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Full Length Research Paper

Evaluation of drought tolerance of some corn (*Zea mays* L.) hybrids in Iran

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The effect of drought stress on yield and its components was studied on 28 new hybrids of maize along with 6 commercial control hybrids at the Khorasan Razavi Agricultural Research and Natural Resources Institute Mashhad, Iran in 2010. The study was conducted in a completely randomized block design with three replications under normal irrigation and drought stress conditions. There were significant differences among hybrids under both conditions for all traits. The mean grain yield of SC500 hybrid in the normal irrigation condition and N11 hybrid in the stress condition was highest. Result of simple correlation between traits under stress condition showed that number of kernel in row was the highest correlation with yield and in normal irrigation ear diameter was higher than other traits correlated. In order to identify the tolerant genotypes, drought resistance indices were calculated. SC500 and SC250 hybrids were the best genotypes under normal condition and H11 and SC250 showed the best behavior under drought stress condition. In summary, it seems Harm, STI and GMP indices have a similar ability to separate drought sensitive and tolerant genotypes. We also used cluster analysis (Ward's method) to classify tolerance hybrids in similar classes.

Key words: Corn, drought resistance indices, hybrid, cluster analysis.

INTRODUCTION

Among various abiotic and biotic stress factors, drought is an important cause of genotype by environmental interactions in maize across years, locations (Löffler et al., 2005; Setimela et al., 2005) and most likely within individual fields (Bruce et al., 2002). Drought is one of the most important abiotic stress factor (Bruce et al., 2002), which affects almost every aspect of plant growth (Sadras and Milroy, 1996; Aslam et al., 2006). Drought, or more generally, limited water availability is the main factor limiting crop production (Seghatoleslami et al., 2008, Golbashy et al 2010). Drought is a permanent constraint to agricultural production in many developing countries, and an occasional cause of losses of agricultural production in developed ones (Ceccarelli and Grando, 1996). The best option for crop production, yield improvement and yield stability under drought stress conditions is to develop drought tolerant crop varieties. One of the main goals in breeding programs is selection of the best genotypes under drought stress conditions (Richards et al., 2002). However, low heritability of drought tolerance and lack of effective selection approaches limit development of resistant crop cultivars to environmental stress (Kirigwi et al., 2004). A wide variety of physiological, morphological and molecular traits have been suggested for improving the drought and salinity tolerance of crops since most of them are potentially applicable to maize. Several recent reviews are available (Barker et al., 2005; Cushman and Bohnert, 2000; Flowers, 2004; Hasegawa et al., 2000, Holmberg and Bulow, 1998; Ingram and Bartels, 1996; Munns, 2002). No exact figures on yield and economic losses in maize due to drought are available. Heisey and Edmeades, (1999) estimated that 20 – 25% of the global maize planting area is affected by drought in any given year. In maize, grain yield reduction caused by drought ranges from 10 to 76% depending on the severity and stage of occurrence (Bolaòos et al., 1993). Drought stress

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coinciding with flowering delays silking and results in an increase of anthesis-silking interval (Bolaòos and Edmeades, 1993); this usually associates with reduction in grain number and yield (Edmeades et al., 1993). To evaluate the response of plant genotypes to drought stress, some selection indices based on mathematical relation between stress and non-stress (optimum) conditions have been proposed (Rosielle and Hambelen, 1981; Clarke et al., 1992; Fernandez, 1992; Sio-Se et al., 2006; Fereres et al., 1983). Fernandez (1992) classified plants according to their performance in stress and non-stress environments in four groups: genotypes with good performance in both environments (Group A); genotypes with good performance only in non-stress environments (Group B) or genotypes with good performance in stress environments (Group C); and genotypes with weak performance in both environments (Group D). Shirinzade et al. (2009) found that stress tolerance index was a more efficient index in identifying group A from other groups; it was chosen as the most suitable index for selecting tolerant genotypes to drought stress. Moghaddam and Hadi-Zadeh (2002) found that stress tolerant index (STI) was more useful in order to select favourable 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 could be selected. To improve corn yield and stability in stress environments, there is a necessity to identify selection indices able to distinguish high yielding corn cultivars in these situations. The present study was conducted to evaluate the effects of drought stress on grain yield and its component of maize hybrids and to compare the efficiency and profitability of different selection indices in selecting drought tolerant genotypes.

MATERIALS AND METHODS

The present study was conducted at the Khorasan Razavi Agricultural Research and Natural Resources Institute Mashhad, I.R. Iran during 2009. Two independent experiments were laid out in a randomized complete block design (RCBD) with three replications and 34 hybrids at both normal and drought stress conditions. The hybrids were grown in two-row plots with 3.15 m length and 0.75 cm spacing between rows. The plant density was 75000 plant/ha. Fertilizer was used based on soil test. Irrigation was applied based on 50 and 80% allowing water depletion for non-stress and stress conditions, respectively. Drought tolerance indices were calculated using the following equations (Fischer and Maurer, 1978; Rosielle and Hambelen, 1981; Fernandez, 1992; Sio-Se et al., 2006):

$$\text{Stress Tolerance Index}\,(STI) = \frac{Y_P \times Y_S}{(\bar{Y}_P)^2}$$

$$\text{Tolerance Index}(TOL) = Y_P - Y_S$$

$$\text{Geometric Mean Productivity}\,(GMP) = \sqrt{(Y_P)(Y_S)}$$

$$\text{Mean Productivity}\,(MP) = \frac{Y_P + Y_S}{2}$$

$$\text{Stress Susceptibility Index}\,(SSI) = \frac{(\frac{Y_S}{Y_P})}{1-(\frac{\bar{Y}_S}{\bar{Y}_P})}$$

$$\text{Harmonic Mean}\,(HARM) = \frac{2(Y_P \times Y_S)}{Y_P + Y_S}$$

Where Ys and Yp are stress and non-stress (potential) yield of a given genotype, respectively.

$Y_{\bar{S}}$ and $Y_{\bar{P}}$ are average yields of all genotypes under stress and non-stress conditions, respectively. Data were recorded on 10 competitive plants from each plot for yield components and grain yield (kg ha^{-1}) was calculated for the entire plot. Data were statistically analyzed using ANOVA appropriate for RCBD with SAS ver. 9.1 and SPSS ver. 16 software's. Means were compared using Duncan's multiple range test at 0.05 level of probability when the F-values were significant (Steel and Torrie, 1984).

RESULTS

Results of ANOVA showed significant differences among hybrids for all of traits in both condition (P ≤ 0.01) (Table 1), which demonstrated existence of high diversity among hybrids studied for drought tolerance. Among all hybrids, SC500 (13.79 ton/ha) and SC302 (12.89 ton/ha) had the highest and H11 (5.69 ton/ha) and SC250 (4.51 ton/ha) produced the highest yields in optimal and stress conditions, respectively (Table 1). The other researcher showed that drought stress declined seed yield and its components (Reca et al., 2001; Seghatoleslami et al., 2008). Results of this experiment also indicated that yield component such as ear number per plant, 300- kernel weight, row number per ear, kernel number per row and ear length were adversely affected in water deficit condition. Water stress reduced both plant height (-32.8%) and ear height (-30.57%). However, the stress affected total leaves number positively (Table 1), and this was associated with the reduction in mean plant height (-32.8%) and stem diameter (-17.02%). The percent of total yield reduction in stress condition was 71.54% (Table 1). The maximum ear weight, kernel no. per row, total kernel no. per ear and kernel percentage in ear was obtained in H11 hybrid (data not shown) in the water stress condition. Westgate and Boyer (1985) found that water stress during the critical period of silking to early grain filling inhibits photosynthesis and consequently lowers the carbohydrate reserves to levels that are insufficient to support optimum reproductive development. Such effects explain the observations made in this study concerning the reduction of kernel number in ear in the

Table 1. Analysis of variance for different traits of corn hybrids tested under normal and drought stress conditions.

	Normal condition					Stress condition					
	Replication	Genotype	Error	CV (%)	Mean	Replication	Genotype	Error	CV (%)	Mean	Trait variation percentage
Plant height (cm)	1140.37**	749.19**	140.02	5.08	232.73	4242.03**	479.05**	89.81	6.05	156.4	-32.80
Ear height (cm)	49.23ns	494.06**	58.4	7.21	105.97	1096.7**	231.9**	30.7	7.53	73.57	-30.57
Stem diameter (mm)	22.47**	9.98**	3.65	9.71	19.68	13.96*	11.31**	2.87	10.37	16.33	-17.02
Leaves no.	7.04**	2.17**	0.18	3.35	12.94	5.45**	2.63**	0.17	3.22	13.11	1.31
Upper leaves no.	0.05ns	0.52**	0.03	3.34	5.82	0.0003ns	0.35**	0.02	2.74	5.73	-1.55
Ear no. in plant	0.0004ns	0.04**	0.01	12.53	1.06	0.0006 ns	0.19**	0.02	12.43	1.34	26.42
10 ear weight (Kg)	1.55**	0.22**	0.03	7.54	2.61	0.03 ns	0.1**	0.01	13.86	0.84	-67.82
10 cob weight (Kg)	0.05**	0.03**	0.003	11.36	0.5	0.002 ns	0.01**	0.001	12.55	0.28	-44
300 kernel weight (gr)	364.28**	235.59**	69.07	9.9	83.93	175.47 *	155.45**	48.35	9.62	72.26	-13.9
Row no./ear	0.11ns	5.78**	0.55	4.54	16.38	5.46 **	4.76**	0.83	7.65	11.96	-26.98
Kernel no./row	90.87**	20.09**	3.3	4.57	39.73	4.95 ns	33.88**	5.49	13.05	17.95	-54.82
Total kernel no./ear	30842.82**	9396.63**	2072.36	7	649.77	5452.08 *	9965.13**	1694.37	18.77	219.24	-66.26
Ear length (cm)	14.87**	6.42**	0.6	4.66	16.68	3.81 *	6.92**	0.95	8.12	12.04	-27.82
Ear diameter (mm)	32.46**	14.37**	1.68	2.64	49.1	9.66 ns	25.03**	9.28	8.1	37.59	-23.44
Cob diameter (mm)	4.88*	9.33**	1.38	4.2	27.99	0.08 ns	16.43**	3.88	8.48	23.22	-17.04
Kernel depth (mm)	3.04**	2.13**	0.51	6.78	10.55	0.99 ns	2.25**	0.39	8.64	7.25	-31.28
Total yield (ton/ha)	28.46**	7.12**	2.64	15.62	10.4	4.18 **	2.58**	0.38	20.98	2.96	-71.54

** Significant at $P \leq 0.01$ level.

non-stress condition versus drought stress condition (Table 1). Other research showed that under water stress condition, a maize plant will be able to make better use of available water if vegetative growth is restricted early in the season (Shekoofa and Emam, 2006). Our results concur partly with observations made by Chogan et al. (2009) and Golbashy et al (2010) who reported that the total yield decreased with increasing water deficit. The measurement of total yield components showed that in drought stress condition total yield decline was mainly due to reduction of kernel no. per row and total kernel no. per ear (Shoa et al., 2008). Seed weight reduction under drought stress condition might be a result of kernel depth reduction.

Combined statistical analysis of the data revealed that irrigation condition and their interaction (Condition × Hybrids) had significant differences for all of investigated traits (data not shown). Correlation coefficients between the studied variables and total yield in both conditions showed that all variables, except stem diameter (-0.02ns) and total leaf number (-0.04ns) were positively correlated with total yield under drought condition (data not shown). In non-stress condition the highest correlations were for ear diameter and total yield (0.68**) and in drought stress condition for kernel number per row and total yield (0.79**). The correlation between plant height and ear height in drought stress was 0.98**; the highest of all variables studied. This finding was in agreement with the results of Shoa et al. (2007). Result of this study showed that, kernel number per row could be used as an important trait for prediction of total yield under drought stress.

Drought resistance indices were calculated to identify the tolerant genotypes (Table 2).

H28 was as a tolerant hybrid based on TOL and SSI, which its low quantity indicates tolerant hybrids (Tables 2 and 3). It seems TOL had succeeded in selecting hybrids with high yield under stress, but had failed to select genotypes with proper yield under both environments (Rosielle and Hambelen, 1981). Using SSI, SC500 and H4 were selected as sensitive ones

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

Number	Hybrid	Yp	Ys	SSI	TOL	MP	GMP	STI	M_{HAR}
1	H1	8.67 def	3.22 defgh	0.88	5.45	5.94	5.28	0.26	4.70
2	H2	10.90 abcdef	3.22 efghi	0.99	7.68	7.06	5.92	0.33	4.97
3	H4	10.23 bcdef	1.47 jk	1.20	8.76	5.85	3.88	0.14	2.57
4	H5	9.75 bcdef	3.33 bcdefg	0.92	6.42	6.54	5.70	0.30	4.97
5	H6	10.40 bcdef	4.02 bcde	0.86	6.38	7.21	6.47	0.39	5.80
6	H7	10.91 abcdef	3.34 bcdefg	0.97	7.57	7.12	6.03	0.34	5.11
7	H8	8.10 ef	2.15 ghijk	1.03	5.95	5.12	4.17	0.16	3.40
8	H9	11.39 abcd	2.98 defghi	1.04	8.41	7.19	5.83	0.32	4.72
9	H10	11.45 abcd	3.57 bcdef	0.97	7.88	7.51	6.39	0.38	5.44
10	H11	10.87 abcdef	5.70 a	0.67	5.17	8.28	7.87	0.58	7.47
11	H12	12.59 ab	4.05 bcd	0.95	8.53	8.32	7.14	0.48	6.13
12	H13	10.94 abcdef	2.87 defghi	1.04	8.08	6.90	5.60	0.29	4.54
13	H14	10.08 bcdef	2.00 hijk	1.12	8.08	6.04	4.49	0.19	3.33
14	H15	9.16 cdef	1.83 ijk	1.12	7.33	5.50	4.09	0.16	3.05
15	H16	8.89 def	2.33 fghijk	1.03	6.56	5.61	4.56	0.19	3.70
16	H17	10.68 abcdef	2.38 fghijk	1.09	8.30	6.53	5.04	0.24	3.90
17	H18	12.30 abc	2.86 defghi	1.08	9.44	7.58	5.93	0.33	4.64
18	H19	10.80 abcdef	2.86 defghi	1.03	7.94	6.83	5.55	0.29	4.52
19	H20	11.02 abcde	2.7z fghi	1.06	8.31	6.86	5.46	0.28	4.34
20	H22	8.97 def	2.32 ghijk	1.04	6.65	5.64	4.56	0.19	3.68
21	H23	9.84 bcdef	2.58 fghij	1.04	7.26	6.21	5.04	0.24	4.09
22	H24	7.70 f	2.57 fghij	0.93	5.12	5.13	4.45	0.19	3.86
23	H25	10.50 bcdef	2.78 fghi	1.03	7.72	6.64	5.40	0.27	4.39
24	H26	10.69 abcdef	2.32 fghijk	1.10	8.36	6.51	4.98	0.23	3.82
25	H27	8.20 def	2.81 efghi	0.92	5.39	5.50	4.80	0.22	4.18
26	H28	8.87 def	4.44 bc	0.70	4.42	6.65	6.28	0.37	5.92
27	H29	10.07 bcdef	2.94 defghi	0.99	7.13	6.51	5.44	0.28	4.55
28	H30	8.23 def	3.38 bcdefg	0.83	4.85	5.80	5.27	0.26	4.79
29	DC370	8.80 def	1.76 ijk	1.12	7.04	5.28	3.94	0.15	2.93
30	SC250	12.77 ab	4.51 b	0.91	8.25	8.64	7.59	0.54	6.67
31	SC302	12.89 ab	3.34 bcdefg	1.04	9.55	8.12	6.56	0.40	5.31
32	SC400	10.4 bcdef	4.05 bcd	0.86	6.36	7.23	6.50	0.40	5.83
33	SC500	13.80 a	1.19 k	1.28	12.60	7.49	4.06	0.15	2.20

In each column, means with similar letters do not differ significantly at 0.05 probability level (with Duncan's multiple range test mean comparison). Yp: Potential yield, GMP: geometric mean productivity, Ys: stress yield, SSI: stress susceptibility index, TOL: tolerance index, M_{HAR}: harmonic mean, MP: mean productivity and STI: stress tolerance index.

Table 3. Selected hybrids based on different drought tolerance indices.

Selected hybrids	Different indices
SC500 , SC302 , SC250	Select based on Y_P
H11 , SC250 , H28	Select based on Y_S
H28 , H30 , H24	Select based on TOL
H11 , H28 , H30	Select based on SSI
SC250 , H12 , H11	Select based on MP
H11 , SC250 , H12	Select based on GMP
H11 , SC250 , H12	Select based on STI
H1 , SC25 , H12	Select based on M_{HAR}

(Tables 2 and 3). It seems if a given hybrid has high yields under both stress and normal conditions, though there is much variation in its yields between these two situations, it would not be detected as tolerant by SSI (e.g., SC250). This finding was in agreement with the results of Jafari et al. (2009) and Chogan et al. (2009).

There were high and significant correlations between GMP, STI and Harm (Table 4). Therefore, the results showed that different indices will produce similar results (Table 2). A higher STI, GMP and Harm value is indicative of more drought stress tolerant (Fernandez, 1992). Based on these indices, H11, SC250 and H12 were

Table 4. Correlations between different selection indices and mean yield of corn hybrids under normal and stress conditions.

	Ys	SSI	TOL	MP	GMP	STI	M_{HAR}
Yp	0.29^{ns}	0.22^{ns}	0.79**	0.88**	0.55**	0.55**	0.36*
Ys		-0.82**	-0.24^{ns}	0.66**	0.92**	0.92**	0.99**
SSI			0.69**	-0.21ns	-0.59**	-0.59**	-0.77**
TOL				0.46**	0.04ns	0.04ns	-0.16ns
MP					0.84**	0.84**	0.71**
GMP						1	0.96**
STI							0.96**

ns: Not significant, **: Significant at P ≤ 0.01 and *: Significant at P ≤ 0.05 level, respectively.

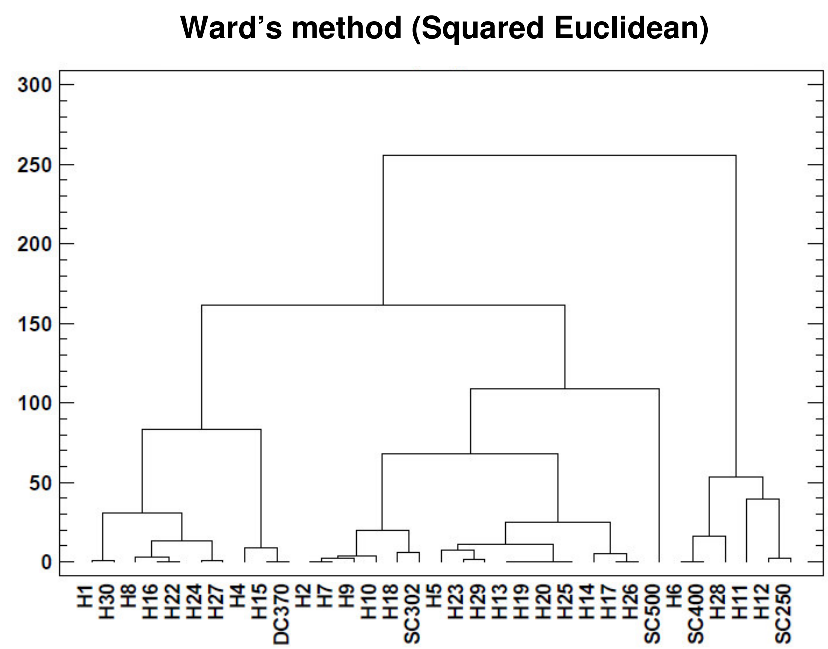

Figure 1. Dendrogram resulting from cluster analysis (Ward's method) of hybrids based on stress tolerance and susceptibility indices for grain yield in normal and stress condition. The hybrid names are those given in Table 2.

identified as superlative and H4 and DC370 as the weakest hybrids in response to drought stress tolerance (Tables 2 and 3). Based on GMP and Harm indices, H11, SC250 and H12 were classified in group A (Fernandez, 1992; Table 2). Some hybrids with high Harm value did not settle in group A, due to lower Yp (Jafari et al., 2009). STI was able to detect all hybrids with high Ys as tolerant hybrids, which could all be classified in group A (Fernandez, 1992; Table 2). H4 and DC370 are the most vulnerable hybrids, located in group D. Accordingly, as indicated by Fernandez (1992), STI is able to detect and distinguish genotypes A from B and C groups (Table 2). There were significant and positive correlations between Ys and Yp with MP, GMP, STI and Harm (Table 4). Thus, as Sio-Se et al. (2006) stated, it seems these indices are reliable indices being able to identify high-yielding, drought tolerant genotypes under both environmental conditions (Table 2). Shirinzade et al. (2009) and Chogan et al. (2008) reported similar results.

We also used cluster analysis (Ward's method) based on stress tolerance and susceptibility indices and grain yield in both normal and stress conditions to classify different hybrids in similar classes. As it appears in Figure 1, the hybrids were classified in three groups with low intra- and high extra-group similarities.

The first group includes H1, H30, H6, H16, H22, H24 and H27 hybrids. The second group, including H6, SC400, H28, H11, H12 and SC250 hybrids, which had the highest STI, Harm and GMP among other hybrids (Table 2), and their average seed yield is higher than other groups (Figure 1), located in group A of Fernandez's classification as tolerant hybrids (Table 2).

Other hybrids settled together in similar groups (Figure 1). These genotypes are located in group D (low Ys and Yp) and in most cases, have higher TOL and SSI values among all hybrids (Table 2).

Conclusion

In this experiment, drought stress had significant effects on maize hybrids yield and its components. SC500 (13.8 ton/ha) and SC250 (12.9 ton/ha) hybrids were the best genotypes under normal condition and H11 (5.7 ton/ha) and SC250 (4.51 ton/ha) showed the best behaviour under drought stress condition. In summary, it seems Harm, STI and GMP indices have a similar ability to separate drought sensitive and tolerant genotypes (Jafari et al., 2009; Chogan et al., 2008). Thus, they can be used to detect the studied genotypes which have low water requirements and/or suffer less yield reduction by water deficits during their growth period, and can be cultivated in regions with limited water resources in order to increase cultivated area and production efficiency. In conclusion, it can be suggested that H11 and SC250 hybrids should be grown in Khorasan Razavi Plains.

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