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Grain yield and drought tolerance indices of maize hybrids

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Abstract

Drought is one of the major abiotic stress factors limiting crops production in Oltenia area, Romania. In order to study the response of six maize hybrids to drought stress, the trials were conducted in research field of ARDS Simnic – Craiova, during 2017-2018 (non-stressed conditions) and 2018-2019 (drought stress). Six tolerance indices including: abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), Stress tolerance index (STI), mean productivity (MP), relative drought index (RDI) and golden mean (GM), were utilized on the basis of grain yield. Results from analysis of variance showed that there is a significant difference in 1% of probability level among hybrids in terms of grain yield and tolerance indices. The yield in non-stress conditions (Yp) showed significant positive correlations with ATI, SSPI, STI and MP, and negative correlation with RDI and GM. The yield in drought conditions (Ys) showed significant positive correlation with RDI and GM, and negative correlation with ATI and SSPI. None of the tolerance indices used could identify the high yielding hybrids under drought and non-stress conditions. Based on the ranking method, the hybrids 'Felix' and 'P 9903' were the most droughts tolerant. Therefore, they hybrids are recommended to be grown under drought prone areas and to be used as parents for breeding of drought tolerance in other cultivars.

Keywords: correlation analysis; drought tolerance indices; maize; ranking method

Abbreviations: ARDS Simnic: Agricultural Research and Development Station Simnic; ATI: Abiotic Tolerance Index; DF: Degrees of Freedom; GM: Golden Mean; MP: Mean Productivity; NARDI Fundulea: National Agricultural Research and Development Institute Fundulea; RS: Rank Sum; RDI: Relative Drought Index; SOV: Source of Variation; SSPI: Stress Susceptibility Percentage Index; STI: Stress Tolerance Index; Yp: yield under non-stress; Ys: yield under drought stress

Introduction

Maize (*Zea mays* L.) is a valuable species of the Poaceae family due to nutritional value and its biological characteristics, being the second crop worldwide after wheat. In Romania, maize occupies around 2,442 thousand hectares with total production of 18,664 thousand tonnes and grain yield of 7 641 kg ha^{-1} (FAO, 2018). Romania has a real potential for developing the maize crop by increasing first of all the yield, but need to overcome one of the main constraints which is the drought, especially in South part (Ion *et al*., 2013).

The important factors that limiting the maize yield in the world are abiotic and biotic stresses. Drought is the most severe abiotic factor that leads always to different yield losses levels depending on the constrainer

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length, its intensity, crop stage and hybrid sensitivity. Oltenia region is a dry area from Southwestern of Romania, where only two years out of ten are favourable to agricultural crops (Chaturvedi *et al*., 2019; Bonea and Urechean, 2020). Therefore, selection for drought tolerant maize hybrids is the most important objective for breeding program. The development of maize hybrids that are more resistant to drought stress is a practical and economical approach to lessen the negative effects of drought on the crop.

Blum (2005) proposed that plant breeding programs should mainly focus on selecting cultivars that have high yield firstly under non-stress conditions and secondly under drought stress conditions.

Choosing genotypes having tolerant genes is a difficult task due to its intricate heritability (Anwaar *et al*., 2019). Some researchers found that, despite the lack of understanding of the drought tolerance mechanisms, an efficient approach for improving drought tolerance, remain the grain yield under drought stress condition (Talebi *et al*., 2009; Geravandi *et al*., 2011). However, the cultivars with high grain yield may not be stress tolerant to drought and the reverse (Sio-Se Mardeh *et al*., 2006). According to Tiwari *et al.* (2017), the use of selection indices is more efficient than direct selection for grain yield alone.

Many researchers believe that selection based of some statistical parameters as well as drought tolerance indices, considering yield under non-stress and drought stress conditions, is a more efficient strategy, especially under unpredictable rain fed conditions with various yearly drought scenarios (Mitra, 2001; Moosavi *et al*., 2008; Saad *et al*., 2016).

Moosavi *et al.* (2008) introduced ATI and SSPI for screening drought tolerant genotypes in stressed and non-stressed conditions. The STI is a useful tool for identifying high yielding genotypes that also have a high stress tolerance potential (Fernandez, 1992). Rosielle and Hamblin (1981) defined MP as the mean value of yield in stress and non-stress conditions. Fischer and Wood (1979) suggested that RDI is a positive index for indicating stress tolerance. Moradi *et al.* (2012) presented GM as benefit to identify maize to drought stress tolerance. For selection based on a combination of indices, Farshadfar and Elyasi (2012) have suggested correlation coefficient and ranking method.

Farshadfar *et al.* (2012a) found that a good criterion for screening the best cultivars and indices used is the correlations analysis between grain yield and drought tolerance indices. The best indices to identify drought tolerant cultivars are those which have high correlation with grain yield in both conditions (Mitra, 2001).

In this perspective, the objectives of the study were to evaluate drought tolerance levels in six maize hybrids and to determine the best selection criteria for the drought tolerance, so that suitable hybrids can be recommended for cultivation in drought prone areas of Romania.

Materials and Methods

Experimental design and plant material

Six maize hybrids were evaluated in present study ('Felix', 'F 376', 'PO 216', 'P 9903', 'DK 5068', 'DK 4590'). 'Felix' and 'F 376' are semi-late hybrids developed at NARDI Fundulea which have a high yielding potential of 8.6-10.9 t ha^{-1} and of 8.2-11.2 t ha^{-1}, respectively (Horhocea *et al*., 2019). The hybrids 'PO 216' (semi-late) and 'P 9903' (semi-early) developed by the DuPont Pioneer Company can touch a yielding potential of 8.7-11.7 t ha^{-1} and of 9.7-11.8 t ha^{-1}, respectively (www.pioneer.com). 'DK 5068' (semi-late) and 'DK 4590' (semi-early) hybrids are developed by the Monsanto Company and have a yielding potential of 11.1-12.6 t ha^{-1} and of 8.0-12.0 t ha^{-1}, respectively (www.dekalb.ro).

The hybrids were grown in the research area of Field Breeding Crops Laboratory, ARDS Simnic - Craiova, located in the central zone of Oltenia region, Romania, during 2017-2018 (non-stressed conditions) and 2018-2019 (drought conditions) growing seasons. The trials were conducted in a randomized block design with 3 replications. Each plot consisted of 4 rows 4.8 m long. Plot area was sowing on 23^{th} of April 2018 and 17^{th} of April 2019, respectively. At each trial, fertilization was applied as 250 kg ha^{-1} (NPK 20:20:0), before sowing and 250 kg ha^{-1} ammonium nitrate during the V7 and V10 growth stages. The weed control was made by applying DUAL GOLD 960- 1.5 l ha, just after sowing and EQUIP 1.5 l ha + BUCTRIL 1 l ha^{-1} post emergent (V6-V8 growth stages).

Calculate drought tolerance indices

The six drought stress tolerance indices (ATI, SSPI, STI, MP, RDI and GM) were calculated using the formulas from Table 1.

Table 1. The drought tolerance indices

Drought tolerance indices	Code	Equation	References
Abiotic Tolerance Index	ATI	$ATI = \frac{(Yp - Ys)}{(Ypi - Ysi)} \times \sqrt{Yp \times Ys}$	Moosavi *et al.* (2008)
Stress Susceptibility Percentage Index	SSPI	$SSPI = \frac{(Yp - Ys)}{2(Ypi)} \times 100$	Moosavi *et al.* (2008)
Stress Tolerance Index	STI	$STI = \frac{Yp \times Ys}{(Ypi)2}$	Fernandez (1992)
Mean Productivity	MP	$MP = \frac{Yp + Ys}{2}$	Rosielle and Hamblin (1981)
Relative Drought Index	RDI	$RDI = \frac{(Ys / Yp)}{Ysi / Ypi}$	Fischer and Wood (1979)
Golden Mean Index	GM	$GM = \frac{Yp \times Ys}{(Yp - Ys)}$	Moradi *et al.* (2012)

where Yp, Ys and Ypi, Ysi represent yield under non-stress, yield under drought stress for each cultivar and yield mean in non-stressed and drought stress for all cultivars, respectively.

Statistical analysis

The data on the grain yield and the tolerance indices have analyzed using ANOVA: single factor program with MS Excel. Means were compared using Duncan's multiple range tests at 0.05 level of probability. Pearson's correlation coefficients were calculated on the basis of tolerant indices. The variability presence was estimated by coefficient of variations (CV).

Results and Discussion

Analysis of variance

The analysis of variance showed highly significant differences ($p \leq 0.01$) for grain yield (Yp and Ys) and all drought tolerance indices (Table 2). Those results demonstrated that all tolerance indices revealed an important genetic diversity and were able to discriminate between the hybrids in both conditions.

Several researchers also reported the similar results for grain yield under stressed and non-stressed conditions and for most of the drought tolerance indices (Sabaghnia and Janmohammadi, 2014; Saad *et al.*, 2016; Erdemci, 2018; Rosmaina *et al.*, 2019).

The values of the CV varied between 7% (Ys) and 51% (ATI). These results displayed the low, moderate or higher influence of environment for each index and indicated that all hybrids had exploitable genetic variability for the studied indices.

Table 2. ANOVA for grain yield performances of maize hybrids in non-stressed and drought conditions and drought tolerance indices

SOV	DF	Yp	Ys	ATI	SSPI	STI	MP	RDI	GM
Hybrids	5	6.708**	0.712**	278.026**	219.061**	0.028**	1.633**	0.091**	11.927**
Error	12	0.109	0.025	5.073	5.238	0.0003	0.017	0.003	1.318
CV		14	7	51	45	14	16	16	40

SOV: source of variation; DF: degrees of freedom; CV: coefficient of variation; **: significant on 0.01 level

Comparison of hybrids based on stress tolerance indices

To investigate suitable drought tolerance indices for screening maize hybrids, some indices were calculated based on Yp and Ys (Table 3). Hybrids with low tolerance indices (ATI and SSPI) and hybrids with high tolerance indices (Yp, Ys, STI, MP, RDI and GM) would be more tolerant.

Based on grain yield in non-stressed conditions (Yp), the hybrid 'DK 4590' was found the promising hybrid with higher yield, while the low performing hybrid was the hybrid 'F 376'.

Under drought conditions (Ys), the higher performing hybrids were 'Felix' and 'P 9903' and the low performing hybrids were 'F 376', 'DK 5068' and 'PO 216'.

The stress intensity index (SI) would get value between 0 and 1. In this study SI was equal to 0.37 indicated less severe stress.

Drought stress reduced grain yield by 23.58% to 51.63 % (Table 3). Khodarahmpour and Hamidi (2011) observed 15%, 40% and 60% yield reduction due to drought in maize inbred lines at vegetative, pollination and grain filling stages, respectively.

Table 3. Grain yield (t ha^{-1}) under non-stressed and drought conditions (SI = 0.37) with reduction in yield (%)

Hybrids	Non-stress	Drought	Yield reduction %
'Felix'	8.86 bc	6.77 a	23.58
'F 376'	8.28 c	5,78 bc	30.02
'PO 216'	9.89 b	5.70 c	42.36
'P 9903'	9.06 bc	6.71 a	25.93
'DK 5068'	9.81 b	5.77 bc	41.18
'DK 4590'	12.53 a	6.06 b	51.63

Means followed by different letters in each column are significantly different from each other at 5% level of significance

The ATI and SSPI indices favour genotypes with good grain yield under drought conditions (group C) – Figures 1 and 2. According to Moosavi *et al.* (2008), ATI and SSPI indices have high correlation together and both of them are able to separate relative tolerant and non-tolerant genotypes better than previous indices (SSI and TOL). A high value of ATI and SSPI show more sensitivity to drought.

Based on these two indices, the three hybrids i.e. 'Felix', 'F 376' and 'P 9903' had the lowest ATI and SSPI values which authenticated that these hybrids were more tolerant to drought conditions. Hybrid 'DK 4590' with higher ATI and SSPI was more sensitivity to drought.

Generally, higher STI and MP values are indices of genotypes with higher yield potential under drought and non-stressed conditions (Fernandez, 1992; Farshadfar *et al.*, 2012b). Based on STI and MP, tolerance level of 'DK 4590' was more pronounced, whereas F 376 was more sensitive (Figures 3 and 4).

According to Fischer and Wood (1979) the genotypes with RDI value > 1 were relatively drought tolerant, while the genotypes with RDI value < 1 were considered drought susceptible. Based on RDI, the higher value is obtained for hybrids 'Felix' and 'P 9903' showed that these hybrids were much more tolerant than other hybrids (Figure 5).

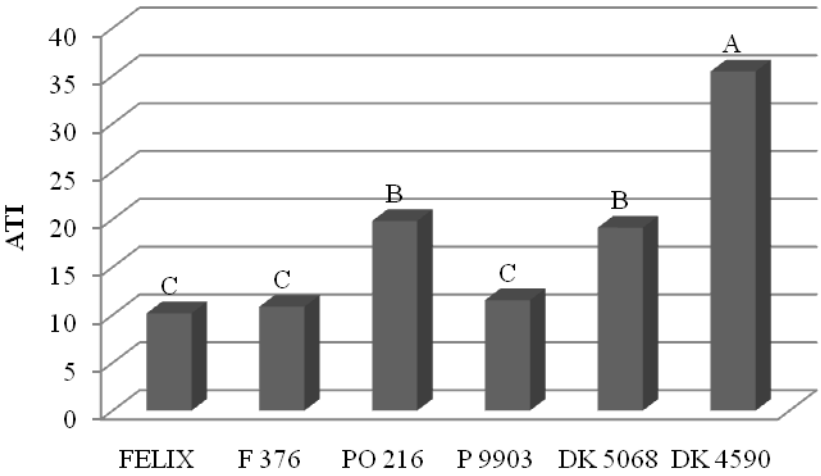

Figure 1. Comparison of abiotic tolerance index of maize hybrids
Same letters on the bars bear non-significant diference at p ≤ 0.05

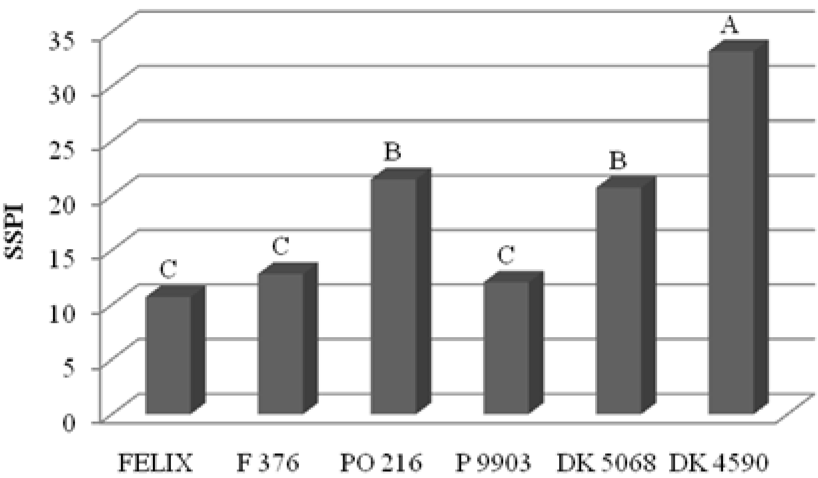

Figure 2. Comparison of stress susceptibility percentage index of maize hybrids
Same letters on the bars bear non-significant diference at p ≤ 0.05

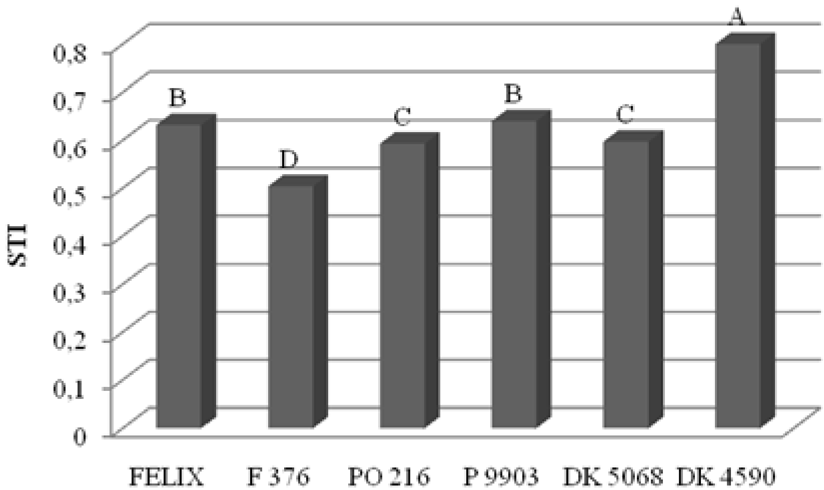

Figure 3. Comparison of stress tolerance index of maize hybrids
Same letters on the bars bear non-significant diference at p ≤ 0.05

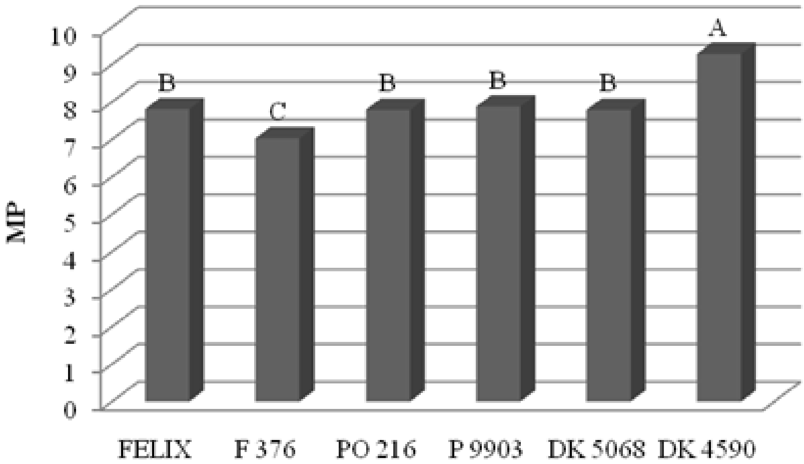

Figure 4. Comparison of mean productivity of maize hybrids
Same letters on the bars bear non-significant diference at $p \leq 0.05$

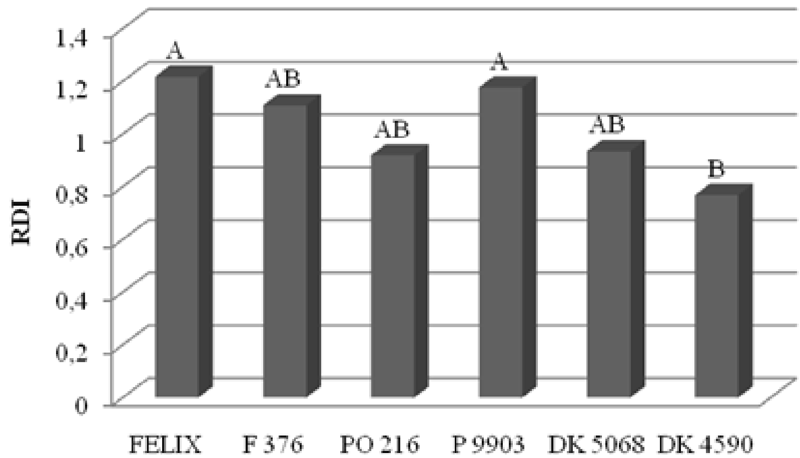

Figure 5. Comparison of relative drought index of maize hybrids
Same letters on the bars bear non-significant diference at $p \leq 0.05$

According to Moradi *et al.* (2012), more GM indicated that yield value in drought pressure was close to yield potential and the studied genotype had lesser damage. Based on GM index, the two hybrids i.e. 'Felix' and 'P 9903' had more tolerance to drought (Figure 6).

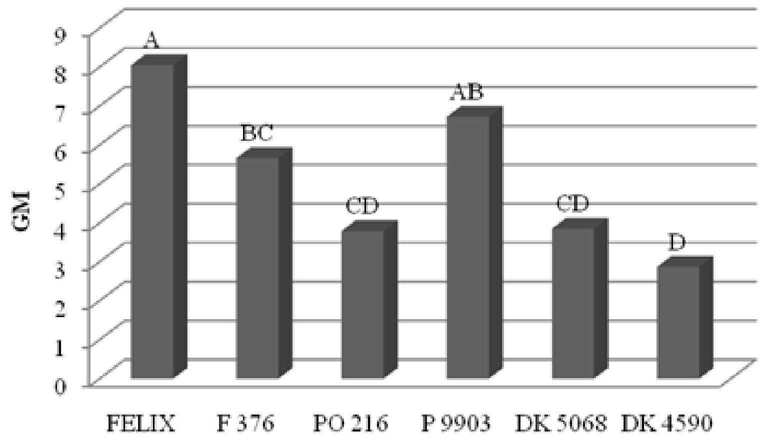

Figure 6. Comparison of golden mean index of maize hybrids
Same letters on the bars bear non-significant diference at $p \leq 0.05$

Correlation between grain yield and drought tolerance indices

To determine the most desirable tolerance indices for screening the maize hybrids, the correlation between Yp, Ys and six drought tolerance indices were calculated and compared (Figures 7 and 8).

In this study, correlation analysis revealed a non-significant association between Yp and Ys (r = - 0.223), which indicated that high yield potential under non-stressed conditions does not anticipate superior yield under stress condition. Similar results were also reported in maize by Bonea and Urechean (2011, 2017), in chickpea by Erdemci (2018), in chilli pepper by Rosmaina *et al.* (2019).

Yield in non-stress condition (Yp) was significantly and positively correlated with ATI, SSPI, STI and MP, but significantly and negatively correlated with RDI and GM. Similar results were also reported by Erdemci (2018). The positive correlations between Yp and ATI, and SSPI were in agreement with the results obtained by some authors (Moosavi *et al.*, 2008; Farshadfar *et al.*, 2012a,b; Erdemci, 2018). On the contrary, Saad *et al.* (2016) and Sahar *et al.* (2016) reported non-significantly and negatively relationship between Yp and ATI, and SSPI.

Yield in stress condition (Ys) was significantly and positively correlated with RDI and GM, but significantly and negatively correlated with SSPI. Similar findings were reported by Erdemci (2018) in chickpea. On the contrary, Naghavi *et al.* (2013) found that Ys was significantly and negatively correlated with RDI, but significantly and positively correlated with SSPI in maize.

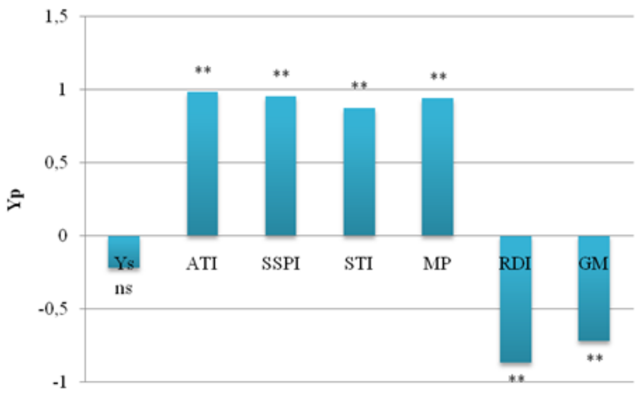

Figure 7. Correlation between drought tolerance indices and grain yield under non-stressed conditions
* and ** Significant at 5% and 1% level of probability, respectively

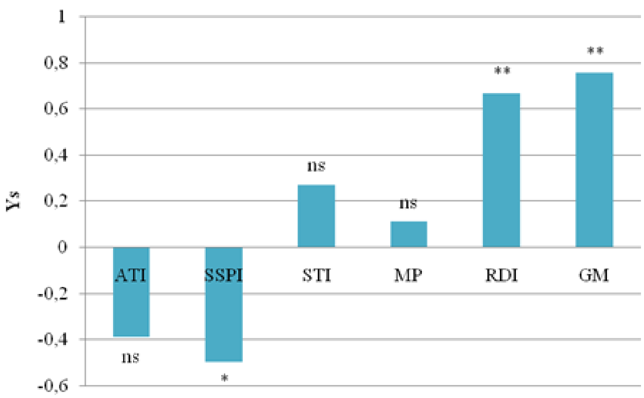

Figure 8. Correlation between drought tolerance indices and grain yield under drought conditions
* and ** Significant at 5% and 1% level of probability, respectively

Many researchers reported that the most suitable index for selection of drought tolerant genotypes is an index which shows a positive and significant correlation with grain yield under both stressed and non-stressed conditions (Fernandez, 1992; Khodarahmpour and Hamidi, 2011; Saad *et al.*, 2016; Rosmaina *et al.,* 2019). This give means that hybrids selected based on these indices will produce high grain yields under non-stressed conditions, but under low drought stress conditions will have a low yield potential.

Also, positively and significantly correlations were found between Ys and RDI, and GM, while between Yp and RDI, and Yp and GM correlations were negative.

The strong correlation of STI and MP with Yp and the lack of correlation with Ys indicated that STI and MP indices may be useful for identifying the hybrids with high yield potential in non-stressed conditions, but not for identifying hybrids with high performance across a range of conditions.

On the contrary, Bonea and Urechean (2011) and Sánchez-Reinoso *et al.* (2019), observed the strong correlations of STI and MP indices with Ys, and non-significant correlations with Yp.

Therefore, in our study, none of the tolerance indices used could identify the high yielding hybrids under both drought and non-stress conditions (group A cultivars). These findings are in accordance with the results of Bonea and Urechean, (2017). Some researchers concluded that the effectiveness of selection indices depends on the stress severity (Khayatnezhad *et a.l,* 2010; Kutlu and Kinaci, 2010). According to Panthuwan *et al.* (2002) only under moderate stress conditions, potential yield greatly influences yield under stress.

Comparison of genotypes based on rank (ranking method)

The estimation of drought tolerance genotypes based on single index is contradictory (Farshadfar *et al.*, 2012a), however, selection based on combination of indices may provide a useful criterion for improving drought tolerance.

Thus, to determine the most suitable drought tolerant hybrids according to the all indices, the rank mean, standard deviation of ranks and rank sum were calculated (Table 4). Ranking method has been used for screening drought tolerant cultivars by other researchers in bread wheat (Farshadfar and Elyasi, 2012), in maize (Naghavi *et al.*, 2013).

Relative similar ranks for the hybrids were observed between ATI and SSPI, between STI and MP and between RDI and GM, which suggest that these indices are equal for selecting genotypes. Many other authors reported similar ranks for the genotypes observed by STI and MP indices (Naghavi *et al.*, 2013; Sabaghnia and Janmohammadi, 2014; Rosmaina *et al.*, 2019) and by RDI and GM (Erdemci, 2018).

The drought tolerant hybrids should have low rank sum in the drought tolerant indices. With respect to rank sum of drought tolerant indices, the hybrids 'Felix' and 'P 9903' recorded lower rank sum of 3.51 and 4.86 respectively.

Table 4. Rank (R), Rank Mean (RM), Standard Deviation of Ranks (SDR) and Rank Sum (RS) of drought tolerance indices

Hybrids	Yp	Ys	ATI	SSPI	STI	MP	RDI	GM	RM	SDR	RS
	R	R	R	R	R	R	R	R			
'Felix'	5	1	1	1	3	3	1	1	2.0	1.51	3.51
'F 376'	6	4	2	3	6	6	3	3	4.1	1.64	5.74
'PO 216'	2	6	5	4	5	4	5	5	4.5	1.40	5.90
'P 9903'	4	2	3	2	2	2	2	2	2.4	1.46	4.86
'DK 5068'	3	5	4	5	4	5	4	4	4.3	1.20	5.50
'DK 4590'	1	3	6	6	1	1	6	6	3.8	1.79	5.59

Yp: yield under non-stress; Ys: yield under drought stress; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; STI: Stress Tolerance Index; MP: Mean Productivity; RDI: Relative Drought Index; GM: Golden Mean

Conclusions

The results of this study showed that none of the tolerance indices used could identify the high yielding hybrids under both drought and non-stressed conditions. For screening of maize hybrids for drought tolerance under less drought stress intensity (SI = 0.37) proved to be more efficient the ranking method, that discriminated the hybrids 'Felix' and 'P 9903' as the most drought tolerant. Therefore, they hybrids are recommended to be grown under drought prone areas and to be used as parents for breeding of drought tolerance in other cultivars.

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Conflict of Interests

The author declares that there are no conflicts of interest related to this article.

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