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Drought Tolerance Evaluation of Maize Hybrids using Biplot Method

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Abstract: Drought stress is one of the most important a-biotic stresses influencing performance of crop plants. Therefore, the identification or the development of tolerant genotypes is of high importance for incorporating in maize production. So, in order to find the best drought tolerant hybrids, thirty eight maize hybrids were planted in two separate experiments with normal irrigation and water deficit at grain filling period using a Randomized Complete Block Design (RCBD) with three replications. Drought tolerance indices such as Stress Susceptibility Index (SSI), Mean Productivity (MP), Tolerance (TOL), Geometric Mean Productivity (GMP), Harmonic Mean Productivity (HAR) and Stress Tolerance Index (STI) were used to evaluate susceptibility and tolerance of the hybrids. Hybrids No. 4, 8, 17 and 38 had higher grain yield over the mean of the two conditions. These hybrids located at part of high yield potential and low sensitivity to drought (i.e., in part with up component one and down component two) in biplot. According to Y_P (grain yield in normal irrigation condition) and Y_S (grain yield in water deficit condition), hybrid No. 8 (K74/2-2-1-3-1-1-1-1 × K3653/2) was the best hybrid and can be used in future breeding programs to develop commercial hybrid.

Key words: Maize, drought tolerance indices, biplot

INTRODUCTION

Water deficit is a common phenomenon in plants. It is accentuated when drought or lack of sufficient water in the rhizosphere occurs and the rate of evapo-transpiration is high. Drought may occur in any type of crop, irrigated or rainfed and may have a special impact in association with the prevalent farming system and environment. This fact has prompted agronomists, breeders, physiologists and physical scientists to study the nature of development and yield, management practices that would alleviate drought and to identify for drought tolerant genotypes (Koocheki, 1998). Maize (*Zea mays* L.) is one of the important cereal crops in the world and Iran after wheat and rice (Gerpacio and pingali, 2007). Drought stress at grain filling period reduces grain yield in maize by 40% in Pars Abad-e-Moghan (Iran) (Shirinzadeh *et al*., 2009). Loss of yield is the main concern of plant breeders; hence they emphasize on yield performance under water deficit conditions (Golabadi *et al*., 2006). For this reason, it seems necessary to use appropriate criteria for selecting drought tolerant genotypes for breeding programs.

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The drought tolerance indices, which provide a measure of drought based on loss of yield under drought condition in comparison to normal irrigation condition, have been used for screening drought tolerant genotypes (Mitra, 2001). Several indices have been utilized to evaluate genotypes for drought tolerance based on grain yield such as Mean Productivity (MP), (Rosielle and Hamblin, 1981), Stress Susceptibility Index (SSI) (Fischer and Maurer, 1978), Harmonic Mean Productivity (HAR) (Farshadfar *et al*., 2001), Stree Tolerance Index (STI) (Fernandez, 1992), Geometric Mean Productivity (GMP) (Fernandez, 1992) and Tolerance (TOL) (Rosielle and Hamblin, 1981). These indices have been studied by some researchers (Fernandez, 1992; Farshadfar *et al*., 2001; Shiri and Akhavan, 2005; Shirinzadeh *et al*., 2009).

Biplot is an exploratory data visualization technique to display the multivariate data into a two dimensional scatter plot. The concept of biplot was first developed by Gabriel (1971). This technique has extensively been used in the analysis of multi-environmental trails (Ahmadi *et al*., 2000; Farshadfar *et al*., 2001; Golabadi *et al*., 2006).

Ahmadi *et al*. (2000) used multivariate analysis of drought tolerance in maize. They analyzed data by using Principal Factor Analysis (PCA). The factor analysis technique extracted two factors, PCA1 and PCA2 that explained 66.6 and 33.4% of the total variation in terminal stress condition, respectively. These two PCA were related to yield potential and sensitivity to stress. Farshadfar *et al*. (2001) and Golabadi *et al*. (2006) revealed that genotypes with larger PCA1 and lower PCA2 scores gave high yields and genotypes with lower PCA1 and larger PCA2 scores had low yields. The objectives of this research were to study the effect of water deficit on the grain yield of new maize hybrids and to identify more tolerant and stable hybrids for drought stress.

MATERIALS AND METHODS

Thirty six new late maturity maize hybrids along with two checks (S.C.704 and S.C.700) were planted in two experiments with normal irrigation and water deficit at grain filling stage in Pars Abad-e-Moghan (39° 41' N 47° 32' E, with 40-50 m above from sea level), Ardebil, Iran in 2008, using an RBCD design with three replications. Hybrids S.C.704 and S.C. 700 were used as tolerant and susceptible check based on previous study of Shiri and Akhavan (2005), respectively. The pedigree, days to maturity and grain filling duration of studied hybrids are given in Table 1. The plot was made of four rows of 5 m length with the distance between rows and hills of 75 and 18 cm, respectively. Sowing was performed by three seeds per hill and thinning 18 days after planting reduced the stand at one plant per hill to reach a planting density of 75000 plant ha^{-1}.

The climate of this region (Pars Abad-e-Moghan) is semi-arid with average annual precipitation of 271.2 mm and from June to October (maize growing season) average precipitation is 55.1 mm. In addition, the averages of annual maximum temperature, minimum temperature and relative humidity are 20.5, 9.6°C and 72%, respectively. The soil type in the plot area is clay loam and is well drained. The Electrical Conductivity (EC) of the irrigation water is 2.1 dS m^{-1}.

In 2008, the annual average maximum temperature, minimum temperature, relative humidity and total rainfall were 20.7, 9.8°C, 70.3% and 216.8 mm, respectively. In the growing season (sowing to physiological maturity), these values were actually 30.6, 18.9°C, 63.9% and 64.4 mm, respectively. Total precipitation of the growing season (64.4 mm) was more than the average of long years (55.1 mm). A large part of the total rainfall in 2008, about 70% was received out of the growing season and the rest (30%) in the growing season

Table 1: Pedigree, day to maturity and grain filling duration of thirty eight maize hybrids used in this study

Code	Hybrids	DTM_P	DTM_S	GFD_P	GFD_S
1	KLM77008/1-3-3-1-2-2-1× K3653/2	120	111	52	41
2	KLM77012/4-1-1-4-1-2-1 × K3653/2	119	107	50	37
3	KLM77021/4-1-2-1-2-1-2 × K3653/2	119	108	49	37
4	KLM77029/8-1-1-1-2-1-5 × K3653/2	118	110	50	41
5	KLM77029/8-1-1-1-2-2-2 × K3653/2	121	109	52	40
6	KLM76004/3-5-1-2-2-1-1-1 × K3653/2	123	119	52	47
7	KLM76012/1-3-1-1-1-2-1-1 × K3653/2	122	108	51	36
8	K74/2-2-1-3-1-1-1-1 × K3653/2	118	111	46	39
9	K74/2-2-1-4-4-1-1-1 × K3653/2	121	111	49	38
10	K74/2-2-1-19-1-1-1-1 × K3653/2	124	108	52	35
11	K74/2-2-1-21-2-1-1-1 × K3653/2	128	120	54	45
12	K74/2-2-1-21-3-1-1-1 × K3653/2	123	112	51	39
13	K74/1 × K3653/2	119	116	48	41
14	K3545/7 × K3653/2	120	111	48	39
15	K3544/4 × K3653/2	120	109	48	37
16	K3640/6 × K3653/2	117	112	45	39
17	KLM75010/4-4-1-2-1-1-1 × K3653/2	121	110	50	39
18	KLM76010/1-13-1-2-1-1 × K3653/2	121	109	52	40
19	KLM77008/1-3-3-1-2-2-1× K3615/1	117	111	46	42
20	KLM77012/4-1-1-4-1-2-1 × K3615/1	116	107	48	39
21	KLM77021/4-1-2-1-2-1-2 × K3615/1	117	108	46	37
22	KLM77029/8-1-1-1-2-1-5 × K3615/1	116	108	46	40
23	KLM77029/8-1-1-1-2-2-2 × K3615/1	116	107	47	38
24	KLM76004/3-5-1-2-2-1-1-1 × K3615/1	119	110	49	41
25	KLM76012/1-3-1-1-1-2-1-1 × K3615/1	117	113	45	41
26	K74/2-2-1-3-1-1-1-1 × K3615/1	119	108	45	36
27	K74/2-2-1-4-4-1-1-1 × K3615/1	120	108	47	37
28	K74/2-2-1-19-1-1-1-1 × K3615/1	119	110	49	39
29	K74/2-2-1-21-2-1-1-1× K3615/1	119	110	47	39
30	K74/2-2-1-21-3-1-1-1 × K3615/1	119	112	48	40
31	K74/1 × K3615/1	117	115	46	43
32	K3545/7 × K3615/1	118	110	46	38
33	K3544/4 × K3615/1	118	112	45	38
34	K3640/6 × K3615/1	116	107	45	38
35	KLM75010/4-4-1-2-1-1-1 × K3615/1	116	107	46	38
36	KLM76010/1-13-1-2-1-1 × K3615/1	119	110	49	41
37	SC700 (drought susceptible check)	122	114	47	38
38	SC704 (drought tolerant check)	119	111	45	37
Mean		119	110	48	39

DTM_P: Day to maturity under normal irrigation condition; DTM_S: Day to maturity under water deficit at grain filling stage condition; GFD_P: Grain filling duration in normal irrigation condition; GFD_S: Grain filling duration under water deficit at grain filling stage condition

(only 12% in grain filling stage) (Fig. 1). Therefore, maize was heavily dependent upon irrigation in the growing season. The irrigation intervals were 7-10 days according to regional norm.

In normal irrigation condition, the irrigation was performed nine times based on crop water requirements during growth period, but in water deficit at grain filling stage condition, the irrigation was done six times from planting time till the end of flowering period and then, in order to apply water stress, irrigation was withheld completely from the end of flowering till crop maturity (grain filling stage). The duration of water stress varied from 30 to 47 days depending on grain filling duration of different hybrids. The environmental severity degree is estimated with SI (stress intensity) and maximal rate of SI is one (Fischer and Maurer, 1978). In this study, SI was 0.30, so stress intensity was moderate. Grain yield was determined under both normal irrigation and water deficit experiments and used as Yp and Ys, respectively.

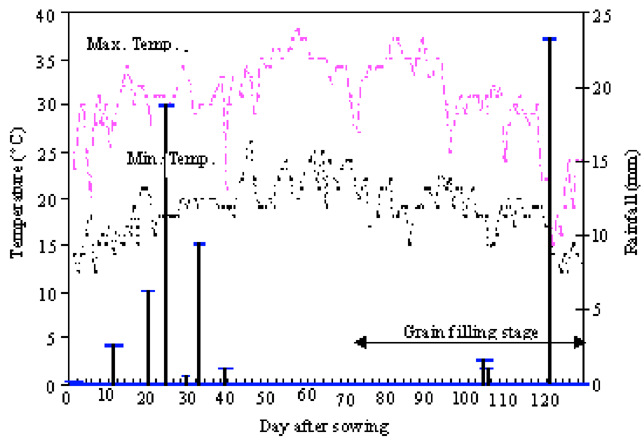

Fig. 1: Maximum temperature, minimum temperature and rainfall (vertical bars) during the field evaluation of thirty eight maize hybrids during 2008 at Pars Abad-e-Moghan, Ardebil, Iran

For every genotype, the six drought tolerance indices were calculated based on their grain yield in normal irrigation and water deficit conditions.

The drought tolerance indices were calculated as follows:

- Stress Susceptibility Index (Fischer and Maurer, 1978):

$$SSI = \left[1-\left(\frac{Y_s}{Y_P}\right)\right]/SI$$

where: $SI = 1\left(\overline{Y_s}/\overline{Y_p}\right)$

- Mean Productivity (Rosielle and Hamblin, 1981):

$$MP = \frac{Y_P + Y_S}{2}$$

- Tolerance (Rosielle and Hamblin, 1981):

$$TOL = Y_P - Y_S$$

- Stress Tolerance Index (Fernandez, 1992):

$$STI = \frac{(Y_p.Y_s)}{\left(\overline{Y}_p\right)^2}$$

- Geometric Mean Productivity (Fernandez, 1992):

$$GMP = \sqrt{Y_P.Y_S}$$

- Harmonic Mean Productivity (Farshadfar *et al.*, 2001):

$$HAR = \frac{2(Y_p\text{-}Y_s)}{(Yp+Ys)}$$

Where:
Yp = Yield of a genotype in normal irrigation condition
Ys = Yield of a genotype in water deficit condition
$\overline{YP}$ = Mean yield in normal irrigation condition
$\overline{YS}$ = Mean yield in water deficit condition

The multivariate display as a biplot was used to investigate the relationships between more than two variables. The biplot graph provides a useful tool for data analysis and allows the visual appraisal of the structure of a large two way data matrix. To display the genotype by trait two way data in biplot, a principal component analysis is required. An analysis of principal components often reveals relationships that were not previously suspected and thereby allows interpretations that would not ordinarily result (Johanson and Wichern, 1996). The biplot display of principal component analysis was used to identify stress tolerant and high-yielding genotypes and to study the interrelationship among the drought tolerance indices. The data were statistically analyzed by SPSS (Nasiri, 2006) and MSTATC (Alizadeh and Tarnajad, 2001) computer programs.

RESULTS AND DISCUSSION

Producers in water-limited environments would prefer to use high-yielding maize hybrids that perform consistently from environment to environment, respond to favorable irrigation levels and produce some threshold amount of grain yield under less favorable irrigation levels. The results of analysis of variance showed highly significant differences ($p<0.01$) for grain yield in both normal irrigation and water deficit at grain filling stage conditions (data not shown), indicating the existence of genetic variability among the hybrids. Therefore, it is possible to identify stress tolerant and high-yielding hybrids. The combined analysis of variance for grain yield (Table 2) indicated that the effect of irrigation regimes, hybrids and irrigation × hybrid interaction were all significant at 1% probability level.

In this study, the grain yield varied from 6.09 t ha^{-1} (in hybrid No. 22) to 11.19 t ha^{-1} (in hybrid No. 8) in normal irrigation condition and from 4.70 t ha^{-1} (in hybrid No. 23) to 7.27 t ha^{-1} (in hybrid No. 38) in water deficit condition. Mean grain yield under normal irrigation condition was 8.21 t ha^{-1} while in water deficit condition was 5.65 t ha^{-1}, indicating a reduction of 30% in comparison to the normal irrigation condition (Table 3).

The significant interaction (irrigation×hybrid) suggested that it would be more appropriate to maize hybrids selection on a combination of yield and yield stability across normal irrigation and water deficit conditions than on mean yield alone. In this study, drought tolerance indices and biplot method were used to identify stress tolerant and high-yielding hybrids across two conditions.

Table 2: Combined analysis of variance (mean square) across normal and water deficit conditions for grain yield (t ha^{-1})

SOV	Irrigation	Error	Hybrid	Irri.×Hyb	Error	CV (%)
DF	1	4	37	37	148	-
MS	357.176**	1.380	2.481**	1.828**	0.328	8.18

**: Significant at 1% level of probability

Table 3: Estimation of drought tolerance indices based on grain yield of maize hybrids under normal irrigation and water deficit conditions (SI = 0.3)

Code	Y_P (t ha^{-1})	Y_S (t ha^{-1})	MP	HAR	GMP	STI	TOL	SSI
1	10.26ab+	6.00a-h	8.13	7.57	7.85	0.91	4.25	1.36
2	8.17c-i	5.77b-h	6.97	6.76	6.86	0.70	2.41	0.97
3	7.13g-j	4.75gh	5.94	6.31	6.42	0.50	2.38	1.10
4	8.86b-f	6.21a-e	7.53	7.30	7.42	0.82	2.65	0.98
5	9.23b-e	5.79b-h	7.51	7.11	7.31	0.79	3.44	1.22
6	7.67e-ij	5.37b-h	6.52	5.83	5.87	0.61	2.30	0.99
7	8.16c-i	6.01a-h	7.08	6.92	7.00	0.73	2.16	0.87
8	11.19a	6.11a-f	8.60	7.91	8.27	1.01	5.10	1.49
9	8.65c-g	5.03c-h	6.84	6.36	6.60	0.64	3.62	1.37
10	9.32bcd	5.07c-h	7.20	6.57	6.88	0.70	4.24	1.49
11	8.87b-f	5.69b-h	7.28	6.93	7.11	0.75	3.18	1.18
12	8.65c-g	6.00a-h	7.33	7.09	7.20	0.77	2.65	1.00
13	7.84d-i	5.76b-h	6.80	6.64	6.72	0.67	2.08	0.87
14	8.22c-i	5.95b-h	7.09	6.90	7.00	0.73	2.27	0.91
15	8.08d-i	6.04a-g	7.06	6.92	6.99	0.72	2.04	0.83
16	6.98hij	5.98a-h	6.48	6.44	6.46	0.62	1.00	0.47
17	9.12b-e	6.62ab	7.87	7.67	7.77	0.89	2.50	0.90
18	8.70b-g	6.19a-e	7.45	7.23	7.34	0.80	2.51	0.95
19	7.35f-j	5.99a-h	6.67	6.60	6.63	0.65	1.36	0.61
20	6.80ij	5.96b-h	6.38	6.35	6.36	0.60	0.83	0.40
21	6.60ij	5.21c-h	5.91	5.60	5.62	0.51	1.39	0.69
22	6.09j	5.19c-h	5.64	5.88	6.08	0.47	0.91	0.49
23	7.88d-i	4.70h	6.28	6.12	6.29	0.55	3.18	1.32
24	8.44c-h	5.18c-h	6.80	6.42	6.61	0.65	3.30	1.27
25	7.96d-i	4.96d-h	6.46	5.96	6.16	0.59	3.00	1.24
26	7.92d-i	4.78fgh	6.35	6.70	6.73	0.56	3.14	1.30
27	7.41f-j	6.11a-f	6.76	6.63	6.70	0.67	1.31	0.58
28	7.71d-i	5.81b-h	6.76	6.82	6.84	0.66	1.90	0.81
29	9.11b-e	5.31b-h	7.21	6.71	6.95	0.72	3.80	1.37
30	8.71b-g	5.52b-h	7.11	6.76	6.93	0.71	3.18	1.20
31	7.60e-j	5.47b-h	6.53	6.36	6.45	0.62	2.13	0.92
32	6.99hij	4.91e-h	5.95	5.77	5.86	0.51	2.09	0.98
33	8.48c-h	6.29a-d	7.38	7.22	7.30	0.79	2.19	0.85
34	7.41f-j	6.32abc	6.86	5.70	5.81	0.69	1.09	0.48
35	9.24b-e	5.83b-h	7.54	7.15	7.34	0.80	3.41	1.21
36	8.83b-f	5.53b-h	7.18	6.80	6.99	0.72	3.30	1.23
37	6.79ij	6.37abc	6.58	6.57	6.58	0.64	0.41	0.20
38	9.74bc	7.27a	8.51	8.33	8.42	1.05	2.47	0.83
Mean	8.21	5.71	6.86	6.61	6.80	0.68	2.56	0.97

Y_P: Grain yield under normal irrigation condition; Y_S: Grain yield under water deficit condition; MP: Mean productivity; HAR: Harmonic mean productivity; GMP: Geometric mean productivity; STI: Stress tolerance index; TOL: Tolerance; SSI: Stress susceptibility index; Means with similar letter(s) in each column are not significantly different at 1% probability level by Duncan's Multiple Range Test (DMART)

Genotypes with high values of TOL and SSI are sensitive to water stress and therefore, selection must be done based on low rates of these indices. Based on TOL and SSI indices, hybrids No. 16, 20, 22, 34 and 37 had the highest yield stability among the studied hybrids. Hybrids No. 1, 8, 17 and 38 had the highest rate of MP, HAR and GMP indices (Table 3). So, these hybrids were selected based on MP, HAR and GMP indices. According to Fernandez (1992) more stable genotypes have higher rate of STI. Hybrids No. 1, 4, 8, 17 and 38 were selected based on STI index (Table 3). So, the use of drought tolerance indices couldn't select the similar genotype. Therefore, it is better that genotype selection must be done based on combination of different indices.

Selection based on a combination of indices may provide a more useful criterion for improving drought tolerance of maize while study of correlation coefficients are useful in finding out the degree of overall linear association between any two attributes. In addition, using 3D plot are useful in finding out the relationships of three variables (for example, among Ys, Yp and STI).

Thus, a better approach than a 3D plot and correlation analysis, such as biplot is needed to identify the superior genotypes for both stress and non stress environments. So, for profiting of the biplot utility, the principal component analysis was performed for the data matrix of eight index and thirty eight genotypes and the results were shown in Table 4.

Principal component analysis revealed that the first PCA explained 70.5% of the total variation and had high and positive correlation with Yp, Ys, MP, GMP, HAR and STI. Thus, the first component can be named as the yield potential and drought tolerance component. Considering the high and positive value of this PCA on biplot, selected genotypes will be high yielding under normal irrigation and water deficit conditions.

The second PCA explained 28.3% of the total variability and had high and positive correlation with TOL and SSI. Therefore, the second component can be named as a stress-susceptibility component and it recognizes low yielding genotypes in water deficit condition.

Thus, selection of genotypes those have high PCA1 and low PCA2 are suitable for both normal irrigation and water deficit conditions.

In biplot, the studied genotypes were located in different part of biplot graph based on their drought tolerance indices and their yield. Hybrids No. 4, 7, 8, 12, 14, 15, 17, 33 and 38 with high PC1 and low PC2 were located in the area with high yield potential and low sensitivity to drought (above and left) (Fig. 2). These hybrids were the superior genotypes for water deficit and normal irrigation conditions. In the other hand, hybrids No. 4, 8, 17 and 38 were chosen through STI. So, these hybrids could be considered as the best hybrids with high yield potential and drought stress tolerance. Hybrids No. 3, 6, 9, 23, 24, 25, 26, 31 and 32 were located in the low yield and high sensitivity to drought area in biplot (bottom and right) (Fig. 2). Generally, the distribution of genotypes in biplot space showed that there was genetic diversity among genotypes to drought stress.

Ahmadi *et al*. (2000) obtained similar results in multivariate analysis of drought tolerance indices in maize. Their results suggested that PCA1 and PCA2 explained 66.6 and 33.4% of the total variation in terminal stress condition. These two PCA were related to yield potential and sensitivity to stress. Farshadfar *et al*. (2001) and Golabadi *et al*. (2006) revealed that genotypes with larger PCA1 and lower PCA2 scores gave high yields and genotypes with lower PCA1 and larger PCA2 scores had low yields.

The correlation coefficient between any two indices is approximately equal with the cosine of the angle between their vectors in biplot. Thus, $r = \cos 180° = -1$, $\cos 0° = 1$ and $\cos 90° = 0$ (Yan and Rajcan, 2002). The most prominent relations revealed by this biplot were: (a) a strong negative association between SSI and TOL with Ys, as indicated by the large obtuse angles between their vectors, (b) a near zero correlation between SSI with GMP, HAR and STI, as indicated by the near perpendicular vectors and (c) a positive association

Table 4: Principal component loadings for drought tolerance indices on maize hybrids

Component	Cumulative (%)	Y_P	Y_S	MP	HAR	GMP	STI	TOL	SSI
1	70.52	0.937	0.611	0.998	0.951	0.983	0.982	0.617	0.425
2	99.74	0.347	-0.791	-0.062	-0.307	-0.182	-0.18	0.785	0.90
3	99.95	-0.042	0.02	-0.025	0.041	0.009	-0.002	-0.053	0.094
4	99.99	0.011	0.015	0.014	0.006	0.011	-0.054	0.002	0.002
5	99.99	0.003	0.01	0.006	-0.015	-0.003	0.003	-0.003	0.006
6	100.00	0.001	0.00	0.002	0.002	-0.005	0.00	0.00	0.00
7	100.00	0.00	0.002	-0.003	0.00	-0.001	0.00	0.002	0.00
8	100.00	-0.002	0.00	0.001	0.00	0.00	0.00	0.001	0.00

Y_P: Grain yield under normal irrigation condition; Y_S: Grain yield under water deficit condition; MP: Mean productivity; HAR: Harmonic mean productivity; GMP: Geometric mean productivity; STI: Stress tolerance index; TOL: Tolerance; SSI: Stress susceptibility index

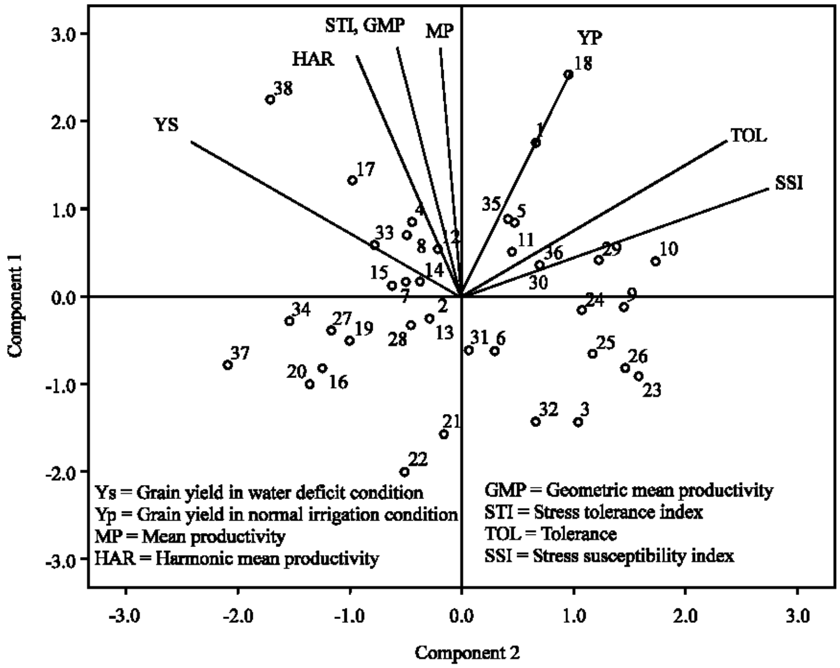

Fig. 2: The biplot display of maize hybrids and drought tolerance indices based on the first and second principal components

between Yp and Ys with MP, HAR, GMP and STI, as indicated by the acute angles (Fig. 2). Similar results have been reported by Golabadi *et al.* (2006). Since selection of drought tolerant genotypes is done based on the combination of indices in the biplot method, thereby this method is better than one index alone to identify superior genotypes for drought conditions.

The hybrid No. 8 produced a greater grain yield ($p<0.01$) than SC 704 (Tolerant check) in normal irrigation. The mean grain yield of hybrid No. 8 was 18% more than SC 704 in normal irrigation condition, but grain yield difference between No. 8 and SC 704 was not significant in water deficit condition (Table 3). Furthermore, this hybrid was selected as stable and high yielding hybrid from the point of STI, MP, HAR, GMP and biplot method. Therefore, between studied hybrids, hybrid No. 8 is identified as drought tolerant hybrid for Pars Abad-e-Moghan and areas with similar environmental conditions.

CONCLUSION

Overly, based on yield in water deficit and normal irrigation conditions and bipolt analysis, hybrids No. 4, 8, 17 and 38 (SC704), especially hybrid No. 8 (K74/2-2-1-3-1-1-1-1 × K3653/2), were the best hybrids in this study.

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