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The Study on Drought Tolerance Indices in Corn Hybrids Using Main Component Analysis

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Abstract: An experiment was conducted to determine the best indices for tolerance against drought using split plots in the form of randomized complete blocks with three replications. Plots included four irrigation regimes (without stress, stress during 6-7 leaf stages, stress during flowering and stress during grain filling period), whereas sub plots included four hybrids of corn varieties (Single Cross 704, 604, 500 and Double Cross 370). The results from evaluation of hybrids were examined for tolerance against drought using various indices such as Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Stress Susceptibility Index (SSI) and Mean Harmonic Productivity (HARM). Results indicated that indices such as MP, GMP, STI and HARM were more useful in separating the genotypes of group A (genotypes with higher yield both at stressed and non-stressed conditions) than other groups and the most appropriate hybrid in mean stressed condition and based on abovementioned indices was hybrid of Single Cross 704. The first two components, in total accounted for about 99% of the changes based on the results from analysis of the main components under all of the applied drought stress conditions. In all of the applied stress conditions, indices such as MP, GMP, STI and HARM were of highest significance. Therefore, the first component was designated as component of potential under all stress conditions. In second component indices such as SSI and TOL had positively high values, thus the second component was designated as component of susceptibility against stress.

Key words: Indices of tolerance against drought · Corn · Analysis of main components · Yield

INTRODUCTION

Corn is one of the oldest crop grains and one of the most productive plant species with a global yield of more than 4 tons/ha [1, 2]. Based on an investigation it is reported that in more than 25% of highlands in the world the agricultural productions are suffering from decreased yield as a result of drought [3]. In global agriculture, tolerance against drought is of great importance for crop plants. Drought can happen any times at every stage of growth season or in a yearly basis in some regions. Currently, varieties tolerant against drought have been extended by breeding and are commercially available for farmers [4]. Studies on tolerance against drought and selection of tolerant genotypes are conducted based on conditions present in every region. Dry regions are characterized by severe precipitation changes, intensive and highly scattered precipitation and temperature fluctuations. Insufficiency of water sources in the country and the need to minimize water consumption necessitate developing varieties that need less water or are less damaged or negatively affected in terms of yield by water insufficiency [5]. Damand and Shav [6] after investigating the effect of humid stress of the soil on growth and yield of corn in different growth stages concluded that humid stress decreases the grain yield by 25% before the appearing of tassel, 50% during the appearance of tassel and 21% in grain filling period. One of the ways to deal with drought stress is to breed the tolerant and early-maturing plants and it is highly important to identify that how any plant or genotype deals with stress [7]. Different varieties use different mechanism for tolerating drought and also every variety uses different drought tolerance mechanisms in various growth stages [8]. There have been numerous selection indices proposed for selecting genotypes based on their yield under both stressed and

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without stress conditions [9]. Fernandez divided the genotypes into four groups based on their yield in stressed and without stress media in 1992:

Group A: genotypes with similar superiority in both stressed and without stress media.
Group B: genotypes with optimal yield in without stress medium, only.
Group C: genotypes with higher relative yield in stressed medium, only.
Group D: genotypes with low yield in both stressed and without stress media.

An ideal selection criterion should discern group A from other three groups [10].

Khalili *et al.* [11] in an investigation conducted on the effect of drought stress on yield and the grain yield performance in 8 late-maturing corn genotypes under without stress and stressed conditions during birth and growth stages found that hybrids with high yield are selected based on GMP and STI indices in both stressed and without stress media, whereas hybrids with high mean yield are selected using SSI in stressed conditions. Moghaddam and Hadizadeh [12] in an investigation on the response of corn hybrids to drought stress using different indices of tolerance against drought demonstrated that among the four indices namely STI, SSI, TOL and MP, STI is of higher benefits for the selection of varieties with high yield under both without stress and stressed conditions. Chokan *et al.* [13] by evaluating tolerance against drought in lines of corn using stress tolerance indices found that high values of indices such as HARM, GMP, STI and MP represent tolerance against stress and these indices are capable of identifying genotypes with high yield under both stressed and without stress conditions. Analysis of main components was developed by Pearson in 1901 and later extended by Chokan *et al.* [14]. The aim of analysis of main components is to analyze the variance found in multivariable data into components so that the first component, so far as possible account for the highest variance found in data. The first component may be followed by the second one and so forth [15]. Chokan *et al.* [14] during evaluation conducted to assess the tolerance of corn hybrids against drought using the indices for tolerance against drought stress demonstrated that indices such as MP, TOL, STI and HARM have the highest values in the first component, thus they are designated as the best indices for drought tolerant varieties.

Ahmadi *et al.* [16] in an investigation on indices for drought tolerance and by using Bi Plot Method in corn hybrids demonstrated that under both conditions of applying drought stress during flowering and grain filling stages, indices such as MP, GMP and STI had the highest value in first component, thus the mentioned indices were designated at stress tolerance indices and the varieties selected based on these indices are those with high yield in both without stress and stressed conditions. Further, TOL and SSI indices had the highest values in second component, thus these indices were designated as susceptibility indices.

The aim of this study is to introduce indices for drought tolerance by which one can select corn varieties with high grain yield in both stressed and without stress conditions in the local climate.

MATERIALS AND METHODS

This investigation was conducted as split plots in the form of randomized complete blocks design with three replications on the farm of Natural Source & Agronomical Research Center of East Azerbaijan Province (Khosroshahr City) in 2008-2009 cropping year. The area of this farm is approximately 52 ha. This center has been located 30 km from west of Tabriz along the Tabriz-Khosroshahr Road and in adjacency to vast plain situated west of Tabriz. The elevation is 1349 m from sea level, at longitude 46°45½ east and latitude 38°15½ north. Maximum and minimum absolute temperatures are 5.32 and -7.7 °C, respectively. Mean precipitation rate of the region is 300 mm. Texture of the surface soil was sandy loam, whereas the texture of subsurface soil was loamy and highly permeable. The amount of salts present in irrigation water was 3000-6000 micro mouse/cm^2 and the pH of the soil was as high as 7.6. The factor included 4 irrigation regime as the first treatment with normal irrigation (once every seven days), second treatment with skipping irrigation for two periods (21 days) during growth stage (6-7 leaf stage), third treatment with skipping irrigation for two periods during flowering stage and fourth treatment with skipping irrigation for two period during grain filling stage and sub factor included 4 corn varieties (hybrids of single cross 704, 604 and 500, hybrid of double cross 370). Farming site was consisted of 48 plots measuring 3.75m wide and 5.5m long each. Each experimental plot consisted of 4 rows recurring 75cm from each other. Seeds were planted on furrows as a pile and in 20cm distance from each other. Three seeds were put into each pile to ensure seed greening and then during second

through fourth leaf stages plantlets were thinned into one plant in every pile. Urea and Ammonium Phosphate fertilizers were applied prior to plantation and were applied based on soil analysis tests. Irrigation was done uninterruptedly every 7 days till sixth to seventh leaf stage and then the stress was applied during vegetative growth, flowering and grain filling stages. 13 plants were selected randomly from each plot and traits being studied were measured on the plants. The indices were calculated by following equations:

$$\text{Stress Susceptibility Index (SSI)} = \left[1-\left(Ysi-Ypi\right)\right]/SI$$

$$\text{Stress Tolerance Index (STI)} = \left[Ypi\times Ysi\right]/\left(Yp\right)^2$$

$$\text{Tolerance Index (TOL)} = Ypi-Ysi$$

$$\text{Geometric Mean Productivity (GMP)} = \sqrt{\left(Ypi\times Ysi\right)}$$

$$\text{Mean Productivity (MP)} = \left(Ypi+Ysi\right)/2$$

$$\text{yield index (YI)} = Ysi/Ys$$

$$\text{SI} = 1-\left(Ys/Yp\right)$$

Where Y_s is yield of varieties under stressed condition; Y_p, yield of varieties under normal condition; $\overline{Y}_S$ the mean yield of all varieties under stressed condition; $\overline{Y}_p$ the mean yield of all varieties under without stress condition and SI is stress intensity.

RESULTS AND DISCUSSION

Results from studying the indices of tolerance against drought indicated that, on average, based on ranking of MP, GMP, STI and HARM, 704 and 370 varieties had the highest and lowest grain yield, respectively (Table 1).

Under stressed condition of 6-7 leaf stage, first two components by having high eigenvalues, accounted for 99.84% of overall changes of indices, whereas the first component accounted for as much as 64.51% of overall changes of the indices. In first component indices such as Yp, MP, GMP, STI and HARM had the highest coefficients. So, this component was designated as the component of potential and yield stability and tolerance against drought. As the high values of these indices are desirable, the varieties with high yield under both stressed and without stress conditions and high MP, GMP and STI indices can be selected by referring to the positively high values of this component in resulted Bi-Plot (Table 2).

Second component accounted for 35.32% of overall changes of the indices. Second component had positively high values for indices such as SSI, R and TOL, so this component can be designated as the component of tolerance and susceptibility against stress. Selection based on higher values of this component leads to selection of genotypes more susceptible to drought stress (Table 2).

Soltani Hoveyzeh *et al.* [16] during an evaluation on various indices for tolerance against stress at the start of vegetative growth in cane stated that first two components account for 99% of overall changes of indices, whereas the first component accounted for 74% of overall changes of indices. In this component indices such as Ys, Yp, MP and GMP had the highest coefficients. Therefore, this component was designated as the component of production potential. Selection based on this component selects those varieties that produce high yield under both stressed and without stress conditions. Second component accounted for 25% of overall changes of the indices. In this component, indices such as SSI and TOL assumed more roles. Thus, this component can be called susceptibility component. Selection based on this component leads to selection of varieties with low tolerance and high susceptibility to stress. Selection of susceptible genotypes can be avoided in a breeding program based on these indices.

Investigations indicated that under the condition of flowering stress the first two components accounted for 99.96 of changes of indices and the contribution of first component for overall changes of the indices was as

Table 1: Values of yield of varieties for average stressed and without stress media, indices of susceptibility and tolerance against drought together with the ranks of genotypes

STI	GMP	TOL	MP	SSI	HARM	YS	YP	Genotyoe
0.174 (4)	2432.783 (4)	862 (4)	2470.667 (4)	1.238 (1)	2395.48 (4)	2039.667 (4)	2901.667 (4)	370
0.907 (2)	5553.822 (2)	1941.889 (2)	5638.056 (2)	1.224 (2)	5470.847 (2)	4667.11 (3)	6609 (2)	5000.
763 (3)	5094.085 (3)	413.44 (4)	5098.28 (3)	0.325 (4)	5089.896 (3)	4891.556 (2)	5305 (3)	604
1.556 (1)	7272.091 (1)	2287.663 (1)	7361.498 (1)	1.12 (3)	7183.769 (1)	7183.769 (1)	8505.33 (1)	704

Table 2: Contribution of each main component in overall changes of the indices and the values of coefficient of indices for each component under the condition of 6-7 leaf stress

	Special vectors of component	
Tolerant indices	1	2
Yp	0.37	0.027
YS	0.34	-0.21
SSI	0.11	0.48
MP	0.37	-0.08
TOL	0.21	0.42
GMP	0.37	-0.086
STI	0.37	-0.05
HARM	0.37	-0.088
Special amount	7.097	3.885
Cumulative variance	64.515	99.837

Table 3: Contribution of each main component for overall changes of the indices and the values of coefficients of indices for each component in flowering stress condition

	Special vectors of component	
Tolerant indices	1	2
Yp	0.341	0.139
YS	0.35	0.036
SSI	-0.197	0.495
MP	0.346	0.093
TOL	0.215	0.462
GMP	0.347	0.086
STI	0.341	0.09
HARM	0.347	0.079
Special amount	8.15	2.788
Cumulative variance	74.09	99.44

much as 72.01%. In first component, indices such as Yp, YI, MP, GMP, STI and HARM had the highest coefficients. So, this component was designated as the component of potential. As the high values of these indices are desirable, the varieties with high yield under both stressed and without stress conditions can be selected by referring to the positively high values of this component in resulted Bi-Plot (Table 3).

Second component accounted for 27.95% of overall changes of the indices. Second component had positively high values for indices such as SSI and TOL, therefore this component can be designated as the component of stress susceptibility. Selection based on the higher values of this component leads to elimination of genotypes more susceptible to drought stress (Table 3).

Ahmadi *et al.* [16] in an investigation on indices of tolerance against drought in corn hybrids argued that under stressed conditions at the middle stages of the growth season, first two components account for 99.93% of overall changes of the indices whereas first component

Table 4: Contribution of each main component for overall changes of indices and the values of coefficients of indices for each component in grain filling stress condition

	Special vectors of component	
Tolerant indices	1	2
Yp	0.34	0.176
YS	0.35	-0.04
SSI	-0.171	0.5
MP	0.35	0.094
TOL	0.238	0.423
GMP	0.353	0.07
STI	0.342	0.149
HARM	0.354	0.047
Special amount	7.92	3.074
Cumulative variance	72.015	99.96

accounted for 59.10% of overall changes of the indices. In this component, indices such as YP, MP, GMP and STI had the highest coefficients. So, this component was designated as the component of production potential. Selection based on this component selects those varieties that produce high yield under both stressed and without stress media. Second component accounted for 40.8% of overall changes of the indices. In this component indices such as TOL, SSI and YS had the highest coefficients and so this component was called the component of susceptibility. Selection based on this component leads to elimination of varieties with low tolerance and high susceptibility to stress.

Hasani *et al.* [18] by evaluating the indices of tolerance against drought stress in the yield of 6 varieties of Virginian Tobacco concluded that the first two components with eigenvalues greater than 1, together accounted for 99.94% of overall changes of data, first component which accounted for 69.73% of overall changes of data and had a positively high correlation with indices such as Yp, Ys, MP, GMP and STI was designated as the component of potential and yield stability and tolerance against drought. As the high values of these indices are desirable, the varieties with high yield under both stressed and without stress conditions and with high MP, GMP and STI can be selected by referring to positively high values of this component. Second component accounted for 30.21% of overall changes of data and had a negatively high correlation with Ys and positively high correlation with TOL, SSI and to some extent with Yp and was designated as the component of susceptibility to drought stress and yield stability.

Results from Table 4 showed that first two components accounted for 99.44% of the changes of indices under the stress of grain filling and first

component accounted for as high as 74.09% of overall changes of the indices. In first component indices such as Yp, Ys, YI, MP, GMP, STI and HARM had the highest coefficients while SSI had negative coefficient for this component. Therefore, this component was designated as component of production potential. As the high values of these indices are desirable, varieties with high yield under both stressed and without stress conditions and with high MP, GMP and STI indices can be selected by referring to the positively high values of this component on the resulted Bi-Plot.

Second component accounted for 25.35% of overall changes of the indices and had positively high values for indices such as SSI and TOL. So, this component can be designated as component of tolerance or susceptibility to stress. Selection based on the high values of this component leads to elimination of genotypes more susceptible against drought stress. This component had positively high values for yield reduction rate whereas yield stability index had negatively high value in this component (Table 4). In fact, yield stability and yield reduction rate select varieties in opposite directions i.e. a variety selected by YSI (yield stability index) is designated as one with high yield stability under stressed condition which has the lowest rate of change and/or yield reduction, while the same variety will be placed at the lowest ranks in terms of reduction rate index [19].

Rezaiea-zad [20] in an investigation on response of some genotypes of sunflower to drought stress argued that the highest changes between the indices are accounted for by the first two components (99.85%) and the first component have positively high coefficients for indices such as Yp, STI, GMP and Ys and negative coefficient for indices such as SSI and TOL. Thus, increase of first component will lead to selection of those varieties that produce high yield under both conditions and high values for indices such as STI and GMP. On the other hand, the second component had positive values for indices such as GMP, STI and Ys and high coefficients for indices such as SSI and TOL. Thus, the first component can be designated as the component of potential yields whereas the second component as component of susceptibility.

Examining the Bi-Plot diagram for response of indices of tolerance and susceptibility against drought stress in corn varieties being studied under all the applied drought stress conditions (Figs 1, 2 and 3) indicated that the indices such as MP, TOL, STI and HARM had the highest value in first component, thus they are introduced as the best indices for selection of drought tolerant varieties and

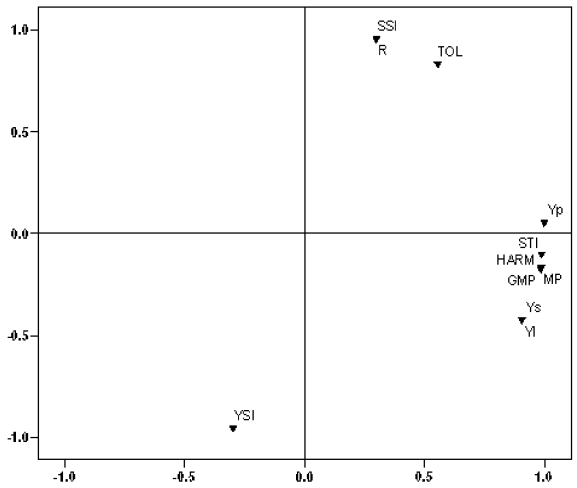

Fig. 1: Bi-Plot diagram for response of indices of tolerance and susceptibility to drought stress in four corn varieties under the conditions of applied 6-7 leaf stress based on the first and second main components

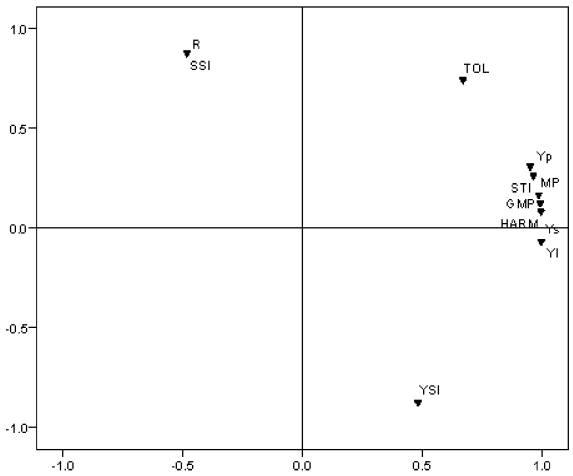

Fig. 2: Bi-Plot diagram for response of indices of tolerance and susceptibility to drought stress in four corn varieties under the conditions of applied flowering stress based on the first and second main components

the selection based on these indices under local condition produces genotypes with high yield.

In general, under the different conditions of applied stress it was observed that in first component indices such as MP, GMP, STI and HARM had the highest coefficients. Therefore, this component is designated as component of potential under all stressed conditions and based on the abovementioned indices 704 variety had a higher yield in both stressed and without stress

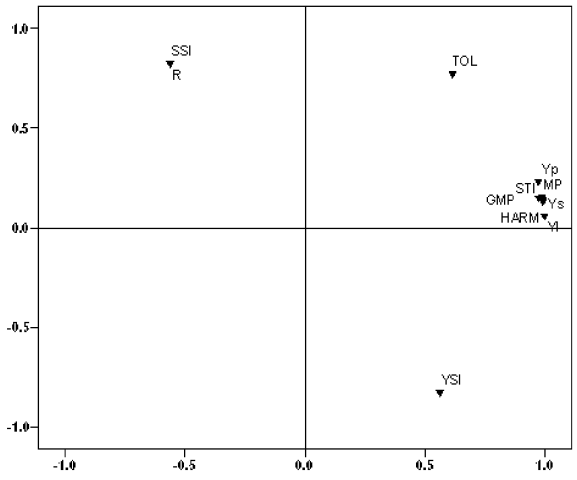

Fig. 3: Bi-Plot diagram for response of indices of tolerance and susceptibility to drought stress in four corn varieties under the condition of applied grain filling stress based on first and second main components

conditions. In second component indices such as SSI and TOL had positively high values, so this component is introduced as the component of susceptibility to stress.

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