices for maize breeding programs to introduce drought tolerant hybrids. Consequently, they indicated that Stress Tolerant Index (STI) was more useful in order to select favorable corn cultivars under stress and non-stress conditions. Results showed that among drought tolerance indices, MP, GMP, STI, YI, SSPI, K_1STI and K_2STI can be used as the most suitable indicators for screening drought tolerant cultivars because had highest correlation with Yp and Ys and this tolerant correlation had positive correlation together. Khalili *et al.* (2012) suggested that indices of stress tolerance/resistance such as K_1STI, K_2STI, can be used as the most suitable indicators for screening drought tolerant cultivars. In the study conducted by Farshadfar and Elyasi (2012) and Farshadfar *et al.* (2012a,b) grain yield in the stress and non-stress conditions were positively correlated with MSTI. Also, our results showed significantly and positively correlation between SSPI with Yp and Ys, thus this index may be able to use as the index for screening tolerant cultivars. Farshadfar *et al.* (2001) believe that the most suitable indices for selection of drought tolerant cultivars are indicators which show a relatively high correlation with grain yield in both stress and non-stress conditions.

Ranking method

The estimates indicators of drought tolerance (Tab. 2) indicated that the identification of drought tolerant cultivars based on a single criterion may be contradictory. To determine the most desirable drought tolerant cultivar according to the all indices, mean rank, and standard deviation of ranks of all drought tolerance criteria were calculated and based on these two criteria the most desirable drought tolerant cultivars were identified. In consideration to all indices, cultivars 'KSC720', KSC 710 GT and 'KSC 700' exhibited the best mean rank and almost low standard deviation of rank, hence they were identified as the most drought tolerant cultivars, while cultivars 'KSC 708GT'and KSC-N84-02 as the most sensitive (Tab. 4). These results for this method can be supported with other works (Farshadfar *et al.,* 2012 a, b; Khalili *et al.,* 2012).

Three dimensional plots

Three dimensional plots are presented to show the interrelationships among these three variables to separate the cultivars of group A (high yielding cultivars in both stress and non-stress conditions) from the other groups (B, C and D), and to illustrate the advantage of STI index as selection criterion for identifying high-yielding and stress tolerant cultivars. In three dimensional plots, 'KSC720', KSC 710 GT and 'KSC 700' were included in A group, this cultivars had stable grain yield in stress

Tab. 3. Correlation coefficient between Yp, Ys and resistance/tolerance indices

Indices	Yp	Ys	TOL	MP	GMP	STI	RDI	SSI	YI	DI	YSI	SSPI	k1	k2
Yp	1													
Ys	0.98**	1												
TOL	0.99**	0.98**	1											
MP	1.0**	0.99**	0.99**	1										
GMP	0.99**	0.99**	0.99**	0.99**	1									
STI	0.98**	0.98**	0.98**	0.99**	0.99**	1								
RDI	-0.84**	-0.75*	-0.85**	-0.82*	-0.80*	-0.77*	1							
SSI	0.84**	0.75*	0.85**	0.82*	0.80*	0.77*	-1.0**	1						
YI	0.98**	1.0**	0.98**	0.99**	0.99**	0.98**	-0.75*	0.75*	1					
DI	0.92**	0.97**	0.91**	0.93**	0.95**	0.94**	-0.60	0.60	0.97**	1				
YSI	-0.84**	-0.75*	-0.85**	-0.82*	-0.80*	-0.77*	1.0**	-1.0**	-0.75*	-0.60	1			
SSPI	0.99**	0.98**	1.0**	0.99**	0.99**	0.98**	-0.85**	0.85**	0.98**	0.91**	-0.85**	1		
k1	0.93**	0.91**	0.93**	0.93**	0.92**	0.96**	-0.70*	0.70*	0.91**	0.85**	-0.70*	0.93**	1	
k2	0.93**	0.94**	0.93**	0.94**	0.94**	0.97**	-0.66	0.66	0.94**	0.91**	-0.66	0.93**	0.99**	1

* and ** Significant at the 5% and 1% levels of probability, respectively

Tab. 4. Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of drought resistance/tolerance indices

Cultivar	YP	YS	TOL	MP	GMP	STI	RDI	SSI	YI	DI	YSI	SSPI	K1STI	K2STI	$\bar{R}$	SDR
'KSC720'	1	1	8	1	1	1	2	4	1	2	2	1	1	1	1.93	1.94
'KSC 700'	3	3	6	3	3	3	1	8	3	4	1	3	3	3	3.36	1.78
'KSC- N84-01'	5	5	4	5	5	5	3	6	5	6	3	5	5	5	4.79	0.89
'KSC 708GT'	8	8	1	8	8	8	8	1	8	7	8	8	8	8	6.93	2.53
KSC 710 GT	2	2	7	2	2	2	5	7	2	1	5	2	2	2	3.07	2.02
KSC-Mog84-062	4	4	5	4	4	4	4	5	4	3	4	4	4	4	4.07	0.47
KSC 704	6	6	3	6	6	6	6	3	6	5	6	6	6	6	5.5	1.09
KSC- N84-02	7	7	2	7	7	7	7	2	7	8	7	7	7	7	6.36	1.86

and non-stress conditions. The 'KSC 708GT' and KSC-N84-02 cultivars were in D group that performed poorly in both conditions (Fig. 1). This graph showed the ability of this index to detect Fernandez (1992) groups. Rosielle and Hamblin (1981) reported that stress tolerance index and mean productivity were defined as the difference in yield and the average yield between stress and non-stress conditions, respectively. Mevlüt and Sait (2011) indicated that the genotypes with high STI usually have high difference in yield in two different conditions. In general those reported, similar ranks for the genotypes were observed by GMP and MP parameters as well as STI, which suggests that these three parameters are equal for selecting genotypes.

Cluster analysis

Cluster analysis showed that the cultivars, based on indices tended to group into three groups with 3, 2 and 3 cultivars, respectively (Fig. 2). In this analysis, the first group had the highest MP, GMP, YI, YSI, DI, RDI, K_1STI, K_2STI, and STI, and was thus considered to be the most desirable cluster for both growth conditions (Tolerant group). The second group had mean indicators values.

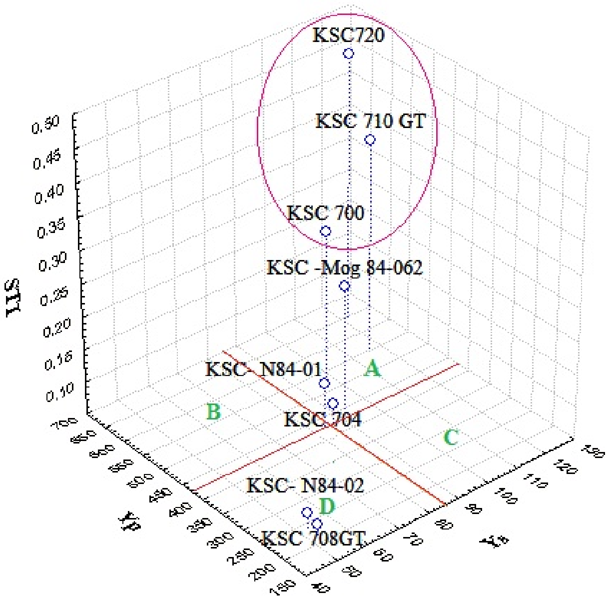

Fig. 1. The three dimensional plots among STI, Yp and Ys

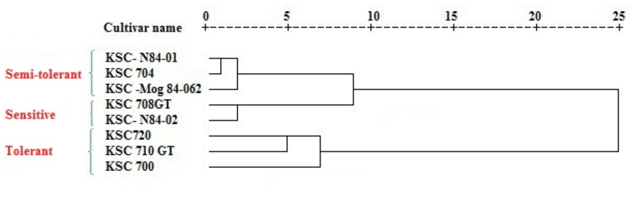

Fig. 2. Dendrogram using Ward method between groups showing classification of cultivars based on resistance/tolerance

Therefore, the cultivars of this group were considered to be stable non-stress conditions (Semi- Sensitive/ Semi- tolerant). In the third group, all cultivars had high SSI, thus they were susceptible to drought and only suitable for irrigated conditions. The results obtained of cluster analysis confirmed by three dimensional plots.

Conclusions

Among different resistance and tolerance indices were evaluated all indices expect RDI and YSI have high correlation with grain yield under stress and non-stress condition indicating more suitability of these indices for selection of resistant genotype. Screening drought tolerant cultivars using ranking method and Cluster analysis discriminated cultivars 'KSC720', KSC 710GT and 'KSC 700' as the most drought tolerant. Therefore they are recommended to be used as parents for improvement of drought tolerance in other cultivars. In addition to, results of this study showed that among drought tolerance indices YI, SSPI, K_1STI and K_2STI can be used as the most suitable indicators for screening drought tolerant cultivars.

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