Original Research Article

Evaluation of four maize (*Zea mays* L.) genotypes using drought tolerance indices

Abstract

Drought tolerance is not often considered an independent trait by breeders. The objective of this study was to evaluate and identify drought-tolerant genotypes using eight drought toleranceindicesnamelythe Stress Susceptibility Index (SSI), the YSI, the YR (Yr), yield index (YI), tolerance index (TOL), average productivity (MP), mean geometric productivity (GMP) and stress tolerance index (STI) of maize genotypes (*Zeamays* L.). A field trial was conducted to evaluate four genotypes during the hot dry season of 2016 and 2017 at the irrigated perimeter of Jirataoua. Drought tolerance indices were calculated based on yield under optimal and stressed conditions. The comparison of the means of drought tolerance demonstrated the effects of drought on yield and showed significant differences between genotypes. The correlation coefficient and principal component analysis showed that the GMP, MP and STI indices were able to discriminate drought-sensitive and tolerant genotypes. Two genotypes CZH131001 and CZH142013 produced high grain yieldandboth optimal and stressed conditions. Overall, GMP, MP, and STI indices can be used as effectively drought tolerance screening indices and able to identify better genotypes, suitable for both optimal and stress conditions..

Keywords:, *correlation coefficient, drought tolerance index, genotypes, principal component analysis*

1. INTRODUCTION

"Water is one of the key factors in agricultural production.and, its availability has a strong influence on agricultural production [1]. It also plays an important role in the transfer of salts and nutrients"[2]."Low rainfall and lack of sufficient irrigation are thechallenges of crop production in arid and semi-arid regions. The effects of water stress on growth and yield components are very different. Yield loss is a major concern for farmers and breeders alike. Consequently, the focus is on genotypes selected for yield performance under water stress conditions. Research has been underway since the early 1980s, intending toassociate yield variations and their interactions with growing environment conditions with stress tolerance indices based on yield loss under water deficit compared with normal conditions"[3]. "The results of several previous investigations have shown that genotype x environment (G x E) interactions could be described in part by stress tolerance indices"[4]. "These indices provide a measure of impairment and enable adequate screening of stress-tolerant genotypes"[5].

"However the variation in yield potential comes from factors related to adaptation rather than drought tolerance. Thus, drought indices provide a measure of drought based on yield losses under drought conditions compared to normal conditions and are used for the selection of drought-tolerant genotypes"[5]. [6]proposed"a cultivar stress susceptibility index (SSI)". "Lower SSI values (<1) indicate low yield variation in stressed and unstressed environments and demonstrate greater yield stability, and higher SSI values (>1) suggest greater susceptibility"[7-8-9].[10]defined"a new leading index (STI = stress tolerance index), which can be used to identify high-yielding genotypes under both optimal and stressed conditions. He suggested that selection based on STI results in genotypes with higher stress tolerance and yield potential". "IL demonstrated that GM indices

are mathematical derivatives of yield. Thus, genotypes ranked with high yields under both conditions rather than relative performances are the best indicator for assessing drought tolerance”[11]. [12]observed that genotypes with high YSI show greater stability in the environment. Based on the existed knowledge it ishypothesized that use of effectiveness drought tolerance indices is more important than simply estimating absolute yield under stress.
The aim of this study was to and identify drought-tolerant genotypes and suitable drought-tolerant screening indices..

2. MATERIALS AND METHODS

2.1.Plant material and growing conditions

. Four genotypesnamely, CZH131001, CZH142013, and SC303obtained from were obtained from the (CIMMYT) and the National Institute of Agronomic Research of Niger (INRAN)was used in this study.). The genotypes except P3K were developed for drought tolerance.The experiment was conducted at the Keguel in the Jiratawa site in the 2016 and 2017 dry season using irrigation. The experimental site is 10 km from the town Maradi, Niger, located in latitude latitude 13°41' and longitude = 7°14') in altitude of ……, , The maximum and minimum temperature: 45.44-34.88°C: 28.74-12.93°C and min: max relative humidity: 20.36-49.28%: 83.00-99.26%) during the hot season (March to June). The soils are sandy-loam, representing 95% of the irrigated perimeter soils. These soils have a light texture with 85.17% (w/w) sand, 13.44% (w/w) silt and 1.39% (w/w) clay. The PH_{eau}, and $_{PHCaCl2}$ of the soil solution are 7.20 and 6.97 respectively.
Drought tolerance indices were calculated using the following equations:
Ten drought tolerance indices, namely stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), tolerance index (TOL), stress susceptibility index (SSI), yield stability index (YSI), yield reduction rate (Yr) and yield index (YI) were calculated based on yields under drought (Ys) and irrigated (Yp) conditions. Drought tolerance indices were calculated using the following equations:

Indice de susceptibilité au stress (SSI)$SSI = \frac{1-\frac{Yd}{Yp}}{DII}$[6]

Yield Stability Index (YSI) $YSI = Yd/Yp$[13]

Yield index (YI) $YI = Yd/\overline{Y}d$[14]

StressToleranceIndex(STI) $STI = \frac{(Yp * Yd)}{(\overline{Y}p)2}$[10]

Yield reduction (Yr) $Yr = 1 - (Yd/Yp)$ [15]

Productivité géométrique moyenne (GMP)$GMP = \sqrt{(Yd * Yp)}$[16]

Tolerance index (TOL) $TOL = Yd - YP$[17]

Average productivity (MP) $MP = (Yp + Yd)/2$[17].

2.2.Data analysis

Analysis of variances was undertaken using ……. and phenotypic correlation was done coefficients wereanalysed with ……and Principal component analysis (PCA) were carried out using XLSTAT 2019 software version 21.1.2.56803.

3. RESULTS

3.1.Comparison of genotypes based on stress tolerance indices

. The mean values of various indices are given in Table 1.Significant variation among genotypes was observed for grain yield under optimum and drought conditions. Drought stress reduced the grain yield of maize genotypes and the genotypes respond differently due to the effect of drought as indicated by drought indices. Among the four genotypes, CZH142013 and CZH1310001 showed high values of stress tolerance index (STI), geometric mean productivity (GMP) and mean productivity (MP) compared with genotypes SC303 and P3K.. These tolerant genotypes also recorded high Yield Stability Index (YSI) and Yield Index (YI) values. In addition, these genotypes showed higher tolerance than the other two (SC303 and P3K) due to the low values of tolerance index (TOL), yield reduction (Yr) and stress susceptibility index (SSI). Consequently, these two genotypes with high STI, GMP and MP values can be selected as water stress-tolerant genotypes.,Tthe Stress Susceptibility Index (SSI) estimates the rate of yield variation for each genotype between optimal and stress conditions, relative to the average variation for all genotypes.

Table 1: Average comparison of drought tolerance indices and grain yield (Kg/ha) of different maize genotypes under stressed and unstressed conditions.

Genotypes	Yp	Yd	Yr	YSI	SSI	STI	GMP	MP	TOL	YI
CZH142013	954,4^{ab}	732,71^{b}	23^{bc}	76,77^{ab}	0,8^{b}	1,13^{a}	836,24^{ab}	843,56^{ab}	121,69^{b}	1,30^{ab}
CZH1310001	1046,77^{a}	1012,39^{a}	3^{c}	96,65^{a}	0,12^{b}	1,71^{a}	1029,43^{a}	1029,58^{a}	34,38^{c}	1,80^{a}
SC303	572,8^{b}	139,31^{c}	75^{a}	24,31^{c}	2,7^{a}	0,12^{b}	282,48^{c}	356,06^{c}	433,49^{a}	0,25^{c}
P3K	568,46^{b}	334,89^{bc}	41^{b}	58,9^{b}	1,46^{a}	0,3^{b}	436,31^{bc}	451,68^{bc}	233,57^{b}	0,59^{bc}

Means followed by the same letters in each column are not significantly different ($p < 0.01$). Yp: yield under optimal conditions, Yd: yield under water stress, GMP: geometric mean productivity, MP: mean productivity, SSI: stress susceptibility index, STI: stress tolerance index, Yr: yield reduction ratio, YSI: yield stability index, YI: yield index, TOL: tolerance index.

3.2.Correlation analysis

Phenotypic correlation coefficients of grain yield under drought stress, no stress and drought tolerant indices are given in Table 2. The correlation coefficient of grain yield under stress was positive and strong with drought tolerant indices (GMP=0.99); (M=0.99); (STI=0.99); (YI=0.99); and (YSI=0.96). In contrast, grain yield under drought was negatively correlated with (SSI=-0.96) and (TOL=-0.92).

Some indices have been developed based on quantitative traits under optimal and stressed conditions that can be used as indicators of stress tolerance. To determine the most desirable drought tolerance criteria, phenotypic correlation coefficients between Yd, Yp and other quantitative drought tolerance indices were calculated (Table 2). As a general rule, indices with a high correlation with yield under both optimal and stressed conditions are presented as the best, as they can separate high-yielding genotypes under both conditions. An appropriate index should have a significant correlation with yield under both conditions [5].

Table 2: Correlation coefficients between Yp, Yd and the drought tolerance and susceptibility indices of 4 maize genotypes

	SSI	GMP	MP	STI	TOL	YI	YSI	Yd	Yp	Yr
ISD	1,00									
GMP	-0,96*	1,00								
MP	-0,94^{ns}	0,99***	1,00							
STI	-0,93^{ns}	0,99**	0,99**	1,00						
TOL	0,97*	-0,89^{ns}	-0,87^{ns}	-0,89^{ns}	1,00					
YI	-0,96*	0,99**	0,99**	0,99**	-0,92^{ns}	1,00				
YSI	-0,99***	0,95*	0,94^{ns}	0,93^{ns}	-0,97*	0,96*	1,00			
Yd	-0,96*	0,99**	0,99**	0,99**	-0,92^{ns}	0,99***	0,96*	1,00		
Yp	-0,88^{ns}	0,98*	0,99**	0,98*	-0,79^{ns}	0,97*	0,97*	0,97*	1,00	
Yr	0,99***	-0,96*	-0,94^{ns}	-0,93^{ns}	0,97*	-0,96*	-0,99***	-0,96*	-0,88^{ns}	1,00

ns. * and **: non-significant and significant at the 5% and 1% probability levels, respectively. Yp: yield under optimal conditions, Yd: yield under stressed conditions, GMP: geometric mean productivity, MP: mean productivity, STI: stress tolerance index, SSI: stress susceptibility index, Yr: yield reduction ratio, YSI: yield stability index, YI: yield index, TOL: tolerance index.

3.3.Principal component analysis

A PCA was performed using the tolerance indices and the genotypes were subjected to a biplot analysis to obtain the relationships between the indices (Table 3). Many researchers have used this analysis to compare different genotypes for different criteria and different species. The results of the principal component analysis (PCA) showed that the first two components explained 95.84% and 3.75% of the total variation. The PCA revealed that the first component (F1) explained 95.84% of the variation in total yield, and was positively correlated with Yp, Yd, YSI, YI, MP, GMP and STI.

Table 3: Principal component analysis results for grain yield of different maize genotypes under optimal (Yp) and stressed (Yd) conditions, geometric mean productivity (GMP), mean productivity (MP), stress tolerance index (STI), stress susceptibility index (SSI), yield reduction rate (Yr), yield stability index (YSI), yield index (YI) and stress tolerance index (TOL).

Tolerance index	F1	F2
Yp	0,307	0,508
Yd	0,322	0,107
Yr	-0,317	0,298
YSI	0,316	-0,306
STI	0,318	0,252
GMP	0,321	0,180
MP	0,319	0,266
TOL	-0,303	0,525
YI	0,322	0,107
SSI	-0,317	0,306

F2
(3,
75)

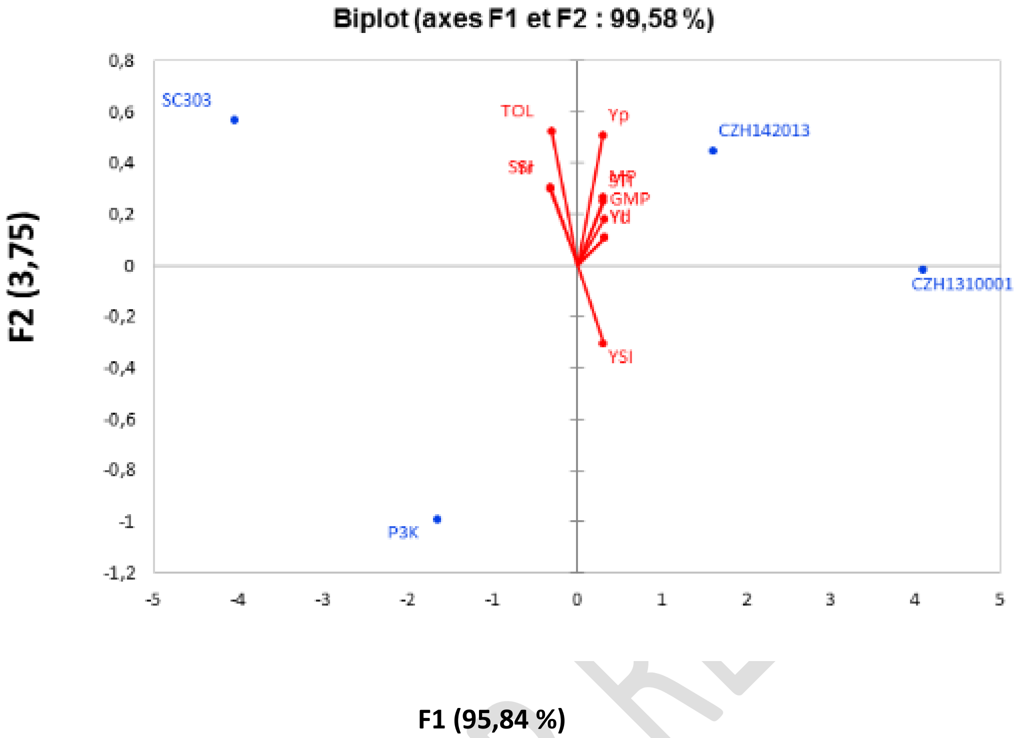

Figure 1: Biplot drawn based on first and second axes obtained from principal component analysis using stress susceptibility index (SSI), yield reduction rate (Yr), yield index (YI), stability index (YSI), stress tolerance (TOL), mean productivity (PM), geometric mean productivity (GMP), stress tolerance index (STI) and yield under optimal (Yp) and stress (Yd) conditions of 4 maize genotypes.

4. DISCUSSION

In this study drought intensity of about 0.27 % was observed and it was s considered moderate based on the work of various authors. (Include references associated with similar reports). Water stress is considered severe for intensity values above 0.7 [11].[18]suggested that simultaneous evaluation of genotypes under optimal and stressed conditions would appear to be the most suitable procedure for selecting genotypes in environments frequently confronted with abiotic stresses such as water deficit. Indeed, selection based solely on the performance of genotypes under normal conditions does not necessarily lead to productivity gains under stressed conditions, and vice versa [10]. Several selection criteria have been proposed to evaluate the performance of plant species under optimal and stressed conditions. [6] proposed the water stress susceptibility index (SSI) as an indicator of a genotype's sensitivity to water stress. SSI values below 1 indicate low sensitivity to drought (or high yield stability), and values above 1 indicate high sensitivity to drought (or low yield stability). [10]defined the geometric mean productivity (GMP) and the water stress tolerance index (STI), which could be used to identify high-yielding genotypes under both normal and stressed conditions. The higher the STI value, the more drought-tolerant the genotype and the higher its yield potential. According to [19], a genotype's ability to exhibit high yield and geometric mean productivity (GMP) is linked to its drought tolerance. The value of STI as a function of yield under optimal and stressed conditions showed that the genotypes (CZH1310001 and CZH142013) with the highest yields in both environments also had the highest tolerance index (STI). These results are in line with those of [20]and [10], who respectively showed that STI values were higher in sesame and wheat genotypes with the highest yields in two contrasting environments. Similarly, working on maize, [21] found STI to be the best predictor of high yields under different environmental conditions for the selection of lines for water stress, while [22]selected from among five stress indices, the stress tolerance index (MSTI) to which they made a modification using a correction factor ki. The STI was even suggested for the selection of tolerance to high temperatures [23]. "When stress is severe, TOL, SSI and STI were more useful as indices to distinguish between resistant and susceptible, although no single indicator could identify high-yielding cultivars under stressed and unstressed conditions. It has been concluded that the effectiveness of selection indices under severe stress confirms that different stress conditions influence yield under stress"[24-25]. The SC303 and P3K genotypes showed susceptibility due to higher TOL and SSI values. Our results concur with those of [7]who used the stress susceptibility index (SSI) to assess drought tolerance in wheat genotypes. It was observed that both TOL and SSI were successful in selecting high-yielding genotypes under drought stress.

The correlation matrix shows that a significant positive correlation was observed between yield under stressed (Yd) and optimal (Yp) conditions with stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), indicating that these criteria discriminated between drought-tolerant genotypes with high yields in stressed and unstressed environments. Our results are similar to observations made by [4-22-26-27-28-29-30], who claim that these three indices (STI, MP and GMP) would be the best predictors of yields under optimal and stressed conditions. [31]also concluded that “MP, GMP and STI were practical parameters for selecting high-yielding wheat genotypes under optimal and stressed conditions”. [32]found that “STI and GMP, which showed the strongest correlation with yield under optimal and stressed conditions, can be used as the best indices for breeding programs aimed at introducing drought-resistant hybrids. A significant negative correlation was observed between (Yd) with the tolerance index (TOL), the stress susceptibility index (SSI) and the yield reduction ratio (Yr). The tolerance index (TOL) was not significantly correlated with Yp and MP. Consequently, indices with significant associations were also able to identify drought-tolerant genotypes. The higher the TOL and SSI values, the higher the yield production under optimal conditions, and the greater the reduction in production under stressed conditions”. Our results are similar to those reported by [33]on soft wheat cultivars, who conclude that the higher the TOL values, the greater the yield reduction under water stress and the higher the sensitivity to stress. Similarly, [30] working on durum wheat, suggests that selection for TOL decreases yield under water deficit and increases it under optimal water conditions. Yd and Yp were negatively correlated with SSI in both environments. SSI has been widely used by many researchers to identify drought-sensitive and drought-tolerant genotypes [7-30]. Since in both water regimes, yield under optimal and stressed conditions (Yd and Yp) is significantly correlated with the STI and GMP factors, these two indices can be validly used to discriminate between water-stress-tolerant and water-stress-sensitive genotypes. Indices that correlate with yields (Yd and Yp) under both optimal and stressed conditions are considered the best because they can separate genotypes with high yields under both water regimes [10]. The latter author introduced the STI and GMP factors to select bean genotypes that are both drought-tolerant and have high yields in contrasting environments.

PCA revealed that genotypes with high F1 values (Table 3) should have high yields under both conditions. Similar results were reported by [30-34]in durum wheat and cotton. F2 explained 3.75% of the variation in total yield and correlated positively with TOL, Yr and SSI. F2 is associated with yield under stress conditions and stress sensitivity. Consequently, F1 and F2 can be considered as yield potential and stress susceptibility respectively. Biplot results based on F1 and F2 data for the 4 genotypes showed that genotypes CZH142013 and CZH1310001 are close to the best drought tolerance indices with high F1, but low F2 values (figure 1). On the other hand, the two genotypes (SC303 and P3K) with low F1 and high F2 values were identified as sensitive genotypes. Our results are in line with the report by [35]who found that “wheat genotypes with higher F1 and lower F2 values had high yields (stable genotypes) and genotypes with lower F1 and higher F2 scores had low yields (unstable genotypes)”.

5. CONCLUSION

This study aims to evaluate selection criteria for identifying drought-tolerant genotypes with high yields under both optimal and stressed conditions. As stress tolerance indices are only mathematical derivations of the same yield data, selection based on a combination of different stress tolerance indices would be able to characterize the most productive and water-stress-resistant genotypes. The positive and significant correlations obtained with Yd and Yp and MP, GMP and STI lead to the conclusion that these indices are the best for determining yield in both environments. The tolerant genotypes CZH1310001 and CZH142013 with strong correlations with these three indices showed the highest yields under both optimal and stressed conditions. Whereas genotypes (SC303 and P3K) with high values of TOL and SSI were able to produce high yields only under optimal conditions. Consequently, breeders can select genotypes that are tolerant under water-stressed conditions and compare their performance under optimal conditions using MP, GMP and STI indices.

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