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SCREENING FOR DROUGHT TOLERANCE IN MAIZE HYBRIDS USING NEW INDICES BASED ON RESILIENCE AND PRODUCTION CAPACITY

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Abstract

Drought is a major abiotic factor limiting the grain yield and yield stability of maize throughout the world therefore, the development of drought tolerant genotypes is an important breeding objective. In this study, an experimental field was conducted at Agricultural Research and Development Station Simnic in the water-stressed (2017) and non-stressed conditions (2018) to select the best performing maize hybrids. For this purpose, the new indices: RCI (the resilience capacity index), PCI (the production capacity index), YSSI (the yield susceptibility score index) and YPSI (the yield production score index) were used. The results indicated that using this new selection method, maize hybrids can be easy identified and classified in four categories of tolerance. The hybrids from category 1: HS 880-13, HS 1158-14, HS 1156-14 were selected as combining high resilience with high productivity.

Key words**:** *drought, grain yield, maize, tolerance indices*

INTRODUCTION

Drought or water deficit is one of the major abiotic stresses which determine the important production constraints in cereals crops, including in maize, especially under rainfed conditions. The loss of grain yield due to the drought varies from 1% to 76% depending on the duration, severity and crop stage [20].

Maize or corn (*Zea mays* L.) is one of the most important cereal crops in Romania and it plays an important role in the country's economy [13].

In the Oltenia region and in other part of the country, maize crop is frequently affected by drought [3, 5].

Thus, the identification and development of genotypes with tolerance to drought stress are the important objectives in maize breeding programs.

The efficiency of breeding programme for tolerance to abiotic stresses depends upon the breeder's ability to find a compromise among the three conflicting response factors: yield obtained under non-stress conditions, yield obtained under stress conditions and yield losses due to stress [2].

Screening for drought tolerance in maize facilitates selection of genotypes, which will eventually help in breeding programs [1].

Numerous studies reported that the most effective selection techniques for drought tolerance in rain fed conditions are those based on levels of yields obtained in both water-stressed and non-stressed conditions [12].

In this regard, five tolerance indices have been proposed by [6, 7, and 14]. These were the most used indices for drought tolerance screening in sorghum [11], maize [4, 19], wheat [10] and canola [15].

However, the use of these indices also has some disadvantages such as the different rankings of the genotypes tested their different ability to highlight genotypes with good yield and the impossibility of highlighting genotypes with overlapping responses in drought conditions.

For this reason, other studies have suggested that the selection methods used for improving drought tolerance should be based on a combination of different indices [17].

Recently, [18] suggested screening for tolerance based on resilience and production capacity of tested genotypes using two new indices: YSSI (the yield susceptibility score index) and YPSI (the yield production score index).

These indices combine the tolerance indices proposed by many authors into two classes: Class 1 (SSI and TOL) and Class 2 (MP, GMP and STI), thus are more effective in understanding the basis of any yield limitations under stress.

In light of the above, the objectives of this study were to screen several maize hybrids for identify the most suitable hybrids for drought-prone areas and also to evaluate the use of new indices in breeding programmes.

MATERIALS AND METHODS

A total of ten new hybrid creations of maize obtained to NARDI (National Agricultural Research and Development Institute) Fundulea, were selected and used in the present study to determine their drought tolerance.

The field experiment was carried out during two consecutive years at the ARDS (Agricultural Research and Development Station) Simnic and was arranged in Randomized Blok Design with three replications.

Experimental area is located in the central part of the Oltenia region.

The first year of study (2017) was characterized by well-defined drought in June and August and the second year (2018) was favourable for growing of maize (non-stressed conditions) - Table 1.

Table 1. Mean monthly rainfall recorded during two cropping seasons (2017and 2018)

Months	Rainfall (mm) 2017	2018	Multiannual average
April	64.0	32.0	53.1
May	71.0	51.0	71.7
June	24.0	141.0	73.6
July	100.0	135.0	82.2
August	9.0	41.0	47.0
Total	268	388	327.6

Source: Craiova Meteorological Station.

The tolerance indices were calculated using the formulas cited in Table 2.

Table 2. The calculate tolerance indices

Indices	Formulas
SSI (The stress susceptibility index) [7]	$SSI = [1 - (Ys/Yp)]/SI$ where $SI = 1 - (Ysi/Ypi)$
TOL (The tolerance index) [14]	$TOL = (Yp - Ys)$
MP (The mean productivity) [14]	$MP = (Ys + Yp)/2$
GMP (The geometric mean productivity) [6]	$GMP = \sqrt{Ys \times Yp}$
STI (The stress tolerance index) [6]	$STI = (Yp) \times (Ys)/(Ypi)^2$
YSSI (The yield susceptibility score index) [18]	$YSSI = (STIs + SSIs)/2$
YPSI (The yield production score index) [18]	$YPSI = (MPs + STIs)/2 - (SSIs + TOLs)/2$

Yp = grain yield of maize hybrid in non-stressed conditions (t/ha); Ys = grain yield of maize hybrid in water-stressed conditions (t/ha); Ypi and Ysi = mean grain yield of all maize hybrids in non-stressed and water-stressed conditions, respectively.

Source: Completed by the author according to the references.

Data were statistically processing by regression and correlation analysis using EXCEL program.

RESULTS AND DISCUSSIONS

In Table 3 are presented the data on grain yields obtained in the both conditions (Ys and Yp), the tolerance indices and the rank of indices.

Table 3. Grain yield in the water-stressed (Ys) and non-stressed conditions (Yp), tolerance indices and rank of indices in maize hybrids

Hybrid	Ys		YP		SSI		TOL		MP		GMP		STI	
HS 1154-14	5.91	2	7.37	10	0.51	1	1.46	1	6.64	9	6.60	7	0.54	7
HS 1158-14	6.16	1	8.48	6	0.71	2	2.32	2	7.32	5	7.23	4	0.64	4
HS 1191-14	5.64	5	11.31	1	1.30	10	5.67	10	8.47	1	7,99	1	0.78	1
HS1128-14	5.11	9	8.21	8	0.97	6	3.10	6	6.66	8	6,48	9	0.52	9
HS 734-13	5.52	6	10.16	3	1.17	7	4.64	8	7.84	2	7.49	2	0.69	2
HS 570-15	5.21	8	7.98	9	0.89	5	2.77	4	6.59	10	6.45	10	0.51	10
HS 880-13	5.81	3	8.85	5	0.88	4	3.04	5	7.33	4	7.17	5	0.63	5
HS 580-15	4.72	10	8.90	4	1.20	8	4.18	7	6.81	7	6.48	8	0.52	8
HS 1156-14	5.70	4	8.22	7	0.79	3	2.52	3	6.96	6	6.84	6	0.57	6
HS 141-14	5.26	7	10.43	2	1.28	9	5.17	9	7.84	3	7.41	3	0.67	3

Source: Own calculation.

In this study, all the selection indices showed different rankings for tested hybrids, except the rankings for GMP and STI indices which showed similarity.

According to [18], for define the resilience and production capacity, is necessary that the original indices used in the Table 3 to be divided into two classes: Class 1 (SSI and TOL) and Class 2 (MP, GMP and STI) and a the score index should be calculated for the each individual index (by a scoring scale from 1 to 10) - Table 4.

The results showed small differences of scores between SSI and TOL and between MP and (GMP, STI), while between GMP and STI score differences have been very similar.

Table 4. Scores of indices for used tolerance indices (SSI, TOL, MP, GMP, STI) in maize hybrids

Hybrid	Class 1		Class 2		
	SSI	TOL	MP	GMP	STI
HS 1154-14	10	10	2	4	4
HS 1158-14	9	9	6	7	7
HS 1191-14	1	1	10	10	10
HS1128-14	5	5	3	2	2
HS 734-13	4	3	8	9	9
HS 570-15	6	7	1	1	1
HS 880-13	7	6	7	6	6
HS 580-15	3	4	4	3	3
HS 1156-14	8	8	5	5	5
HS 141-14	2	2	9	8	8

Source: Own calculation.

For verify the relationships between the value of the tolerance indices used in this study and their scores, the simple correlation coefficients were calculated (Table 5).

Table 5. The correlation coefficients between the tolerance indices and their score

Correlations	Correlation coefficients (r)
Class 1	
SSI with SSIs	-0.983^{00}
TOL with TOLs	-0.980^{00}
Class 2	
MP with MPs	0.958**
GMP with GMPs	0.968**
STI with STIs	0.962**

*and ** or ^{0} and ^{00} = significant positive or negative at 5% and 1% probability, respectively

Source: Own calculation.

The results obtained showed that, in general, for Class 1 of indices the correlations were negative and for Class 2 of indices the correlations were positive.

The tolerance indices SSI and TOL were highly significant negative correlated with their scores SSIs and TOLs (r = -0.983^{00} and r = -0.980^{00}, respectively).

The associations between the values of the other tolerance indices (MP, GMP and STI) and their scores (MPs, GMPs and STIs) were significantly positive (r = 0.958**, r = 0.968** and r = 0.962**, respectively).

According to [18] and based on these results, it can be concluded that these calculated score indices can be used to screening of drought tolerance as substitutes for their original indices.

Also, the values of the score indices and the correlation coefficients demonstrated that these two classes of indices address two different characteristics: the resilience capacity (RC) and the production capacity (PC), respectively.

In order, for more results and to development a better selection index or a better combination of indices, the relationships between the score indices and grain yield in both conditions (Ys and Yp), were calculated. These relationships were expressed by linear regression (Y) and by the coefficients of determination (R^2) - Table 6.

Table 6. The relationships results between score indices and grain yield in the water-stressed (Ys) and non-stressed conditions (Yp) in maize hybrids

Correlations	Regression equation (Y)	Coefficient of determination (R^2)
SSIs with Ys	Y = 0.088x + 5.017	0.388
SSIs with Yp	Y = -0.343x + 10.88	0.697
TOLs with Ys	Y = 0.071x + 5.110	0.253
TOLs with Yp	Y = -0.369x + 11.02	0.806
MPs with Ys	Y = 0.030x + 5.334	0.047
MPs with Yp	Y = 0.371x + 6.949	0.814
GMPs with Ys	Y = 0.062x + 5.160	0.193
GMPs with Yp	Y = 0.334x + 7.15	0.662
STIs with Ys	Y = 0.062x + 5.160	0.193
STIs with Yp	Y = 0.334x + 7.15	0.662

Source: Own calculation.

The results obtained demonstrated that the high yielding hybrids in both conditions could not be clearly identified if these indices have been used individually.

Among the calculated scores indices from different classes, SSIs, TOLs, GMPs and STIs indices registered close but weak relationships with Ys (R^2 = 0.388, R^2 = 0.253 and R^2 = 0.193, respectively), while SSIs, TOLs, MPs, GMPs and STIs indices registered close and strong relationship with Yp (R^2 = 0.697, R^2 = 0.806, R^2 = 0.814, R^2 = 0.662, respectively). Similar results were reported by [16] in common bean, by [9] in wheat and by [8] in cowpea.

Therefore, among maize hybrids with the highest score in Class 1, HS 1154-14, HS 1158-14, HS 1156-14, HS 880-13 and HS 570-15 proved to be superior maize hybrids. Similarly, in terms of Class 2, HS 1191-14, HS 734-13, HS 141-14, HS 1158-14 and HS 880-13 proved to be superior maize hybrids (Table 5).

In order to make a comparative analysis of resilience and productivity, the two indices RCI and PCI as proposed by [18] that are based on the combination of five score indices were calculated (Table 7).

In addition, the two indices: yield stress score index (YSSI) and yield potential score index (YPCI), based on these two components (RC and PC) were calculated for all tested hybrids.

Table 7. Values of RCI and PCI and their combination into YSSI and YPSI in maize hybrids

Hybrids	RCI	PCI	YSSI	YPSI
HS 1154-14	10	4	7	-7
HS 1158-14	9	7	8	-1.5
HS 1191-14	1	10	5.5	9
HS1128-14	5	2	3.5	-2.5
HS 734-13	4	9	6.5	5
HS 570-15	6	1	3.5	-5.5
HS 880-13	7	6	6.5	0
HS 580-15	3	3	3	0
HS 1156-14	8	5	6.5	-3
HS 141-14	2	8	5	6.5

Source: Own calculation.

The relationships between grain yield in both conditions (Ys and Yp) and new indices (YSSI and YPSI) were highly positive (R^2 = 0.896 and R^2 = 0.938, respectively) – Fig. 1.

The results confirmed ability of these new indices for selection of high yielding hybrids. [8], reported that these new indices offer a simple and easy visualization and identification of genotypes with/none resilience and productivity or both.

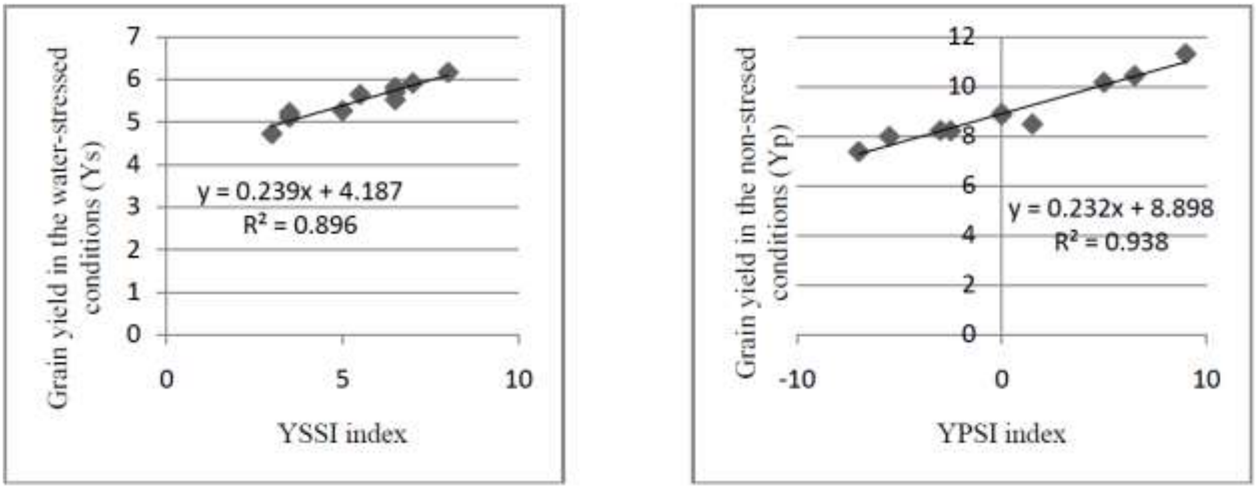

Fig. 1. The relationships between new score indices (YSSI and YPSI) and grain yield (Ys and Yp) in maize hybrids
Source: Own calculation.

Based on RCI index, hybrids HS 1154-14, HS 1158-14, HS 1156-14 and HS 880-13 were identified as having a better resilience as compared to hybrids HS 1191-14, HS 141-14 and HS 580-15.

Similar, based on PCI, hybrids HS 1191-14, HS 734-13 and HS 141-14 were identified as having a better productivity as compared to HS 570-15, HS 1128-14 and HS 580-15.

Based on YSSI and YPSI indices the hybrids HS 1158-14, HS 1156-14 and HS 880-13 were identified as having a better resilience, but HS 880-13 was identified as having and a better productivity as compared to these hybrids.

For YSSI and YPSI indices, the hybrids HS 734-13 and HS 141-14 have had close values which indicates that these hybrids had similar capacities of resilience and productivity. On the contrary, HS 1154-14 and HS 734-13 had close values of YSSI index, but very different values of YPSI index.

Thus, this study showed that using the new indices based on resilience and productivity, the tested hybrids can be classified into four categories:

(1) hybrids with higher resilience and productivity, including: HS 1158-14, HS 1156-14 and HS 880-13;

(2) hybrids with higher resilience and lower productivity, including: HS 1154-14, HS 570-15, HS 1128-14;

(3) hybrids with lower resilience and higher productivity, including: HS 1191-14; HS 141-14, HS 734-13; and

(4) hybrids with lower resilience and productivity, including HS 580-15.

According to [2], hybrids of categories 2 and 3 may be used in breeding programs while hybrids of category 1 could be used for cultivation.

CONCLUSIONS

The new selection method based on RCI and PCI, YSSI and YPSI indices can help maize breeders by defining more effective criteria to identify genotypes with high resilience and high productivity.

Among maize hybrids tested, HS 880-13, HS 1158-14, HS 1156-14 classified in category 1 are the most suitable for drought-prone areas.

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