YIELD AND NUTRITIONAL QUALITY OF DIFFERENT MAIZE HYBRIDS UNDER DROUGHT STRESS

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ABSTRACT

Oltenia from Romania is one of the most important agricultural regions but and one of the most prone regions to extreme weather phenomena i.e. drought and heat. In this region, direct selection for yield is not adequate because of the variable environment. Therefore, the use of different selection procedure and traits in addition to yield has been suggested. In this study we examined the response of different maize hybrids to drought stress conditions, in terms of grain yield traits and nutritional quality. The trials were conducted at Agricultural Research and Development Station Simnic, in the central part of Oltenia, under field conditions in 2016 (without drought) and 2017 (with drought). The grain yield decreased by 50.0%, the 1000-grain weight by 11.2% and the shelling percentage by 1.5%, but the protein percentage increased by 10.1%, under drought stress. The 1000-grain weight was identified as a reliable trait for selecting for drought tolerance in maize. Screening for drought tolerance using ranking method discriminated hybrids PO 216, PO 412 and DK 4590 as the most drought tolerant hybrids. In addition to, results of this study showed that among tolerance indices STI, SSI, MP, GMP and SDI can be used as the most suitable indices for screening drought tolerant hybrids. It can be concluded that the identification of tolerant hybrids to drought stress conditions is crucial for maize breeding programs, considering the climate changes.

INTRODUCTION

Maize (*Zea mays* L.), mainly used as important source of food, feed and energy in most developing countries, is an important annual cereal crop of the world. It is a third leading crop of the world after rice and wheat. Romania produces about 10.746 million tons of maize per year and it is cultivated in approximately 2.6 million hectares (FAO, 2016). Food production in any given year is affected most directly by the values of the critical climate elements (Bonciu, 2016; Bonciu and Sarac, 2016; Bonciu, 2017).

Oltenia region from Romania is situated in the south part of the country. This is one of the most important agricultural regions but one of the most sensitive in terms of extreme weather phenomena i.e. drought and heat.

Climate changes that have occurred in recent years, manifested by increased temperature and reduced rainfall caused emphasizing the effect of desertification in many countries, and in Oltenia region (Dima et al., 2014). Drought and heat is abiotic stresses which have a negative influence on metabolic processes in crop plants, which ultimately manifest itself on the production and quality of agricultural species, including maize. The need for prompt and efficient solutions in this region propelled crops breeding programmes to prioritise identification and development of drought tolerant cultivars. Therefore, many researchers have following these aspects at different agricultural crops (Pandia et al., 2013; Dima, 2014; Popescu et al., 2015, 2017). The effect of water stress on plant growth and yield depends on duration of stress, genotype, weather conditions and growth stages of crops (Robertson and Holland, 2004).

The data from the previously published literature highlights the harmful effects of drought on maize yield due to reduced leaf area, plant height, grains number and weight, 1000-grain weigh, ear length of maize and other traits (Pandey et al., 2000; Khoshvaghti et al., 2014; Yue et al., 2018). The anther and pollen degeneration are the first phenomena that appear to agricultural crops and which negatively influences yield (Bonciu, 2013).

Due to the happening of strong interactions between genotypes and the environment and restricted knowledge about the role and function of tolerance mechanisms, drought tolerance selection is not easy.

In drought prone environments, direct selection for yield is not adequate because of the variable environment and genotype x environment interaction. Therefore, different traits and selection procedure should be applied in the selection process of drought tolerant cultivars for diverse biological materials and growing conditions (Dao et al., 2017).

In previously published works researchers recommended the use tolerance indices for efficient screening of germplasm in different crop plants (Mitra, 2001; Aslam et al., 2015). According to Fernandez (1992), the best indices are those which have high correlation with yield in both conditions (stress and non-stress conditions).

The grain quality parameters under drought stress is the less studied traits. According to Has et al. (2010), evaluation of maize quality is essential to determine the potential of this crop for value-added products. Among the basic chemical components that provide maize quality include protein and oil contents.
Based on the above context, the objectives of the current study were to elucidate the effect of drought stress on maize grain yield traits and, as well as nutritional quality (protein and oil percentage) for six maize hybrids under drought stress in Oltenia region.

MATERIALS AND METHODS

Plant materials and experimental design

Six maize hybrids were used in this study: F 376, Iezer, PO 216, PO 412, DK 4590 and DK 5222. The trials were conducted under field conditions in two years (2016 and 2017) at the Agricultural Research and Development Station Simnic. The station is located in the central part of Oltenia region, Romania, at 44°19' N latitude, 23°48’ E longitude. The preluvosoil from ARDS Simnic is characterized by an acid pH (pH=5.7) by a low content of humus (only in the first 25 cm the humus percentage is 2.35%), medium supplied with potassium and by a significant supply of mobile phosphorus, without being endangered by alkalization or salinization (Popescu and Bora, 2009; Popescu et al., 2016). The experimental design was a 6 x 2 factorial fitted trial into a randomized complete block design (RCBD) with 3 replications. Factor A represented the maize hybrids and factor B the stress conditions.

Crop management

The hybrids were sown manually during first year on 22 April, 2016 and the second year on 10 April, 2017, respectively. The sowing density was of 55,000 plants/ha. During experiments, the fertilization was made by complex fertilizers, consisting of 250 kg ha^{-1} (NPK 20:20:0), before sowing and 250 kg ha^{-1}

ammonium nitrate (34.4% N; 17.2% N-NH_4; 17.2% N-NO_3) in vegetation (8-10 leaves stage). Regarding the maintenance of the crop in both years DUAL GOLD 1.5 L ha^{-1} (96% S-metolachlor) herbicide (pre-emergence) and EQUIP (2.25% foramsulfuron + 2.25% isoxadifen etil (safener)) 1.5 L ha^{-1} + BUCTRIL (28% bromoxinil + 28% 2.4D (ester)) 1 L ha^{-1} herbicide (after emergence) were used to control weeds, two mechanical hoes were also applied.

Climatic data

The climatic condition during the study period was presented in Table 1. The 2016 was considered a normal year, favourable for maize crop, the rainfall deficit being small (−12.3 mm) compared to the normal. Year 2017 was characterized as a year with severe drought stress that occurred during the prior to anthesis and the grain filling period, precipitation deficit reaching (−55.4 mm) compared to normal. During these periods, the heat was also more intense.

Sampling and measurements of grain yield traits

Plant height was recorded in cm, at maturity, by measuring the height of ten randomly taken plants from each sub plot, from ground level to tassels.

Thousand grains weight (1000-grain weight data was recorded by weighing thousand grains randomly taken, with the help of electronic balance, and then average weight was calculated.

Shelling percentage (SP) was calculated by using the following formula:

$$SP = \frac{\text{Grains weight of 10 ears}}{\text{Total weight of 10 ears}} \times 100$$

The grain yield from each plot, adjusted to 15.5% moisture, harvested from cobs in the harvestable rows was calculated and the results were used to compute the yield per hectare.

The protein and oil content of the maize grains was determined by Perten Inframatic 9140, Sweden or Foss Infratec 1241, Denmark.

Table 1. Monthly average temperature and rainfall in the experimental years (ARDS Simnic, 2016 and 2017)

Year	Deviation from normal (±)					
	April	May	June	July	August	April–August
Rainfall (total mm)						
2016	+19.6	+16.6	+31.5	−28.8	−12.0	−12.3
2017	+10.4	+0.1	−50.5	+25.2	−40.6	−55.4
Normal (19 years)	53.6	70.9	74.5	82.8	49.6	331.4
Temperature (°C)						
2016	+2.7	−1.3	+0.5	+0.1	+0.8	
2017	−0.5	−0.3	+1.8	+0.4	+2.7	
Normal (19 years)	12.1	17.6	21.4	23.8	22.3	

Measurements of indices

The seven drought tolerance indices, respectively: TOL, STI, SSI, MP, GMP, YI and SDI, were calculated on the basis of the grain yield in without drought condition (Yp) and in drought stress conditions (Ys) using the following formulas from Table 2.

In order to evaluate the tolerant genotypes by ranking method there was used the formula proposed by Farshadfar and Elyasi (2012):

$RS = \overline{R} + SDR$ where: RS = rank sum; $\overline{R}$ = rank mean; SDR-Standard deviation of rank.

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) and means separated using the Duncan's multiple range tests at 5% level of probability. The relationships between the yield, yield traits and drought tolerance indices were established using Pearson correlation coefficient.

Table 2. The drought tolerance indices

The drought tolerance indices	Equation	References
Tolerance (TOL)	$TOL = Y_P - Y_S$	Rosielle and Hamblin, 1981
Stress Tolerance Index (STI)	$STI = \frac{(Y_S)(Y_P)}{(\bar{Y}_P)^2}$	Schneider et al., 1997
Stress Susceptibility Index (SSI)	$SSI = \frac{1-(\frac{Y_S}{Y_P})}{SI}$, $SI = 1-(\frac{\bar{Y}_S}{\bar{Y}_P})$	Fischer and Maurer, 1978
Mean Productivity (MP)	$MP = \frac{Y_S + Y_P}{2}$	Rosielle and Hamblin, 1981
Geometric Mean Productivity (GMP)	$GMP = \sqrt{(Y_S)(Y_P)}$	Kristin et al., 1997
Yield Index (YI)	$YI = \frac{Ys}{Ysi}$	Gavuzzi et al., 1997
Sensitive Drought Index (SDI)	$SDI = \frac{Y_P - Y_S}{Y_P}$	Farshadfar and Javadinia, 2011

RESULTS AND DISCUSSION

The influence of stress conditions and hybrids on yield, yield traits and nutritional quality

The analysis of variance showed that the stress conditions have significantly influenced (in probability level of 5%), the grain yield, 1000-grain weight, shelling percentage and protein percentage. There were not significant stress conditions effects for plant height and oil percentage (Table 3).

Drought stress caused significant reduction in grain yield (−50.0%), 1000-grain weight (−11.2%), shelling percentage (−1.5%) and a significant increase in protein percentage (+10.1%), as shown in Table 4.

The results of significant differences observed among the two planting conditions stress were due to drought stress. Nesmith and Ritchie (1992) found that yield reductions ranged from 21% to 40 %, with the kernel weight being the most affected component. However, Abrecht and Carberry (1993) reported that non-lethal water deficit prior to anthesis did not significantly affect the grain yield.

Decreasing grain yield under drought stress can be largely attributed to considerable reduction in 1000 grain weight and shelling percentage. This is in corroboration with the findings of which noted that Pandey et al. (2000) which noted that yield losses under deficiency of water at vegetative and reproductive phases of growth were associated with the reduction in kernel number and kernel weight.

Table 3. ANOVA for yield and quality in *Zea mays* L. hybrids under different stress conditions

Source of Variation	Degrees of freedom	Mean of Square					
		GY	PH	TGW	SP	PP	OP
Stress conditions	1	287.69*	2.25^{ns}	7396*	11.69*	15.21*	0.42^{ns}
Hybrids	5	6.73*	294.85*	5735.20*	14.69^{ns}	3.17*	0.94*
Interaction	5	3.67*	199.65*	1430.2*	5.69^{ns}	0.95*	0.03^{ns}
Error		0.02	62.83	109.5	4.36	0.18	0.11

GY – grain yield, PH – plant height, TGW – 1000-grain weight, SP – shelling percentage, PP – grain protein percentage, OP – grain oil percentage; * – significant at 5% probability levels, ns – not-significant

Table 4. Mean comparison for yield and quality yield

	GY $t\ ha^{-1}$	PH cm	TGW g	SP %	PP %	OP %
Stress conditions (A)						
Without drought (a1)	11.2^{a}	194.8	256.7^{a}	84.3^{a}	12.9^{b}	4.6
With drought (a2)	5.6^{b}	194.3	228.0^{b}	83.0^{b}	14.2^{a}	4.8
Drought effect %	**−50.0**	**−0.3**	**−11.2**	**−1.5**	**+10.1**	**+4.3**
Hybrids (B)						
F376 (b1)	7.7^{e}	190.5^{b}	210.0^{e}	82.0	14.4^{a}	5.5^{a}
Iezer (b2)	6.6^{f}	190.0^{b}	209.5^{e}	84.0	14.1^{b}	4.9^{b}
PO 216 (b3)	8.7^{c}	207.5^{a}	272.5^{ab}	83.5	13.6^{c}	4.5^{bc}
PO 412 (b4)	9.6^{a}	198.0^{b}	277.0^{a}	82.5	13.6^{cd}	4.4^{c}
DK 4590 (b5)	8.9^{b}	190.5^{b}	226.0^{d}	84.0	12.5^{e}	4.6^{bc}
DK 5222 (b6)	8.7^{cd}	191.0^{b}	259.0^{c}	86.0	12.9^{e}	4.5^{bc}
A × B						
a1b1	9.7^{e}	181^{e}	244^{efg}	83	13.8^{de}	5.4
a1b2	8.8^{f}	192^{bcde}	229^{fghi}	83	12.9^{fgh}	4.8
a1b3	11.3^{d}	205^{ab}	291^{a}	85	12.6^{gh}	4.4
a1b4	12.7^{ab}	201^{abc}	264^{cd}	84	13.4^{de}	4.4
a1b5	11.9^{c}	198^{abcde}	242^{efgh}	85	12.1^{h}	4.4
a1b6	12.8^{a}	192^{bcde}	270^{c}	86	12.6^{gh}	4.5
a2b1	5.9^{i}	200^{abcd}	176^{j}	81	15.1^{ab}	5.6
a2b2	4.5^{j}	188^{cde}	190^{j}	85	15.4^{a}	5.0
a2b3	6.2^{h}	210^{a}	254^{cde}	82	14.6^{bc}	4.6
a2b4	6.5^{g}	195^{bcde}	290^{ab}	81	13.9^{cd}	4.5
a2b5	5.9^{i}	183^{e}	210^{j}	83	12.9^{fgh}	4.9
a2b6	4.6^{j}	190^{bcde}	248^{def}	86	13.3^{de}	4.6

GY – grain yield, PH – plant height, TGW – 1000-grain weight, SP – shelling percentage, PP – grain protein percentage, OP – grain oil percentage;
Different letter in each column indicate significant difference at $p = 0.05$.

According to Zhao et al. (2009) maize protein content are very sensitive to drought stress during grain filling period. Ghassemi-Golezani et al. (2016) showed that oil percentage decreases as protein percentage increases in response to water deficit. On the other hand, the investigation of Ali et al. (2010) indicated that drought stress has also been shown to cause a small reduction in total protein content in two maize cultivars grown in Pakistan.

Hybrids effects were significant for the grain yield, plant height, 1000-grain weight, protein and oil percentage, and not significant for shelling percentage (Table 3, 4). The highest value of grain yield significantly different than other hybrids, was recorded at PO 412 hybrid (9.6 $t\ ha^{-1}$), and the lowest value at Iezer (6.6 $t\ ha^{-1}$).

Plant height is a trait indirect of production. For this trait and for 1000-grain weight the highest value was recorded at PO 412 hybrid (198 cm and 277 g, respectively).

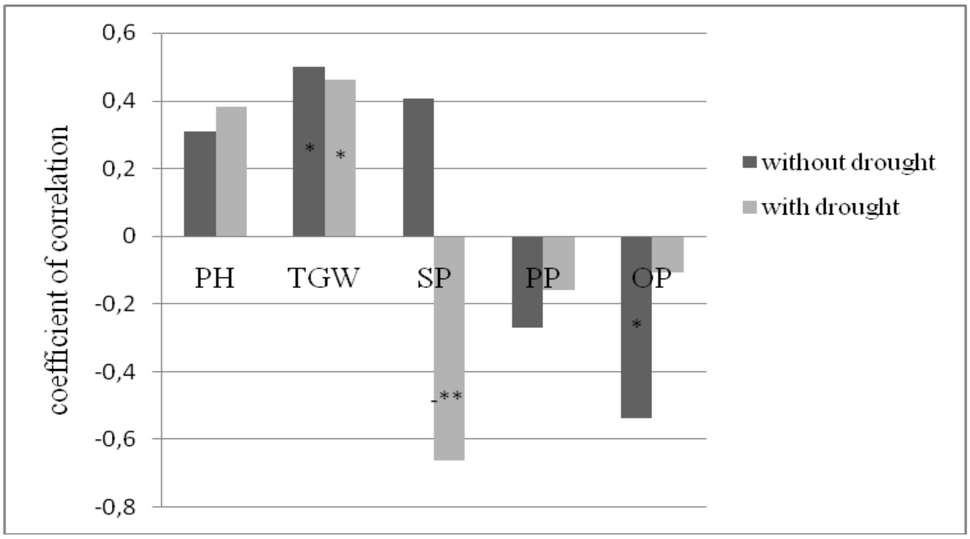
For the protein and oil percentage, the highest values were recorded in F376 hybrid (14.4% and 5.5%, respectively). Randjelovic et al. (2011) and Scrob et al. (2014) were found that hybrids had a significant effect on the protein content.

Stress conditions × hybrids interaction was only significant for the grain yield, plant height, 1000-grain weight and protein percentage, and no significant for shelling percentage and oil percentage (Table 3, 4). According to Sheikh et al. (2017), as a result of significant G (genotypes) × E (environment) interaction, it is important that genotypes screened for drought tolerance are evaluated in the target locations before they are incorporated as parents in the breeding programmes.

Grain yield varied from 4.5 to 6.5 t ha^{-1} under drought stress, and from 8.8 to 12.8 t ha^{-1} under without drought conditions. The 1000-grain weight varied upon maize hybrids from 176 g to 290 g under drought stress and from 229 g to 291 g under without drought conditions. The values recorded for protein percentage were found in the range of 12.9% to 15.4% under drought stress, and in the range of 12.1% to 13.8% under without drought conditions (Table 4).

Correlation analysis

Correlation coefficients between the studied traits and grain yield showed that only the 1000-grain weight was high positive correlated with grain yield (*r* = 0.462*) under drought stress. While, the highest correlations negative were observed for shelling percentage and grain yield (*r* = −0.663**) (Figure 1). It was observed, under without drought stress conditions the 1000-grain weight was highly positive correlated with grain yield (*r* = 0.499*) and oil percentage was highly negative correlated with grain yield (*r* = −0.538**).



PH – plant height, TGW – 1000-grain weight, SP – shelling percentage, PP – protein percentage, OP – oil percentage;
*, ** – significant at the 5% and 1% levels of probability, respectively

Figure 1. Pearson correlation coefficient between grain yield and yield traits of maize hybrids under two stress conditions (without drought and with drought)

The similar results on positive relationship between the grain yield and grain weight under drought stress are expected as reported in previous studies. Yue et al. (2018) found a highly significant positive correlation (*r* = 0.66**) of grain yield with 1000-grain weight under water stress in Hebei Province, China. Homayoun (2011) reported that 500-grain weight has the most positive correlation (*r* = 0.979**) with grain yield in drought stress, emphasizing the importance selection this character for dry conditions.

According to Dao et al (2017), the relative usefulness of secondary traits as indirect selection criteria for maize grain yield is determined by the magnitudes of their genetic correlation with the grain yield. Therefore, this trait (1000-grain weight) could be used as an important trait for prediction of grain yield of maize under drought stress.

Assessment, of maize hybrids by drought tolerance indices and ranking method

In this study, the drought tolerance indices and ranking methods was used to evaluate the drought tolerance of hybrids (Table 5, 6). Parameters used for screening must be associated with grain yield because higher grain yield is ultimate objective of screening (Aslam et al., 2015).

For determining suitable drought tolerance indices to identify the hybrids for drought stress tolerance, was calculated Pearson correlation coefficients (Figure 2). In drought stress conditions, the significative positive correlation was observed between grain yield (Ys) and STI (*r* = 0.863**), MP (*r* = 0.685**), GMP (*r* = 0.849**) and YI (*r* = 0.999**), and while, negative correlation was recorded between grain yield (Ys) and SSI (*r* = −0.553*) and SDI (*r* = −0.576*). Under without stress conditions, the significative positive correlation was observed between grain yield (Yp) and TOL (*r* = 0.863**), STI (*r* = 0.776**), SSI (*r* = 0.549*), MP (*r* = 0.927**), GMP (*r* = 0.800**) and SDI (*r* = 0.550*).

Therefore, according to these results, selection based on STI, SSI, MP, GMP and SDI will improve mean yield in both conditions (without stress and with drought stress).

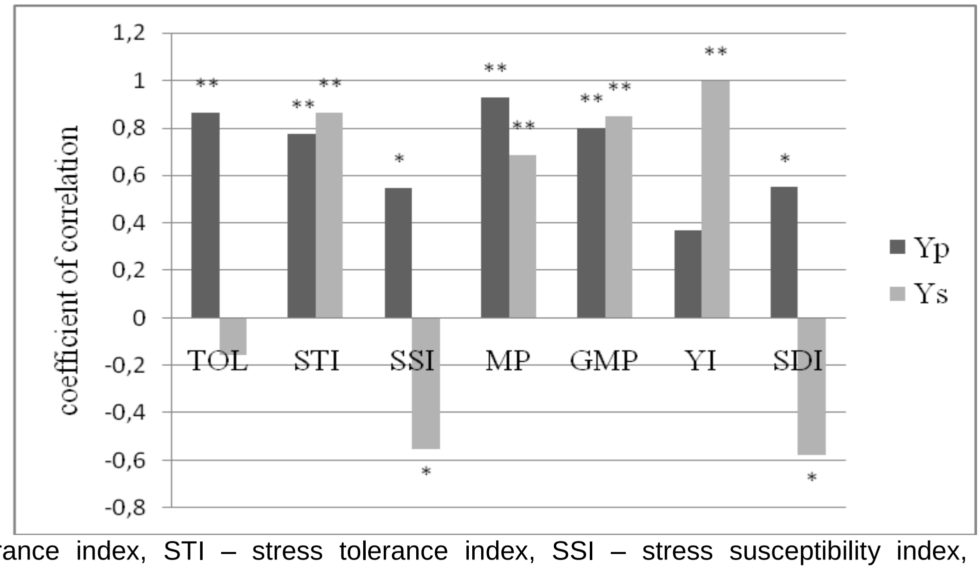
Barutcular et al. (2016) identified GMP, MP, YI, STI, SSI and TOL as the best indices in separation superior cultivars in drought stress conditions.

For evaluation of maize hybrids for drought tolerance, ranking method was used to determine overall judgment (Table 6).

Table 5. Drought tolerance indices (SI = 0.51)

Hybrid / Indices	F376	Iezer	PO 216	PO 412	DK 4590	DK 5222
Yp	9.69	8.78	11.29	12.73	11.94	12.85
Ys	5.71	4.47	6.20	6.52	5.87	4.58
TOL	3.98	4.31	5.09	6.21	6.07	8.27
STI	0.44	0.31	0.55	0.66	0.55	0.46
SSI	0.82	0.98	0.90	0.96	1.00	1.17
MP	7.70	6.62	8.74	9.62	8.90	8.71
GMP	7.43	6.26	8.37	9.11	8.37	7.67
YI	1.02	0.80	1.11	1.17	1.05	0.82
SDI	0.41	0.49	0.45	0.48	0.50	0.64

Yp - yield in without drought condition, Ys – yield in with drought condition, TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index, MP – mean productivity, GMP – geometric mean productivity, YI – yield index, SDI – sensitive drought index



TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index, MP – mean productivity, GMP – geometric mean productivity, YI – yield index, SDI – sensitive drought index;
*, ** – significant at the 5% and 1% levels of probability, respectively

Figure 2. Pearson correlation coefficients between grain yield (Yp and Ys) and drought tolerance indices

Table 6. Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of drought tolerance indices

Indices	F376	Iezer	PO 216	PO 412	DK 4590	DK 5222
Yp	5	6	4	2	3	1
Ys	4	6	2	1	3	5
TOL	1	2	3	5	4	6
STI	5	6	3	1	2	4
SSI	1	4	2	3	5	6
MP	5	6	3	1	2	4
GMP	5	6	3	1	2	4
YI	4	6	2	1	3	5
SDI	1	4	2	3	5	6
$\bar{R}$	3.44	5.11	2.66	2.00	3.22	4.55
SDR	1.87	1.45	0.70	1.41	1.20	1.58
RS	5.31	6.56	3.37	3.41	4.24	6.13

Yp – yield in without drought condition, Ys – yield in with drought condition, TOL – tolerance index, STI – stress tolerance index, SSI – stress susceptibility index, MP – mean productivity, GMP – geometric mean productivity, YI – yield index, SDI – sensitive drought index; RS – rank sum

In consideration to all indices, hybrids PO 216, PO 412 and DK 4590 exhibited the best mean rank and almost low standard deviation of rank, hence they were identified as the most drought tolerant hybrids, while hybrid Iezer as the most sensitive.

Similar ranks for the hybrids were observed by STI, MP and GMP indices as well by SSI and SDI, which suggests that these indices are equal for selecting hybrids. Naghavi et al. (2013) reported similar ranks for GM, MP and STI.

CONCLUSIONS

Considering the climate changes, the identification of tolerant hybrids to drought stress conditions is crucial for maize breeding programs. Our results showed that, yield and some of the yield traits such as 1000-grain weight and shelling percentage were affected negatively by drought stress, whereas some of the nutritional traits such as protein percentage were positively affected.

The 1000-grain weight was identified as a reliable trait for selecting for drought tolerance in maize. Screening drought tolerant cultivars using ranking method discriminated hybrids PO 216, PO 412 and DK 4590 as the most drought tolerant hybrids maize.

In addition to, results of this study showed that among drought tolerance indices stress tolerance index (STI), stress susceptibility index (SSI), mean productivity (MP), geometric mean productivity (GMP) and sensitive drought index (SDI) can be used as the most suitable indicators for screening drought tolerant hybrids.

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