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Evaluation of Four Maize (*Zea mays* L.) Genotypes Using Drought Tolerance Indices

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Drought tolerance is not often considered as an independent trait by breeders. The objective of this study was to evaluate and identify drought tolerant genotypes using eight drought tolerance indices namely the 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 (*Zea mays* L.). A field trial was conducted to evaluate four genotypes during the hot dry season of 2016 and 2017 at the irrigated perimeter of Djirataoua. Drought

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tolerance indices were calculated on the basis of 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 yield under both 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

Africa contributed 81 MT to the global maize (Zea mays L.) production of 1148 MT in 2019 [1]. By 2029, global maize output is expected to reach 1315 MT, with Africa contributing less than 10% [2]. However, maize consumption in Sub-Saharan Africa (SSA) is predicted to expand at the fastest rate, accounting for more than half of the additional 23 MT earmarked for human consumption [2]. Due to extreme climate events, projected global increases in maize demand and consumption will coincide with yield declines in SSA [3]. The increase in maize demand will benefit industrialized countries, but it will result in higher poverty rates, malnourished children, and increased food insecurity in most developing countries in SSA. According to FAO [4], approximately 16.7 million people in West Africa are severely food insecure, with the number potentially increasing to 23.6 million if appropriate measures are not taken. The report attributed the food insecurity to significant localized production deficits caused by adverse climate events regions. For millions of people in Africa and Asia, maize is the most important staple food and the most important single source of calories [2]. As a result, increasing maize yield has the potential to improve food security. Maize is a staple crop in some of the world's poorest regions, including Africa, Asia, and Latin America [3]. In West Africa, specifically in Niger, maize is a widely consumed cereal but whose national production is still very low and cannot meet the food needs of consumers. Niger imports large quantities of maize from neighboring countries (Nigeria, Benin, Burkina, etc.). Corn is used for the preparation of traditional meals such as porridge, couscous, pancakes etc. It is also eaten green where the still immature cobs are either grilled or boiled. Maize stalks are generally used for livestock feed but also left in place and incorporated into the soil during ploughing. Between 2000 and 2017 the average maize yield was 0.95 t/ha (FAOSTAT, 2017) far below the average yields obtained in Africa (3 to 6 t/ha) and the United States, Asia and Europe.

The limiting factors for maize production in Niger are essentially low water availability (irregular rainfall and poor irrigation control) and temperature variations. "Water is one of the key factors in agricultural production and its availability has a strong influence on agricultural production" [5]. "It also plays an important role in the transfer of salts and nutrients" [6]. "Low rainfall and lack of sufficient irrigation are the challenges 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, with the aim of associating yield variations and their interactions with growing environment conditions with stress tolerance indices based on yield loss under water deficit compared with normal conditions" [7]. 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" [8]. "These indices provide a measure of impairment and enable adequate screening of stress-tolerant genotypes" [9].

"But 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 used for the selection of drought-tolerant genotypes" [9]. Fischer and Maurer [10] 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" [11-12-13]. Fernandez [14] 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" [15]. [16] observed that "genotypes with high YSI have more stability across environment. Therefore, YSI is good measure for Drought Tolerance Efficiency and is more useful in selection criteria than mere absolute yield estimate under stress".

The aim of this study was is use drought tolerance indices to identify drought-tolerant genotypes with high yield under optimal and stressed conditions.

2. MATERIALS AND METHODS

2.1 Plant Material and Growing Conditions

Four genotypes namely, CZH131001, CZH142013, SC303obtained from were obtained from the (CIMMYT) and the National Institute of Agronomic Research of Niger (INRAN) were 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 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.

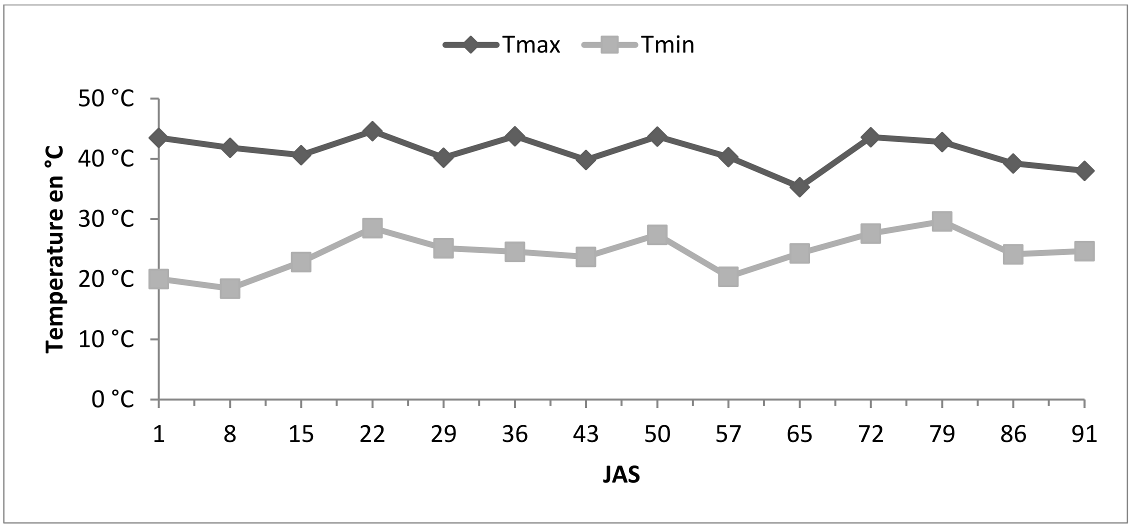

Fig. 1. Air temperature evolution during the field trial period

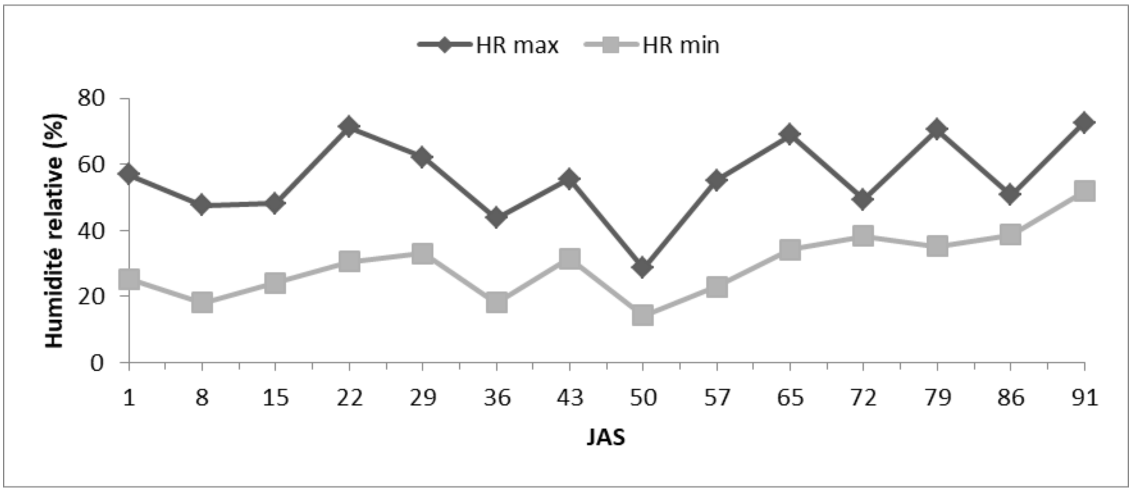

Fig. 2. Evolution of the relative humidity of the air during the field trial

Table 1. Physico-chemical characteristics of the soil of the experimental site (Result of the analysis carried out by the Department of Soil Science, Faculty of Agriculture, Bayero University, Kano)

pH		Granulometry			Organic matter (%)		Absorbent complex Cmol/kg						
H_2O	$CaCl_2$	S	L	A	N	O.C	P	Ca	Mg	K	Na	E.A	CEC
7,21	6,98	85,17	13,44	1,39	0,14	0,35	5,95	1,61	0,74	0,1	0,1	0,39	3,11

2.2 Estimation of Drought Tolerance Indices

Ten drought tolerance indices viz. stress tolerance index (STI), mean productivity (MP), geometric mean productivity GMP), tolerance index (TOL), stress susceptibility index (SSI), yield stability index (YSI), yield reduction ratio (Yr), and yield index (YI) were calculated based on yield under drought (Ys) and irrigated (Yp) conditions. Drought tolerance indices were calculated using the following equations.

Indice de susceptibilité au stress (SSI) $SSI = \frac{1-\frac{Yd}{Yp}}{DII}$ [10]

Yield Stability Index (YSI) $YSI = Yd/Yp$ [17]

Yield index (YI) $YI = Yd/\overline{Y}d$ [18]

Stress Tolerance Index (STI) $STI = \frac{(Yp * Yd)}{(\overline{Y}p)2}$ [14]

Yield reduction (Yr) $Yr = 1 - (Yd/Yp)$ [19]

Productivité géométrique moyenne (GMP) $GMP = \sqrt{(Yd * Yp)}$ [20]

Tolerance index (TOL) $TOL = Yd - YP$ [21]

Average productivity (MP) $MP = (Yp + Yd)/2$ [21].

2.3 Data Analysis

Comparison of means, correlations between indices and yield and principal component analysis (PCA) based on selection criteria (drought tolerance indices) and genotypes were performed using XLSTAT software. 2019 release 21.1.2.56803. This was done to interpret relationships between selection criteria and compare genotypes based on drought tolerance indices allowing the identification of genotypes with some level of drought tolerance.

3. RESULTS

3.1 Comparing Genotypes Based on the Resistance/Tolerance Indices

Drought tolerance and yield are complex traits and different factors affect them. To investigate suitable stress resistance indices for evalued of genotypes under drought was carried out, seed maize yield of genotypes under both non-stress and stress conditions were measured for calculating different sensitivity and tolerance indices. A suitable index must have a significant correlation with yield under both conditions (Mitra, 2001). The mean values of various indices are given in Table 2. 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), mean productivity (MP), low Tolerance Index (TOL) value, a reduction in yield (Yr) and stress susceptibility index (SSI) compared with genotypes SC303 and P3K. The genotypes with high values of STI can be selected as tolerant genotypes to water stress. When the stress was severe, TOL, SSI and STI were found to be more useful indices discriminating resistant from susceptible, although none of the indicators could clearly identify cultivars with high yield under both stress and non-stress conditions.

3.2 Correlation Analysis

Phenotypic correlation coefficients of grain yield under drought stress, no stress and drought tolerant indices are given in Table 3. Some indices have been developed on the basis of 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

Table 2. 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

Table 3. 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*

quantitative drought tolerance indices were calculated (Table 3). 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 [9]. From the correlation matrix, it is observed that a significant positive correlation was found between yield in the stress (Ys) and non-stress (Yp) conditions with stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), yield index (YI), and yield stability index (YSI) indicating that these criteria discriminated drought tolerant genotypes with high yield under stress and non-stress environments. The significant negative correlation was observed between (Ys) with tolerance index (TOL), stress susceptibility index (SSI), and yield reduction ratio (YR). Tolerance index (TOL) was not significantly correlated with Yp and MP. Hence, indices having significant associations were also able to identify drought tolerant genotypes. The higher the TOL and SSI values, the higher the yield production under non-stressed conditions and conversely, there was a trend for smaller TOL and SSI values to be associated with larger yield production under stressed conditions.

Table 4. 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

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 4). Many researchers have used this analysis to compare different genotypes for different criteria and different

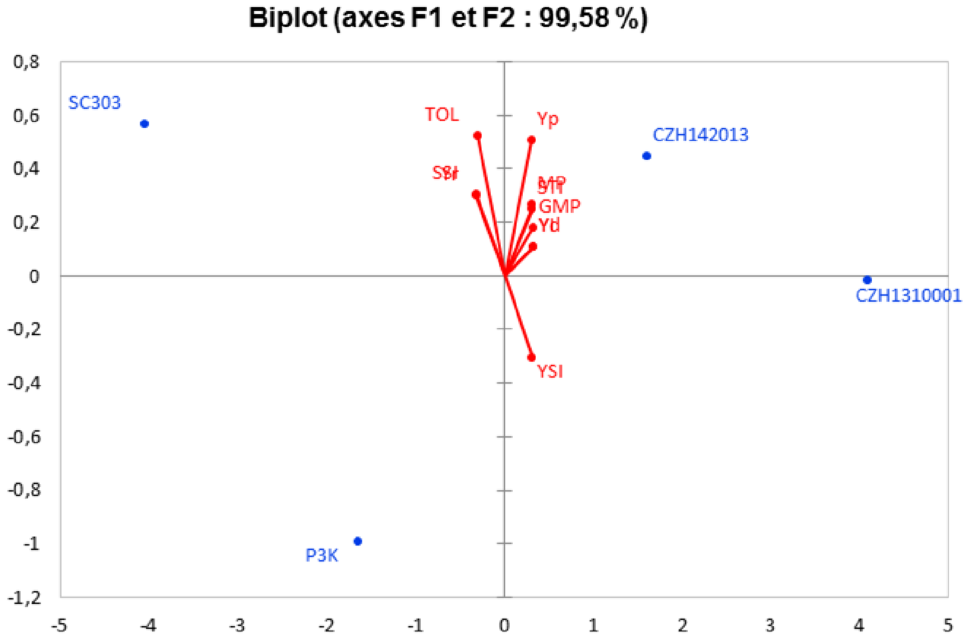

Fig. 3. Biplot drawn on the basis of first and second axes obtained from principal component analysis using stress susceptibility index (SSI), yield reduction rate (Yr), yield index (YI), stability index (YSI), stress tolerance (TOL), mean productivity (PM), geometric mean productivity (GMP), stress tolerance index (STI) and yield under optimal (Yp) and stress (Yd) conditions of 4 maize genotypes

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.

4. DISCUSSION

In this study drought intensity of about 0.27 % was observed and it was s considered as moderate based on the work of various authors. (Include references associated to similar reports). Water stress is considered severe for intensity values above 0.7 [15]. [22] 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 [14]. Several selection criteria have been proposed to evaluate the performance of plant species under optimal and stressed conditions. [10] 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). [14] 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 [23], 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 [24] and [14], 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, [25] found STI to be the best predictor of high yields under different environmental conditions for the selection of lines for water stress. The STI was even suggested for the selection of tolerance to high temperatures [27]. When stress is severe, TOL, SSI and STI were more useful as indices to distinguish between resistant and susceptible, although no single indicator could clearly 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 [28-29]. The SC303 and P3K genotypes showed susceptibility due to higher TOL and SSI values. Our results concur with those of [11] 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 [8-26-30-31-32-33-34-40], who claim that these three indices (STI, MP and GMP) would be the best predictors of yields under optimal and stressed conditions. İlker [35] also concluded that MP, GMP and STI were practical parameters for selecting high-yielding wheat genotypes under optimal and stressed conditions. Jafari, et al. [36] 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, the greater the reduction in production under stressed conditions. Our results are similar to those reported by Sio-Se, et al. [37] 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, Golabadi, et al. [34] working on durum wheat, suggest 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 [11-34]. 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. In fact, 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 [14]. 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 4) should have high yields under both conditions. Similar results were reported by Golabadi et al. [34-38] in durum wheat and in 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 (Fig. 3). 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 Kaya, et al. [39] 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

In the present study positive and significant correlations obtained in Ys and Yp with MP, GMP and STI leads to the conclusion that these indices are the best predictors of yield under water-stressed and non-stressed environments. YSI was also found to be a useful index to discriminate tolerant genotypes CZH1310001 and CZH142013 which were stable in different conditions and produced high yield under high to moderate water-stressed environments. The genotypes (SC303 and P3K) with high values of TOL and SSI were able to produce high yield only in the non-stressed environment. It was also observed that drought stress significantly reduced the yield of some genotypes while some were tolerant to drought, indicating genetic variability for drought tolerance among the genotypes. Therefore, breeders can select suitable genotypes under water-stressed conditions and compare their performance under non-stressed conditions using MP, GMP, and STI indices as a means to decide on performance under stress and non-stress conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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