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Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids

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Abstract

Drought is one of the major problems affecting crops production, including corn, in many parts of Iran. In order to detect drought tolerant grain corn hybrids, an experiment with twenty corn hybrids was conducted during 2006 in Qom Province, Iran, using a complete randomized block design with four replications, under optimal moisture and drought stress condition. Results showed diversity among hybrids in response to moisture conditions. BC504 and BC652 produced the highest yields and BC678 and NS504 produced the lowest yields under optimal and stress conditions, respectively. Assessing hybrids according to some selection indices lead to introduce BC504, BC652, BC404, KSC302, KSC320 and KSC647 as drought tolerant ones. It seems likely that Stress Tolerance Index, Geometric Mean Productivity, and Harmonic Mean 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.

Keywords: Corn hybrids; Drought stress; Selection index

Introduction

The corn cultivated area has been increased during recent years in Qom province (Agricultural Organization of Qom Province, 2006). This points out the necessity of more research about this crop concerning dry climate of this region and its irregular rainfall patterns. However, low heritability for drought tolerance and lack of effective selection approaches limit development of resistant crop cultivars to environmental stress (Kirigwi et al., 2004).

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 (Rosielle and Hambelen, 1981; Clarke et al., 1992; Fernandez, 1992; Sio-Se Mardeh et al., 2006). Fernandez (1992) classified plants according to their performance in stressful and stress free environments 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).

Moghaddam and Hadi-Zadeh (2002) found Stress Tolerant Index (STI) was more useful in order to select favorable corn cultivars under stressful and stress-free conditions. Khalili et al., (2004) showed that based on Geometric Mean Productivity (GMP) and STI indices, corn hybrids with high yield in both stress and non-stress environments can be selected.

To improve corn yield and stability in stressful environments, there is a necessity to identify selection indices able to distinguish high yielding corn cultivars in these situations. Thus, our purpose was evaluation of efficiency and profitability of different selection indices in identification of cultivars which are compatible with stressful and optimal conditions, to achieve cultivars that can tolerate long irrigation intervals or likely no irrigation at sensitive growth stages.

Materials and Methods

This study was conducted during 2006 at Northwest of Qom province, a temperate semi-arid region with 165 mm rainfall per year. The drought tolerance of 20 corn hybrids (Table 1) was evaluated in two separate experiments based on a complete randomized block design with four replications under optimal moisture condition and/or drought stress. Each hybrid was hand-seeded in hills, separated 20 cm from each other. There were three rows in each plot, with 7 m in length and 0.6 m row distance. The final plant population was 8.3 pl.m^{-2}. Irrigation depth was calculated based on average of soil moisture gravimetric percent in rooting zone (maximum to 60 cm) using Eq. 1 (Poor Midani and Ahmad Pour, 2006):

$$I = \frac{FC - \theta}{100} \times D \times BD \qquad \text{[Eq. 1]}$$

Where I is irrigation depth in cm, FC is soil gravimetric moisture percent at field capacity, θ is soil gravimetric moisture percent at irrigating time, and BD is soil bulk density at root zone in gr cm^{-3}. Irrigation of stressed and non-stressed experiments was done when soil moisture content up to 60 cm soil depth were reached to 0.7 and 0.4 of field capacity, respectively.

At plant maturity, five plants were selected randomly to measure yield attributes and final yield was measured in a 9 m^2 area. A sub-sample of grains was used to measure kernel properties. The percent of traits variation due to stress was calculated using Eq. 2:

$$trait\ variation\ percentage = \frac{trait\ value\ under\ stress - trait\ value\ under\ non\text{-}stress}{trait\ value\ under\ non\text{-}stress} \times 100 \qquad \text{[Eq. 2]}$$

Drought tolerance indices were calculated using following equations (Fischer and Maurer, 1978; Rosielle and Hambelen, 1981; Fernandez, 1992; Sio-Se Mardeh et al., 2006):

i) $$Stress\ Susceptibility\ Index\,(SSI) = \frac{1 - (Y_S/Y_P)}{SI} \qquad [3]$$

ii) $$Harmonic\ Mean\,(Harm) = \frac{2(Y_P \times Y_S)}{Y_P + Y_S} \qquad [4]$$

iii) $Tolerance\ Index\ (TOL) = Y_P - Y_S$ [5]

iv) $Mean\ Productivity\ (MP) = \frac{Y_p + Y_s}{2}$ [6]

v) $Stress\ Tolerance\ Index\ (STI) = \frac{Y_p \times Y_s}{\overline{Y}^2}$ [7]

vi) $Geometric\ Mean\ Productivity\ (GMP) = (Y_p \times Y_s)^{0.5}$ [8]

Which in all above equations, Y_s and Y_p are stress and optimal (potential) yield of a given genotype, respectively. $\overline{Y_S}$ and $\overline{Y_p}$ are average yield of all genotypes under stress and optimal conditions, respectively. Statistical analysis was done using SAS and Minitab softwares and figures were drawn using Sigmaplot.

Results and Discussion

There were significant differences among genotypes in respect to yield and yield components (Table 1), which demonstrates high diversity among them that enabled us to screen drought tolerant hybrids. Among all hybrids, BC504 and BC652 had the highest and BC678 and NS504 produced the lowest yields in optimal and stress conditions, respectively (Table 2).

Table 1. The mean of squares of yield and yield components of 20 corn hybrids under optimal and stress conditions.

Trait df	Optimal condition				Stress condition				Coefficient of variation (%)
	Replication	Genotype	Error	Mean	Replication	Genotype	Error	Mean	
	3	19	57		3	19	57		
Row No. in ear	0.95**	15.59**	0.159	15.58	3.56**	11.54**	0.23	13.72	11.93
Kernel No. in ear row	75.94**	73.15**	7.88	38.22	121.36**	89.64**	6.97	23.36	38.88
Ear diameter (cm)	0.327**	0.264**	0.018	4.2	0.71**	0.28**	0.029	3.76	10.47
Kernel No.	5416.69**	41545**	914.11	591.11	6067.88**	2518.8**	195.95	292.91	50.5
Kernel depth (mm)	0.0028	0.059**	0.002	0.829	0.038**	0.144**	0.005	0.705	15.03
Hectolitre weight (gr)	952.85**	5148**	74.37	696	1915.5**	14364.5**	219	612.1	12.05
1000 Kernels weight (gr)	497.36**	7624.29**	451.79	207.84	527.67**	3041.37**	14.64	146.94	29.3
Kernel diameter (mm)	0.1219	5.138**	0.049	4.7	0.16**	1.229**	0.015	3.42	27.23
Kernel width (mm)	0.26**	3.746**	0.037	7.86	0.72**	2.43**	0.036	7.31	9.93
Yield (t.ha-1)	0.506**	3.14**	0.049	6.093	0.71**	2.73**	0.022	4.16	31.72

**significant at 0.01 probability level.

BC462 and OSSK499 were more tolerant hybrids based on TOL and SSI, which their low quantity is indicating tolerant genotypes (Table 2). It seems TOL had succeeded in selecting genotypes with high yield under stress, but had failed to select genotypes with proper yield under both environments. Using SSI, NS540 and KSC320 were selected as sensitive ones. It seems if a given hybrid has high yields under both stress and normal conditions, but there is much variation in its yields between these two situations**,** it would not be detected as tolerant by SSI (e.g., BC504).

Table 2. Average yields of corn hybrids under optimal (Yp) and stress (Ys) conditions, and calculated different drought tolerance indices.

No	Genotype	Maturity Class†	Yield ($t.ha^{-1}$)		Drought Tolerance Indices **§**					
			Ys	Yp*	SSI	STI	TOL	MP	GMP	Harm
1	BC582	MM	4.31^{gf}	5.62^{fheg}	0.73	0.65	1.31	4.96	4.92	4.87
2	BC678	SMM	2.83^{i}	4.92^{j}	1.34	0.37	2.09	3.87	3.73	3.59
3	BC504	MM	5.07^{b}	8.35^{a}	1.24	1.14	3.28	6.71	6.50	6.30
4	NS540	MM	2.05^{m}	5.28^{hi}	1.93	0.29	3.23	3.66	3.28	2.95
5	BC666	SMM	4.38^{gf}	5.79^{fe}	0.76	0.68	1.41	5.08	5.03	4.98
6	BC652	SMM	5.60^{a}	7.28^{cb}	0.72	1.10	1.68	6.44	6.38	6.33
7	BC572	MM	3.37^{k}	5.39^{hg}	1.18	0.49	2.02	4.38	4.26	4.14
8	MV502	MM	4.03^{ih}	5.79^{fe}	0.96	0.63	1.76	4.91	4.83	4.75
9	KSC500	MM	3.29^{k}	5.58^{fhg}	1.29	0.49	2.29	4.43	4.28	4.13
10	OSSK499	SEM	4.50^{ef}	5.53^{fhg}	0.58	0.67	1.03	5.01	4.98	4.96
11	BC462	SEM	4.22^{gf}	5.05^{ji}	0.51	0.57	0.83	4.63	4.61	4.59
12	DSSK444	SEM	4.35^{gf}	5.70^{feg}	0.75	0.67	1.35	5.02	4.98	4.93
13	BC404	SEM	4.61^{ed}	6.97^{c}	1.06	0.86	2.36	5.79	5.66	5.54
14	BC418	SEM	4.74^{cd}	5.96^{e}	0.64	0.76	1.22	5.35	5.31	5.28
15	KSC320	EM	4.06^{ih}	7.39^{b}	1.42	0.81	3.33	5.72	5.47	5.24
16	KSC302	EM	4.88^{cb}	6.96^{g}	0.94	0.91	2.08	5.92	5.82	5.73
17	KSC250	VEM	4.31^{gf}	5.67^{feg}	0.75	0.66	1.36	4.99	4.94	4.89
18	KSC260	VEM	5.00^{b}	6.28^{d}	0.64	0.84	1.28	5.64	5.60	5.56
19	KSC647	SMM	3.88^{ij}	6.59^{d}	1.29	0.69	2.71	5.23	5.05	4.88
20	KSC704	LM	3.69^{j}	5.54^{fhg}	1.05	0.55	1.85	4.61	4.52	4.42

*In each column, means with similar letters do not differ significantly at 0.05 probability level.

†VEM: very early maturing; EM: early maturing; SEM: semi-early maturing; MM: mid-maturing; SMM: semi mid-maturing; LM: late maturing.

§Yp: Potential Yield; Ys: Stress Yield; TOL: Tolerance index; MP: Mean Productivity; GMP: Geometric Mean Productivity; SSI: Stress Susceptibility Index; Harm: Harmonic mean; STI: Stress Tolerance Index.

Table 3. Correlations between different selection indices and mean yield of corn hybrids under normal and stress conditions.

	Y_P	Y_S	TOL	MP	GMP	SSI	HARM	STI
Y_P†	1							
Y_S	0.61^{**}	1						
TOL	0.51^{*}	-0.35	1					
MP	0.90^{**}	0.89^{**}	0.10	1				
GMP	0.85^{**}	0.93^{**}	0.0016	0.99^{**}	1			
SSI	-0.09	-0.71^{**}	0.89^{**}	-0.32	-0.42	1		
HARM	0.80^{**}	0.96^{**}	-0.091	0.97^{**}	0.99^{**}	-0.50^{*}	1	
STI	0.88^{**}	0.90^{**}	0.063	0.99^{**}	0.99^{**}	-0.36	0.98^{**}	1

* and** are significant at 0.05 and 0.01 probability levels, respectively.

† Yp: Potential Yield; Ys: Stress Yield; TOL: Tolerance index; MP: Mean Productivity; GMP: Geometric Mean Productivity; SSI: Stress Susceptibility Index; Harm: Harmonic mean; STI: Stress Tolerance Index.

There were high and significant correlations between GMP, STI and Harm (Table 3). Therefore, it can be concluded these indices will produce similar results (Table 2). A higher STI, GMP and Harm value is indicating more tolerance to drought stress (Fernandez, 1992). Based on these indices, BC504, BC652 and KSC302 were identified as superlative and NS540 and BC678 as the weakest hybrids in respect to drought stress tolerance (Table 2).

Based on GMP and Harm indices, BC504, BC652 and KSC302 were classified as group A (Fernandez, 1992; Table 2). Some hybrids with high Harm value were not settled in group A, due to their low Y_p than others. STI was able to detect all hybrids with high Ys as tolerant hybrids, with all can be classified in group A (Table 2). NS540 and BC678 are the most vulnerable hybrids, located in group D. Accordingly, as indicated by Fernandez (1992), STI is able to detect and distinguish group A genotypes from B and C groups (Table 2). There were significant and positive correlations between Y_s and Y_p with GMP, STI and Harm (Table 3). Thus, as Sio-Se Mardeh et al., (2006) stated, it seems these indices are reliable indices able to identify high-yielding, drought tolerant genotypes under both environmental conditions (Table 2).

We also used cluster method to classify different genotypic groups in similar classes. As it is appear in Figure 1, with linear slicing from equality point of 41.06, the hybrids are classified to three groups with high intra-group and low extra-group similarities. The first group includes BC582, KSC250, DSSK444, BC666, OSSK499 and BC462, which in next step MV502 and KSC704, and finally BC418 and KSC260 are added to them. All mentioned hybrids are located in group C (Table 2). NS540, BC678, BC572 and KSC500 were settled together in similar group (Figure 1). These genotypes are located in group D (low Ys and Yp) and in the most cases, have higher TOL and SSI values among all hybrids (Table 2).

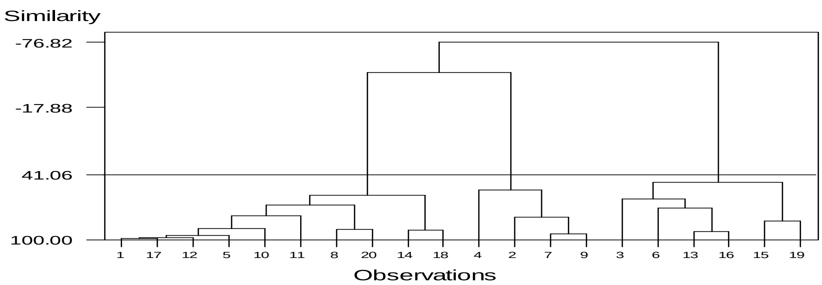

Figure 1. Dendrograph resulted from cluster analysis of genotypes based on stress tolerance and susceptibility indices and grain yield, in both normal and stress environments. Observation numbers present No of hybrids (Table 3).

The third group, including BC504, BC652, BC404, KSC302, and KSC320, had the highest STI, Harm and GMP among other hybrids (Table 2), and their average seed yield is higher than other groups (Figure 1), locating in group A of Fernandez's classification as tolerant hybrids (Table 2).

In summary, it seems Harm, STI and GMP indices have a similar ability to separate drought sensitive and tolerant genotypes. Thus, they can use to detect genotypes which have low water requirements and/or suffer less yield reduction by water shortage during their growth period, to be advised to cultivate in regions with limited water resources in order to enhance cultivated area and production efficiency.

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