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ESTIMATION OF DROUGHT TOLERANCE AMONG MAIZE LANDRACES FROM MINI-CORE COLLECTION

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Global climate change, its impact on stable food production in the future and possibilities to overcome the problem are the major priorities for research. Breeding varieties with increase adaptability to changing environments, together with better tolerance/resistance to abiotic stress, pest and diseases are possible solution. Maize is one of the most important crops, with high grain yield reduction induced by drought stress. In the present study twenty-six maize landraces from drought tolerant mini-core collection were tested under optimal, drought, and a combination of drought and high density stresses in the field. Morphological traits, plant height, total number of leaves, leaf length, leaf width, anthesis-silking interval and grain yield were recorded for each entry in two replications in three experiments. Besides, drought tolerant indices were evaluated to test the ability to separate more drought tolerant accessions from those with less stress tolerance. Five stress tolerance indices, including stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), stress susceptibility (SSI), and stress tolerance (TOL) were calculated. Data analyses revealed that STI, MP and GMP had positive and significant correlations with grain yield under all conditions. Three-dimensional diagrams displayed assignment of landraces L25, L1, L14, L3, L26, L15 and L16 to group A, based on the stress tolerance index and achieved grain yield under optimal, drought stress, and a combination of drought and high density stress. A biplot analysis efficiently separated groups of landraces with different level of drought tolerance and grain yield. Based on all obtained results, maize landraces L25, L14, L1 and L3, as the most valuable source of drought tolerance, could be recommended for further use in breeding programs.

Key words: biplot, drought indices, grain yield, landraces, *Zea mays* L.

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INTRODUCTION

The main consequence from climate change to agriculture and food production is more frequent and severe occurrence of drought and thus, the development of drought-tolerant cultivars become more important. Hence, evaluation of the vast genetic resources in gene banks and in the wild relatives, that hold potential for adaptation of major crops to a changing climate, is the foundation for the sustainable development of new varieties for present and future needs. However, breeding for drought tolerance, as polygenic and complex trait is difficult to obtain due to large genotype x environment interactions and variation in yield is rather a consequences of adaptation than to drought tolerance *per se* (NAZARI and PAKNIYAT, 2010).

To evaluate plant response to drought stress, some indices, based on a mathematical relation between stress and optimal conditions have been proposed. The most appropriate option, suggested by FERNANDEZ (1992) is method that could be able to separate genotypes with high and stable yield in both, stress and non-stress environments in four groups: genotypes with good performance in both environments (Group A); genotypes with high yield only in non-stress environments (Group B) or stressful environments (Group C); and genotypes with poor performance and low yield in both environments (Group D). Several indices have been proposed as useful for drought tolerance identification in wheat (AKÇURA *et al*., 2011), sunflower (GHAFFARI *et al*., 2012), sorghum (KHARRAZI *et al*., 2011) and maize (JAFARI *et al*., 2009; MORADI *et al*., 2012). The most important are stress tolerance index (STI) and geometric mean productivity (GMP) (FERNANDEZ, 1992), mean productivity (MP) and tolerance index (TOL) (ROSIELLE and HAMBLIN, 1981), (GMP) and stress susceptibility index (SSI) (FISHER and MAURER, 1978).

Maize is the crop with the largest annual global production, but most of the 160 M ha of production area is highly affected by drought. In 2012, as implication of drought, maize yields in the United States were reduced by 21%, compared to 2009-11 mean levels (http://quickstats.nass.usda.gov). In Serbia, maize is the most important crop grown mainly without irrigation, which seriously affected genetic potential for yield (VIDENOVIĆ *et al*., 2013). In dry 2012 grain yield was reduced about 48%. Possible solution is breeding of maize hybrids that tolerate drought and have stable yield across environments, which is not easy to achieve. Development of core collections could be efficient tool to evaluate and characterized large collections, and the creation of core and mini-core collections increases usage and effectiveness of genetic diversity (AGRAMA *et al*., 2009).

Maize Research Institute Zemun Polje gene bank is among the ten largest in the world (about 6000 accessions, FAOSTAT, 2010). After two-year of screening for drought tolerance in Egypt under managed stress environment (MSE) conditions, a core collection was created and further tested in the temperate climate regions (Macedonia and Serbia). Based on the field trials´ results and general combining ability, a drought tolerant mini-core collection of 41 accessions (15 inbred lines, 13 local and 13 introduced landraces) was established (VANČETOVIĆ *et al*., 2010; BABIC *et al*., 2011).

In this study, we evaluated a set of 26 maize landraces (local and introduced) from drought tolerant mini-core collection under different field conditions. Our objective was to screen maize plants in the field under optimal and two types of stress (drought and a combination of drought and high density) and to distinguish the most drought tolerant accessions according to morphological traits, grain yield and drought tolerance indices.

MATERIALS AND METHODS

The experiment was carried out in 2012 in Zemun Polje, Serbia (44°52´N, 20°19´E, 81 m asl). The soil was slightly calcareous chernozem with 47% clay and received the usual compound of mineral fertilizer. The average temperature in vegetative period (April-September) was 22ºC, although high air temperatures characterized flowering time (June-July) and grain filing (July-August), e.g. 17 days in June were with the maximal temperatures above 30ºC, 11 days in July were with the maximal temperatures above 35ºC, while in August eight days were with the maximal temperatures above 35ºC. The landraces from mini-core collection were grown in three sets of field experiment, under optimal condition (OC), drought stress (DS), and a combination of drought and high-density stress (HD). A randomized block design with two replications was used in the experiments. Plants were sown in single row plots of 3.6 m and 2.8 m length for OC, DS and HD sets, respectively and spaced 0.75 m apart. Plots were overplanted and thinned to two plants per hill after seedling establishment. Spacing within rows was 0.4 m for OC, DS sets (population density of 66000 plants ha^{-1}) and 0.3 m for HD set (population density of 88000 plants ha^{-1}).

All plants were established under optimal levels of soil water. Thereafter, the plants stayed either under OC, or were subjected to stresses (DS and HD). In stress experiments irrigation stopped three weeks before 50% male flowering. The one additional irrigation was applied 17-19 days after pollination to encourage adequate grain filling.

Morphological traits, such as - plant height, total number of leaves, leaf length, leaf width, anthesis-silking interval (ASI) and grain yield were recorded for each entry in two replications, on ten representative plants in all three sets of experiment. Anthesis-silking interval was calculated as difference between number of days to 50% silking and 50% anthesis. Grain yield was calculated per plant, after manual harvesting and drying to 14% of moisture content. Area per leaf was calculated using the formula: leaf length x maximum width x 0.75 (MONTGOMERY, 1911) and multiplied by total number of leaves for calculating the leaf area per plant. Drought indices were calculated using the following equations:

Tolerance index TOL= $Yp - Ys$ (ROSIELLE and HAMBLIN, 1981)

Mean productivity index MP= $\frac{Yp+Ys}{2}$ (ROSIELLE and HAMBLIN, 1981)

Stress tolerance index STI= $\frac{Ys x Yp}{(\bar{Y}p)^2}$ (FERNANDEZ, 1992)

Geometric mean productivity GMP= $\sqrt{(Yp)(Ys)}$ (FERNANDEZ, 1992)

Stress susceptibility index SSI= $\frac{1-\frac{Ys}{Yp}}{SI}$ SI=1- $\left(\frac{\bar{Y}s}{\bar{Y}p}\right)$ (FISHER and MAURER, 1978)

Yp = potential yield of genotype in non-stress conditions (OC in the present study).
Ys = yield of genotype in stress conditions (in the present study DS-drought and HD-combination of drought and high density stress).

$\bar{Y}p$ = average yield of all genotypes under non-stress conditions (OC in the present study).

$\bar{Y}s$ = average yield of all genotypes under stress conditions (in the present study DS-drought and HD-combination of drought and high density stress).

Correlation analysis was also carried out to determine the associations between the investigated traits and indices. The differences among landraces based on morphological traits and drought indices were evaluated by means of Principle Component Analysis (PCA). Statistical analysis was performed by using SPSS 15.0 for Windows Evaluation.

RESULTS AND DISCUSSION

In temperate climate maize is often exposed to unfavorable conditions, such as high temperatures and water deficit, resulting in significant decrease in grain yield. Average precipitation for maize growing season in Serbia is 397.5 mm (VIDENOVIĆ *et al.*, 2013), but in 2012 total precipitation was 282.9 mm. A precipitation during flowering and grain filing was as following: in June 13.9 mm, in July 39.4 mm, and in August only 4.0 mm. Deficit of water was evident, considering that optimal precipitations in June are 80 mm, in July 100 mm, and in August 95 mm (VUCIC, 1991). Average temperatures and precipitation for vegetative period are presented in Figure 1.

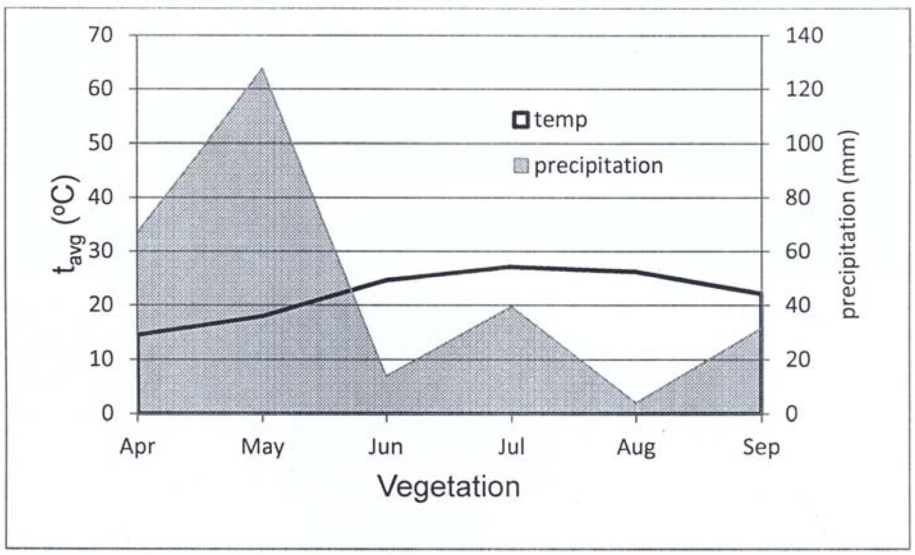


Figure 1. Climate-diagrams by Walter for vegetation season in 2012. in Zemun Polje

The mean values for grain yield and examined morphological traits are given in Table 1.

Table 1. Mean values ± standard deviation (SD) of morphological traits and grain yield in maize landraces calculated from ten plants per genotype from each experiment

Traits	OC[a]	DS	HD
Plant height (cm)	211.3±22.2	182.2±15.6	163.5±17.4
Total no. of leaves	17.6±1.8	16.6±1.9	15.9±2.0
Leaf length (cm)	81.4±6.7	73.8±7.2	68.1±8.1
Leaf width (cm)	9.4±0.7	8.8±0.8	7.8±1.1
Leaf area (m^2)	1.0±0.2	0.8±0.2	0.7±0.2
ASI (d)	2.7±1.5	3.1±1.9	4.0±1.9
Grain yield (g $plant^{-1}$)	106.1±23.4	85.5±17.3	71.7±11.9

[a]OC - optimal condition, DS - drought stress, HD - combination of drought and high density sress

Table 2. Grain yield and drought tolerance indices in maize landraces (L) under different growing conditions[a] (drought stress-DS; combination of drought and high density stress-HD)

L		STI	MP	GMP	TOL	SSI	GY_{OC}	GY_{DS}	GY_{HD}
L1	**DS**	1.309	122.447	121.405	31.895	1.194	138.39	106.50	82.25
	HD	1.011	110.322	106.691	56.145	1.248			
L2	**DS**	0.339	61.773	61.731	4.545	0.368	64.05	59.50	48.50
	HD	0.276	56.273	55.733	15.545	0.747			
L3	**DS**	1.377	124.632	124.481	12.264	0.486	130.76	118.50	81.30
	HD	0.944	106.032	103.107	49.464	1.164			
L4	**DS**	0.863	98.855	98.581	14.709	0.718	106.21	91.50	74.25
	HD	0.701	90.230	88.803	31.959	0.926			
L5	**DS**	0.436	70.238	70.070	10.536	0.723	75.54	65.00	53.50
	HD	0.359	64.518	63.570	22.036	0.898			
L6	**DS**	1.003	107.529	106.251	33.059	1.381	124.06	91.00	73.50
	HD	0.810	98.779	95.490	50.559	1.254			
L7	**DS**	0.587	81.922	81.288	20.344	1.145	92.09	71.75	69.00
	HD	0.564	80.547	79.715	23.094	0.772			
L8	**DS**	0.410	69.425	67.910	28.849	1.783	83.85	55.00	67.00
	HD	0.499	75.425	74.953	16.849	0.618			
L9	**DS**	0.779	93.675	93.616	-6.650	-0.381	90.35	97.00	71.75
	HD	0.576	81.050	80.515	18.600	0.633			
L10	**DS**	0.611	83.795	82.961	23.590	1.279	95.59	72.00	64.75
	HD	0.550	80.170	78.673	30.840	0.993			
L11	**DS**	0.727	90.154	90.465	-5.972	-0.354	87.53	93.50	66.75
	HD	0.519	77.139	76.436	20.778	0.730			
L12	**DS**	0.471	76.139	72.849	44.278	2.334	98.28	54.00	56.25
	HD	0.491	77.264	74.352	42.028	1.316			
L13	**DS**	0.701	89.111	88.827	14.222	0.766	96.22	82.00	59.75
	HD	0.511	77.986	75.824	36.472	1.166			
L14	**DS**	1.328	122.296	122.264	5.591	0.232	125.09	119.50	86.50
	HD	0.961	105.796	104.021	38.591	0.949			

Table 2.cont. Grain yield and drought tolerance indices in maize landraces (L) under different growing conditions[a] (drought stress-DS; combination of drought and high density stress-HD)

L	STI	MP	GMP	TOL	SSI	GY_{OC}	GY_{DS}	GY_{HD}	L
L15	**DS**	0.838	98.662	97.113	34.824	1.554	116.07	81.25	81.00
	HD	0.835	98.537	96.964	35.074	0.930			
L16	**DS**	0.915	102.382	101.470	27.263	1.218	116.01	88.75	85.25
	HD	0.879	100.632	99.449	30.763	0.816			
L17	**DS**	0.998	108.420	105.970	45.840	1.808	131.34	85.50	72.00
	HD	0.840	101.670	97.244	59.340	1.390			
L18	**DS**	0.679	88.609	87.438	28.718	1.445	102.97	74.25	66.50
	HD	0.608	84.734	82.749	36.468	1.090			
L19	**DS**	0.817	98.582	95.902	45.665	1.949	121.41	75.75	70.00
	HD	0.755	95.707	92.190	51.415	1.303			
L20	**DS**	0.724	90.951	90.289	21.902	1.114	101.90	80.00	77.25
	HD	0.699	89.576	88.724	24.625	0.744			
L21	**DS**	0.515	76.418	76.155	-12.664	-0.936	70.09	82.75	64.50
	HD	0.402	67.293	67.235	5.586	0.245			
L22	**DS**	0.632	84.352	84.351	-0.796	-0.049	83.95	84.75	56.50
	HD	0.421	70.227	68.872	27.454	1.006			
L23	**DS**	0.909	101.130	101.130	-0.240	-0.012	101.01	101.25	76.75
	HD	0.689	88.880	88.048	24.260	0.739			
L24	**DS**	0.906	101.505	100.986	20.510	0.951	111.76	91.25	72.00
	HD	0.715	91.880	89.704	39.760	1.095			
L25	**DS**	1.571	136.400	132.969	60.800	1.889	166.80	106.00	101.00
	HD	1.497	133.900	129.795	65.800	1.214			
L26	**DS**	1.079	111.236	110.188	30.472	1.248	126.47	96.00	83.00
	HD	0.932	104.736	102.456	43.472	1.058			

[a] STI-stress tolerance index, MP-mean productivity index, GMP-geometric mean productivity index, TOL-tolerance index, SSI-stress susceptibility index, GY_{OC}- grain yield in optimal conditions, GY_{DS}-grain yield in drought stress, GY_{HD}-grain yield in combination of drought stress and high density.

The reduction of all examined traits, particularly under the most severe stress (HD) is obvious and ranging from 9.9% for total number of leaves to 32.4% for grain yield. The stress tolerance indices for maize landraces in both stresses are given in Table 2. Among evaluated landraces L14, L3, L25, and L1 had the highest yield under drought stress, and the highest value of STI (>1), MP and GMP, whereas landraces L25, L14, L16, L26 and L1 showed the highest yield, STI, MP and GMP under more severe (HD) stress. Although previously chosen as drought tolerant, the landraces showed different response to stress severity: some had lower yield in both stresses compared to control, but some of them (L9, L11, L21, L22) had even higher yield under drought stress than in optimal conditions, with relatively high values of STI, MP and GMP, but with negative values of SSI and TOL under drought stress. Landrace L25 had the highest yield under high density, and also the highest value of all indices, except SSI.

To determinate the most appropriate criterion for drought evaluation, the correlation coefficients between grain yield (under optimal and stress conditions) and indices were calculated (Table 3 and 4.).

Table 3. Correlation coefficients between drought indices and grain yield under optimal and drought stress conditions

Index	GY_{OC}	GY_{DS}	STI	MP	GMP	TOL	SSI
GY_{OC}	1						
GY_{DS}	0.630**	1					
STI	0.913**	0.881**	1				
MP	0.931**	0.870**	0.993**	1			
GMP	0.912**	0.893**	0.994**	0.998**	1		
TOL	0.681**	-0.140	0.334	0.367	0.321	1	
SSI	0.494	-0.341	0.119	0.154	0.109	0.951**	1

STI-stress tolerance index, MP-mean productivity index, GMP-geometric mean productivity index, TOL-tolerance index, SSI-stress susceptibility index, GY_{OC}- grain yield in optimal conditions, GY_{DS}-grain yield in drought stress, * and ** refer to level of significance, P<0.05 and P<0.01, respectively

Table 4. Correlation coefficients between drought indices and grain yield under high density stress

Index	GY_{OC}	GY_{HD}	STI	MP	GMP	TOL	SSI
GY_{OC}	1						
GY_{HD}	0.843**	1					
STI	0.965**	0.937**	1				
MP	0.983**	0.983**	0.991**	1			
GMP	0.971**	0.947**	0.991**	0.998**	1		
TOL	0.907**	0.538*	0.779**	0.813**	0.781**	1	
SSI	0.664**	0.176	0.466	0.520*	0.477	0.903**	1

STI-stress tolerance index, MP-mean productivity index, GMP-geometric mean productivity index, TOL-tolerance index, SSI-stress susceptibility index, GY_{OC}- grain yield in optimal conditions, GY_{HD}-grain yield in combination of drought stress and high density, * and ** refer to level of significance, P<0.05 and P<0.01, respectively

There were high and significant correlations between STI, MP and GMP under both stresses, together with grain yield under all tested conditions. Therefore, it can be concluded, as in study of JAFARI *et al*. (2009) that these indices will produce similar results. Significant relation for the three indices and grain yield were obtain in maize inbreds during vegetative and pollination stages (KHODARAHMPOUR and HAMIDI, 2011), as well as in sorghum under post anthesis water stress (NAROUI RAD *et al*., 2004). Some researches (MITRA, 2001; NAROUI RAD *et al*., 2004; GOLABADI *et al*., 2006;) pointed out that suitable index for screening have to be in significant relations with yield under both, stress and non-stress conditions. In the present study, it was not a case for TOL and SSI, except for correlation between grain yield and TOL under HD stress (r=0.538*). Weak and non-significant association between TOL and GYds under moderate stress (drought in our study) was in agreement with study on genetic stocks of potato (CABELLO *et al*., 2013). TOL was in significant correlation with all indices under more severe-HD stress. However, for drought tolerant landraces, SSI was not in significant correlation with grain yield and indices in all conditions, except with grain yield under optimal conditions and TOL in HD (Table 4.), therefore could not be used to separate drought sensitive landraces in the present study. Numerous studies (SABA *et al*., 2001; SIO-SE MARDEH *et al*, 2006; CABELLO *et al*., 2013) also recommended usage of STI, MP and GMP indices as more promising than TOL and SSI.

As STI is recommended as the best indicator of drought tolerance in stress and non-stress conditions (KHODARAHMPOUR and HAMIDI, 2011), correlation coefficients between this index and all examined traits are presented in Table 5.

Table 5. Correlation coefficients between observed traits of maize landraces and STI under different growing conditions

Traits	Exp.	Plant height	Total no. of leaves	Leaf length	Leaf width	Leaf area	ASI	Grain yield
Total no. of leaves	OC	.722**						
	DS	.718**						
	HD	.743**						
Leaf length	OC	.740**	.712**					
	DS	.734**	.786**					
	HD	.825**	.813**					
Leaf width	OC	.529**	.525**	.353				
	DS	.678**	.644**	.655**				
	HD	.748**	.750**	.802**				
Leaf area	OC	.788**	.918**	.814**	.736**			
	DS	.806**	.930**	.890**	.828**			
	HD	.830**	.918**	.917**	.916**			
ASI	OC	-.374	-.164	-.401*	-.327	-.322		
	DS	-.148	-.161	-.343	-.323	-.254		
	HD	-.593**	-.499**	-.585**	-.659**	-.616**		
Grain yield	OC	.477*	.564**	.545**	.655**	.728**	-.469*	
	DS	.442*	.558**	.540**	.619**	.636**	-.623**	
	HD	.705**	.621**	.566**	.730**	.730**	-.790**	
STI	DS	.342	.493*	.404*	.636**	.575**	-.466*	.881**
	HD	.577**	.743**	.503**	.709**	.661**	-.768**	.937**

OC-optimal conditions; DS-drought stress; HD-combination of drought and high density stress; * and ** refer to level of significance, $P<0.05$ and $P<0.01$, respectively

Correlations between all traits and grain yield and STI were highly significant for HD stress. Similar results were reported in numerous studies related to maize drought tolerance (CHAPMAN and EDMEADES, 1999; MONNEVEUX *et al*., 2006;). Interdependence between ASI and grain yield are among the largest correlations of any secondary trait (), confirming the importance of the flowering process in achieving stabile yield under stress (ARAUS *et al*., 2012). Correlations between obtain grain yield under different stresses and ASI in our study are in accordance with previously stated, being the highest under most severe stress (HD). In breeding programs, ASI and plant height are secundary traits for drought tolerance, which are easy observe and could help to chose drought tolerant genotypes earlier during vegetation (HAO *et al*., 2010).

Previous studies in CIMMYT (BÄNZIGER *et al*., 2000) recommended selection for smaller plant height, tassel and husk under stress contributing toward reduced competition for assimilates at flowering and decreased kernel abortion. In all of the tested landraces decrease in plant height was evident, as well as positive and highly significant correlation with grain yield under HD. Besides the factors controlling transpiration at the single leaf level, a most dominant factor in controlling whole plant and crop transpiration is total leaf area. Leaf growth and ASI are secondary traits of main importance for assimilate accumulations. They depend on the ability of leaves and silks to expand under different environmental conditions, so they might have a partly common genetic determinism. Increased number of leaves and greater leaf area are contributing to increased water and nutrient uptake, assimilation rate and better performance under various stresses, including DS and HD. Like it has been reported for maize hybrids (TOLLENAAR and WU, 1999), in our study highly significant correlations were recorded between leaf parameters, particularly leaf area, and final grain yield and STI under HD stress. Although a correlation analysis is very useful in presenting overall interrelation between traits, it is not efficient in interpreting performance of individual genotype, which is of high importance in breeding.

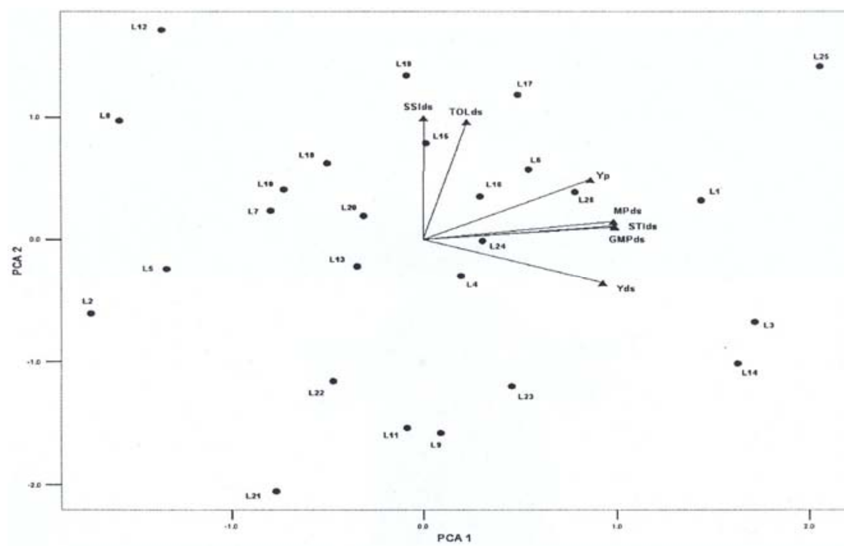


Figure 2. Biplot of principle component analysis of maize landraces and drought tolerance indices under drought stress (DS)

Three-dimensional plots using Yoc (x-axis), Ystress (y-axis) and STI (z-axis) were created to present interrelations between traits and to separate landraces into groups, according to FERNANDEZ (1992) (Figure 2 and Figure 3). It was previously reported and confirmed that in breeding for drought tolerance the most important is group A, with landraces that show superiority in both non-stress and stress condition. Based on the STI and grain yield in optimal and stress conditions, landraces L25, L1, L14, L3, L26, L15 and L16 were assigned to group A for both, DS and HD stresses. All landraces that belong to mini-core collection are with increased drought tolerance, so those belonging to group D could not be strictly considered as drought sensitive, particularly because correlations between grain yield and SSI were low and non-significant. Among them, there are differences in stress response: L2 and L5 had low yield even under optimal conditions (decrease under DS was 7% and 14%, i.e. 24% and 17% under HD, respectively); L8 and L12 showed significant yield reduction in DS (34% and 45%, respectively), but both landraces had higher yield under more severe, HD stress; L21 and L22 showed yield increase in DS, but 8% and 33% decrease under HD stress, respectively. Previous studies (BÄNZIGER *et al.*, 2000) reported that yield potential (including heterosis) is a constitutive trait and in drought tolerant populations reduction in yields was less than 50%. In all of the tested landraces average reduction in grain yield per plant was 17.7% in DS and 31.2% in HD, compared to OC. According to BLUM (1997), high yielding potential could be achieved under optimal and mild stress environmental conditions (e.g. DS in the present study), but under more severe stress (e.g. HD), only germplasm with stress adaptive genes can maintain stable yield.

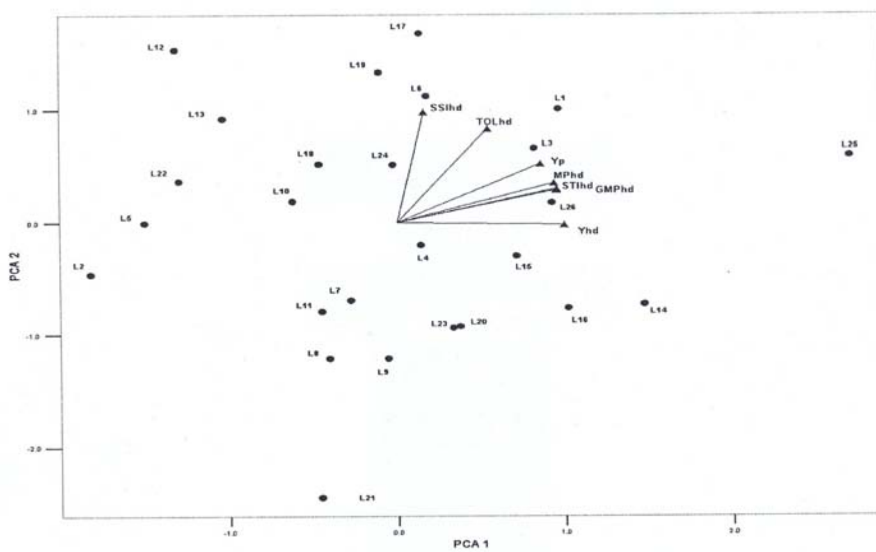
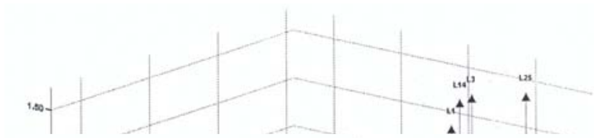


Figure 3. Biplot of principle component analysis of maize landraces and drought tolerance indices under combination of drought and high density stress (HD)

Biplot analysis revealed that the first PCA explained 61.4% for DS (with Yoc, Yds, MPds, STIds, and GMPds) and 77.6% for HD (with Yoc, Yhd, MPhd, STIhd, and GMPhd) of total variation (Figure 4 and Figure 5), and could be labeled as drought tolerance and yield potential.



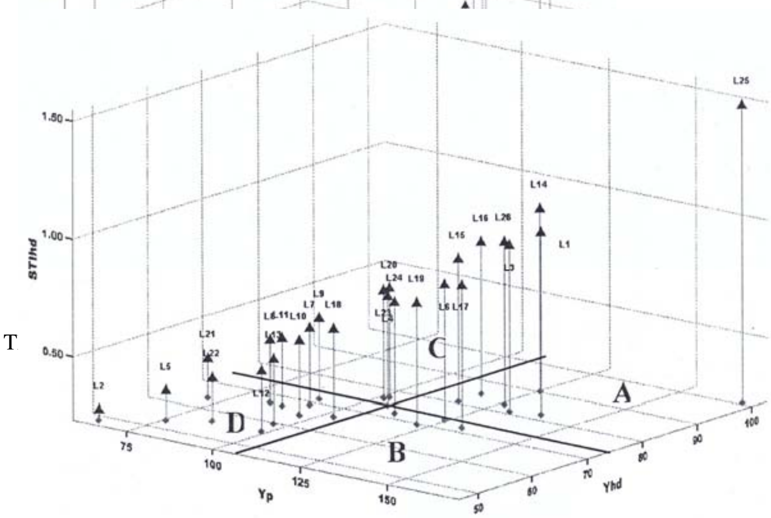


Figure 4. T ith stress

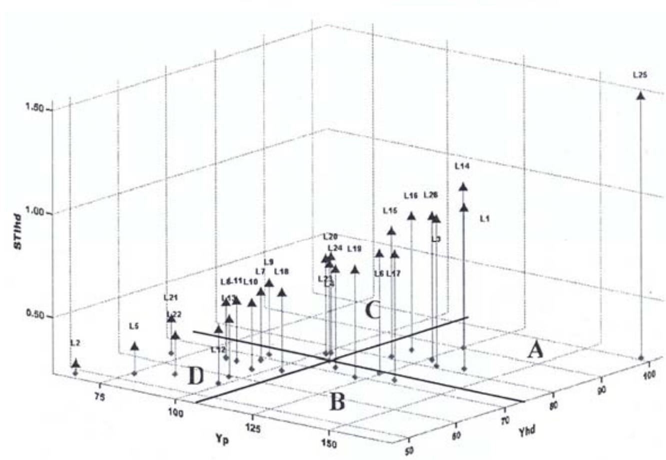


Figure 5. Three dimensional plot of yield in optimal (Yp) and combination of drought and high density stress (Yhd) conditions with stress tolerance index (STI)

The second PCA explained 37.9% (Figure 4) and 21.9% (Figure 5) of total variation, and represent the dimension of stress susceptibility. Under DS, landraces L25, L1, L3 and L14 are positioned in the same direction as vector for STI, and were the most tolerant. In opposite direction to them is a group of landraces (L2, L5, L8 and L12) which exhibited the lowest level of drought tolerance. Under more severe stress (HD), the most drought tolerant landraces were L25, L14, L16, L1 and L26, represented in Figure 5. The most susceptible landraces (L2, L5, L22 and L12) were on the other side of biplot, characterized by low values of PCA1 and high values of PCA2. Efficiency of PCA for adequate separation of genotypes according to drought tolerance in the present study was confirmed in different species: maize (KHODARAHMPOUR and HAMIDI, 2011), sunflower (GHAFFARI *et al*., 2012), wheat (FARSHADFAR *et al*., 2012), grass pea (BASARAN *et al*., 2012), etc.

CONCLUSIONS

The results of this study showed that all examined morphological traits, as well as STI, could be efficiently used for screening of drought tolerance under severe stress conditions. Under moderate stress, only leaf with, leaf area and grain yield were highly correlated with STI, and could be used as good indicators of drought tolerance. Principal component analyses effectively separate landraces according to the level of drought tolerance in both stresses. Results obtained from field trials, along with the application of three-dimensional and PCA analyses indicated that maize landraces L25, L14, L1 and L3 were the superior in all conditions, and could be recommended for breeding as the most valuable source of drought tolerance.

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REFERENCES

AKÇURA, M., F.PARTIGOÇ, and Y.KAYA (2011): Evaluating of drought stress tolerance based on selection indices in Turkish bread wheat landraces. J Anim Plant Sci. *21*: 700-709.

AGRAMA, H.A., W.G. YAN, F. LEE, R. FJELLSTROM, M.H. CHEN, M. JIA and A. MCCLUNG (2009): Genetic assessment of a mini-core subsset developed from the USDA rice genebank. Crop Sci. *49*:1336-1346.

ARAUS, J.L., M.D. SERRET and G.O. EDMEADES (2012): Phenotyping maize for adaptation to drought. Front Physio. *3*:1-20.

BÄNZIGER M, G.O. EDMEADES, D. BECK, M. BELLON (2000): Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice. Mexico DF, CIMMYT.

BASARAN, U., Z. ACAR, M. KARACAN and A.N.ONAR (2012): Variation and correlation of morpho-agronomic traits and biochemical contents (protein and -odap) in Turkish grass pea (*Lathyrus sativus* L.) landraces. Turk J Field Crops. *18*:166-173.

BABIC, M., V. ANDJELKOVIC, S. MLADENOVIC DRINIC and K. KONSTANTINOV (2011): The conventional and contemporary technologies in maize (*Zea mays* L.) breeding at Maize Research Institute Zemun Polje. Maydica. *56*: 155-164.

CABELLO R., P. MONNEVEUX, F. DE MENDIBURU and M. BONIERBALE (2013): Comparison of yield based drought tolerance indices in improved varieties, genetic stoks and landraces of potato (*Solanum tuberosum* L.). Euphytica DOI 10.1007/sl10681-013-0887-1.

CHAPMAN, S.C. and G.O. EDMEADES (1999): Selection improves drought tolerance in tropical maize populations: II. Direct and correlated responses among secondary traits. Crop Sci. *39*: 1315-1324.

FAOSTAT (2010): Statistical databases and data-sets of the Food and Agriculture Organization of the United Nations. http://faostat.fao.org/default.aspx

FARSHADFAR, E., B. JAMSHIDI and M. AGHAEE (2012): Biplot analysis of drought tolerance indicators in bread wheat landraces of Iran. Int J Agr Crop Sci. *4*:226-233.

FERNANDEZ, G.C.J. (1992): Effective selection criteria for assessing plant stress tolerance. In: Proceedings of the Int. Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, 13-18 August, p.257-270. Tainan, TAIWAN.

FISCHER, R.A. and R.MAURER (1978): Drought resistance in spring wheat cultivars. I. Grain responses. Aust J Agr Res. *29*:897-912.

GOLOBADI, M., A.ARZANI, S.A.M. MAIBODY (2006): Assessment of drought tolerance in segregating populations in durum wheat. Afr J Agric Res. *5*: 162-171.

GHAFFARI, M., M.TOORCHI, M.VALIZADEH and M.R.SHAKIBA (2012): Morpho-physiological screening of sunflower inbred lines under drought stress conditions. Turk J Field Crops. *17*: 185-190.

HAO, Z., X. LI, X. LIU, C. XIE, M. LI, D. ZHANG and S. ZHANG (2010): Meta-analysis of constitutive and adaptive QTL for drought tolerance in maize. Euphytica. *174*, 165-177.

http://quickstats.nass.usda.gov.

JAFARI, A., F. PAKNEJAD and M.AL-AHMAIDI (2009): Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. Int J of Plant Prod. *3*:33–38.

KHARRAZI, M.A.S. and M.R.N.RAD (2011): Evaluation of sorghum genotypes under drought stress conditions using some stress tolerance indices. Afr J Agric Res. *10*: 13086-13089.

KHODARAHMPOUR, Z. and J.HAMIDI (2011): Evaluation of drought tolerance in different growth stages of maize (*Zea mays* L.) inbred lines using tolerance indices. Afr J Agric Res. *10*:13482-13490.

MITRA, J. (2001): Genetics and genetic improvement of drought resistance in crop plants. Curr Sci India. *80*: 758-762.

MONNEVEUX. P., C. SÁNCHEZ, D. BECK and G.O. EDMEADES (2006): Drought tolerance improvement in tropical maize source populations: evidence of progress. Crop Sci. *46*: 180-191.

MONTGOMERY, E.G. (1911): Correlation studies in corn. Nebraska Agr. Exp. Sta. Annu Rep. *24*: 108-159.

MORADI,H., G.A.AKBARI, S.K.KHORASANI and H.A.RAMSHINI (2012): Evaluation of drought tolerance in corn (*Zea mays* L.) new hybrids with using stress tolerance indices. European J Sustainable Development. *1*: 543-560.

NAROUI RAD M.R., M.R.ABBASI and H.R.FANAY (2004): Evaluation of drought stress tolerance with use of stress tolerance indexes in sorghum collected germplasms national plant gene bank of Iran. Persian J.Pajouhesh. Sazandegi *82*: 11-18.

NAZARI, L. and H.PAKNIYAT (2010): Assessment of drought tolerance in barley genotypes. Journal of Applied Science. *10*:151-156.

ROSIELLE, A.A. and J. HAMBLIN (1981): Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. *21* (6): 943-946.

SABA, J., M. MOGHDDAM, K. GHASSEMI and M.R. NISHABOURI (2001): Genetic properties of drought resistance indices. J Agric Sci Technol. *3*:43-49.

SIO-SE MARDEH A., A.AHMADI, K POUSTINI and V.MOHAMMADI (2006): Evaluation of drought resistance indices under various environmental conditions. Field Crops Res. *98*: 222-229.

TOLLENAAR. M. and J. WU (1999): Yield improvement in temperate maize is attributable to greater stress tolerance. Crop Sci. *39*:1597-1604.

VANČETOVIĆ, J, S. MLADENOVIĆ DRINIĆ, M. BABIĆ, D. IGNJATOVIĆ-MICIĆ, V. ANĐELKOVIĆ (2010): Maize genebank collections as potentially valuable breeding material. Genetika-Belgrade. *42* (1): 9 – 21.

VIDENOVIĆ, Ž.,Z.DUMANOVIĆ, M.SIMIĆ, J.SRDIĆ, M.BABIĆ and V.DRAGIČEVIĆ (2013): Genetic potential and maize production in Serbia. Genetika-Belgrade, *45* (3), 667-677.

VUCIC. N. (1991): Reduction patterns in yield variations in Vojvodina. Book of papers Institute for field and vegetable crops Novi Sad. (Putevi redukcije magnitude oscilacija prinosa u Vojvodini. Zbornik radova Naučnog instituta za ratarstvo i povrtarstvo, Novi Sad), Sv. 9: 5-8. (in Serbian)

PROCENA TOLERANTNOSTI NA SUŠU KOD POPULACIJA KUKURUZA IZ *MINI-CORE* KOLEKCIJE

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Izvod

Globalne klimatske promene, njihov uticaj na proizvodnju hrane u budućnosti i mogućnosti prevazilaženja problema koje izazivaju su glavni prioriteti u istraživanjima. Kukuruz je jedna od najvažnijih žitarica, ali konačni prinosi mogu da budu značajno umanjeni zbog stresa suše. U ovom radu je testirano 26 populacija iz *mini-core* kolekcije tolerantne prema suši u optimalnim uslovima, kao i u uslovima stresa suše i kombinacije suše i povećane gustine biljaka u polju. Morfološka svojstva visina biljke, ukupan broj listova, dužina lista, širina lista, broj dana između metličenja i svilanja i prinos zrna, merena su za svaki genotip u dva ponavljanja i sva tri eksperimenta. Pored toga, izračunati su indeksi tolerantnosti prema suši, kako bi se ispitala mogućnost razdvajanja uzoraka sa većom tolerantnošću prema ovom stresu. Izračunati su sledeći indeksi: index tolerantnosti na stres (STI), srednje produktivnosti (MP), geometrijske srednje produktivnosti (GMP), osetljivosti na stress (SSI) i tolerantnosti prema stresu (TOL). Signifikantne i pozitivne korelaciju utvrđene su između STI, MP i GMP i prinosa zrna u svim uslovima ispitivanja. Tro-dimenzionalni diagrami i bi-plot analiza efikasno su grupisali ispitivane populacije prema nivou tolerantnosti prema stresu. Populacije L25, L14, L1 i L3, se mogu preporučiti oplemenjivačima za dalji rad kao najznačajniji izvori tolerantnosti prema suši.

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