EVALUATION OF DURUM WHEAT GENOTYPES BASED ON

DROUGHT TOLERANCE INDICES UNDER DIFFERENT

LEVELS OF DROUGHT STRESS

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**Abstract:** Objectives of this study were to assess durum wheat genotypes for drought tolerance and to study relationships among different drought tolerance indices under different drought stress conditions. The total of twenty-two durum wheat lines was evaluated in a RCBD experiment with three replications for three cropping seasons (2008–2009; 2009–2010 and 2010–2011). Different drought indices such as tolerance (TOL), mean productivity (MP), mean relative performance (MRP), stress susceptibility index (SSI), modified severity stress index (SSSI), geometric mean productivity (GMP), stress tolerance index (STI), yield stability index (YSI), relative efficiency index (REI) and drought response index (DRI) were determined based on yields under drought and non-drought conditions. The studied genotypes showed considerable variation in performance and tolerated various drought conditions that could be exploited in the durum wheat breeding program. The screening of genotypes for drought tolerance in environments with a greater value of stress intensity (SI) will be more efficient in the grouping of indices and genotype selection. The indices were classified into groups (G1 and G2). The group G1, which consisted of the indices REI, STI, MRP, GMP, DRI and YSI, distinguished genotypes with higher yield in different levels of drought stress. The durum breeding line nos. 1, 11, 10, 13, 8, 9, and 12 were superior based on the group G1 and could be regarded for further evaluation in drought-prone environments.

**Key words:** durum wheat, drought tolerance indices, stress intensity.

**Introduction**

Precipitation is the most important factor for agricultural production, whereas drought is the serious restriction to crop production (Boyer, 1982). In Iran, wheat is produced in the areas with a variable amount and distribution of rainfall. Drought stress occurs in grain filling, when evapo-transpiration is high due to higher air temperature. The respective yield of lines under drought and non-drought conditions is the first beginning point in the determination of characteristics related to stress for choosing genotypic materials in breeding for drought conditions (Clarke et al., 1992). The study of genotypes under stress conditions is the major work of breeders to improve yield productivity and drought tolerance (Benmahammed et al., 2010). Various yield-based drought resistance indices have been proposed. Tolerance index (TOL) (Rosielle and Hamblin, 1981), mean productivity (MP) (McCaig and Clarke, 1982), stress susceptibility index (SSI) (Fischer and Maurer, 1978), modified stress severity index (SSSI) (Singh et al., 2011), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) are used under different conditions. The use of grain yield per se is the most applicable method for assessing drought resistance. Compared to yield potential, stability of yield seems more relevant to adaptation and stress tolerance in crops (Blum et al., 1990; Van Ginkel et al., 1998; Panthuwan et al., 2002). The breeding for yield potential is often negatively associated with yield stability because of GE interaction (Calderini and Slafer, 1999). However, selection based on multi-trials (including years and sites) will be more useful to select genotypes with high stress tolerance and yield productivity (Yau et al., 1991; Ceccarelli et al., 1992; Kirigwi et al., 2004).

According to other studies on detection of drought tolerant genotypes, it has been suggested that by screening genotypes in non-drought conditions, both adaptability and high yield potential are accessible (Panthuwan et al. 2002; Kirigwi et al. 2004). On the contrary, under stress environments, selection of genotypes with high yield performance can be favored (Ceccarelli et al., 1992). Many of scientists believe that to enhance more effective selection, trials must be conducted in drought and non-drought conditions (Clarke et al., 1992; NasirUd-Din et al., 1992; Fernandez, 1992; Byrne et al., 1995; Rajaram and Van Ginkle, 2001). According to Trethowan et al. (2002), selection in alternating stress and non-stress drought environments has led to an increasing progress in the development of wheat adaptation in dry areas globally. However, selection for drought tolerance should be made using drought tolerance indices based on yield under both conditions, when the aim is to look for widely adapted genotypes (Sio-se Maedeh et al., 2006).

To identify high yielding durum wheat genotypes in variable years, 22 durum genotypes were evaluated for improving tolerance to drought stress by using different drought resistance indices. This study aimed to assess drought tolerance in durum wheat breeding lines and to find relationships among different indices of drought tolerance under various levels of drought.

**Materials and Methods**

The trials were carried out at Sararood station of the Dryland Agricultural Research Institute, Kermanshah, Iran (1351 masl, 34°20' N, 47°19' E) on a clay loam soil with the long-term average rainfall of 415 mm, during 2008–2011. The total of twenty durum wheat breeding lines along with two check cultivars i.e., Zardak (local durum wheat) and Saji (new cultivar) were evaluated in a randomized complete block design (RCBD) with three replications. Meteorological conditions were completely different across experimental years (Figure 1). Different levels of rainfall provided an opportunity to assess the response of durum genotypes to different levels of drought stress. However, due to variable climatic conditions in the region, crops experience different levels of drought stress, which complicates selection of ideal genotypes. For this, the drought stresses were applied to evaluate the genotypes based on different levels of stress. Accordingly, calculations of the drought indices were performed based on the two different datasets as follows:

Dataset A: the first year (Y1: 2008–2009 with 288.3 mm of precipitation) represented stress conditions and the second year (Y2: 2009–2010 with 453.9 mm of precipitation) represented non-stress conditions,

Dataset B: the third year (Y3: 2010–2011 with 342.5 mm of precipitation) represented stress conditions and Y2 represented non-stress conditions.

Drought resistance indices were obtained using the following equations:

(1) Stress susceptibility index (SSI) = (Fischer and Maurer, 1978),



where Ys and Yp are the yields of a given genotype under stress and non-stress conditions, respectively, and are the mean yields of all genotypes under stress and non-stress conditions, respectively, and is the stress intensity (SI).



(2) Modified stress severity index (SSSI) = (1- (Sing et al., 2011).



(3) Mean productivity (MP) = (Hossain et al., 1990).



(4) Tolerance (TOL) = Yp - Ys (Hossain et al., 1990).

(5) Stress tolerance index (STI) = (Fernandez, 1992).



(6) Geometric mean productivity (GMP) = (Fernandez, 1992).



(7) Yield stability index (YSI) = (Bouslama and Schapaugh, 1984).



(8) Mean relative performance (MRP) = (



(9) Relative efficiency index (REI) = ( (Raman et al., 2012).



(10) Drought response index (DRI) (Bidinger et al., 1987) describing the response of genotypes to drought stress by fitting multiple regression of grain yield in stress conditions on grain yield and days to flowering in non-stress conditions: s= a – bF + cYp,



where s is the regression estimate of yield in stress conditions, Yp is the yield under non- stress conditions, F is the days to flowering in non-stress conditions, a is the intercept, b and c are the regression coefficients. Then, the DRI was calculated by the following equation:



DRI = , where SE indicates the standard error.

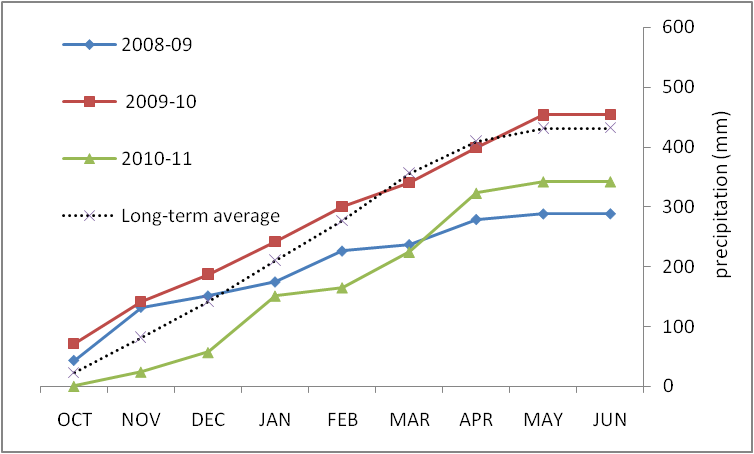


Figure 1. Precipitation of three cropping seasons (2008–2009, 2009–2010 and 2010–2011) compared with the long-term average (20 years).

A combined analysis of variance was performed for partitioning of total variance to its components. A biplot based on principle component analysis (PCA) was applied to classify the drought tolerance indices and characterize the tested genotypes based on the indices using IBM SPSS statistics version 19 software (IBM Corp., Armonk, NY, USA).

**Results and Discussion**

Results of the analysis of variance of grain yield data showed a highly significant genotype × year (G×Y) interaction (Table 1).

Table 1. Combined analysis of variance for grain yield of 22 genotypes in A and B datasets. Dataset A: Y1 (2008–2009) as stress and Y2 (2009–10) as non-stress conditions and Dataset B: Y2 as non-stress and Y3 (2010-2011) as stress conditions.

|  |  |  |  |
| --- | --- | --- | --- |
| Source of variations | df | Mean squares | |
| A | B |
| SI∞ = 0.79 | SI = 0.69 |
| Year (Y) | 1 | 702569000\*\* | 10884900\*\* |
| Block/Y | 4 | 243902 | 21855.2 |
| Genotype (G) | 21 | 880443ns | 251921 ns |
| G×Y | 21 | 629463\*\* | 156768\*\* |
| Residual | 84 | 214233 | 60742.6 |

\*\* significant at the 1% level of probability, ns: non-significant, SI: stress index.

The mean yields of genotypes ranged from 618 kg ha-1(G20) to 1845 kg ha-1(G1) in the first year, from 3495 kg ha-1(G22) to 6611kg ha-1(G10) in the second year and from 1474 kg ha-1(G9) to 2169 kg ha-1(G21) in the third year (Table 2). The ranking of genotypes according to grain yield in each year was different indicating different responses of genotypes to different levels of drought (Table 2). This finding justified the utilization of stress indices and multivariate methods to describe the behavior of genotypes under stress and non-stress conditions (Benmehamad et al., 2010).

Table 2. Mean grain yield (kgha-1) of 22 durum genotypes and their ranks in each cropping season.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Code | | 2008–2009 | | 2009–2010 | | 2010–2011 | |
| Mean | Rank | Mean | Rank | Mean | Rank |
| 1 | Bcr/Gro1//Mgnl1 | 1845.4 | 1 | 6461.4 | 2 | 1766.7 | 13 |
| 2 | Adnan-2 | 1053.2 | 16 | 6275.3 | 6 | 1664.3 | 18 |
| 3 | Waha | 1245.1 | 9 | 5858.7 | 11 | 1809.5 | 9 |
| 4 | Stj3//Bcr/Lks4/3n"er-3 | 991.7 | 18 | 5881.8 | 10 | 1988.1 | 4 |
| 5 | Stj3//Bcr/Lks4/3/Ter-3 | 889.8 | 19 | 5800.8 | 13 | 1640.5 | 19 |
| 6 | Geromtel-1 | 1033.3 | 17 | 5703.6 | 18 | 1704.8 | 16 |
| 7 | Ammar-6 | 1228.7 | 11 | 6304.5 | 5 | 1845.2 | 8 |
| 8 | Ammar-8 | 1429.6 | 6 | 5754.0 | 15 | 1785.7 | 10 |
| 9 | Ammar-1 | 1278.2 | 8 | 5753.1 | 16 | 1473.8 | 22 |
| 10 | Ammar-9 | 1701.4 | 3 | 6611.4 | 1 | 1933.3 | 5 |
| 11 | Mgnl3/Aghrass2 | 1827.3 | 2 | 6460.5 | 3 | 2081.0 | 2 |
| 12 | Ter-1//Mrf1/Stj2 | 1231.5 | 10 | 5751.3 | 17 | 1719.1 | 15 |
| 13 | Mgnl3/Ainzen-1 | 1527.1 | 5 | 6328.1 | 4 | 1916.7 | 6 |
| 14 | Ter-1/3/Stj3//Bcr/Lks4 | 1346.3 | 7 | 5429.5 | 20 | 1776.2 | 11 |
| 15 | EDUYT-15 | 863.9 | 20 | 6071.2 | 8 | 1678.6 | 17 |
| 16 | EDUYT-18 | 1113.0 | 14 | 6027.2 | 9 | 1914.3 | 7 |
| 17 | EDUYT-42 | 756.5 | 21 | 5754.5 | 14 | 1776.2 | 12 |
| 18 | EDUYT-47 | 1116.0 | 13 | 5847.1 | 12 | 1750.0 | 14 |
| 19 | EDUYT-54 | 1111.1 | 15 | 5319.3 | 21 | 1631.0 | 20 |
| 20 | EDUYT-70 | 618.1 | 22 | 6151.3 | 7 | 2035.7 | 3 |
| 21 | Saji | 1575.0 | 4 | 5456.8 | 19 | 2169.1 | 1 |
| 22 | Zardak | 1204.2 | 12 | 3495.2 | 22 | 1561.9 | 21 |
| Mean |  | 1226.7 |  | 5840.8 |  | 1801.0 |  |
| S.E. |  | 69.6 |  | 134.3 |  | 36.7 |  |

No significant correlation was found between mean yields in different years indicating that the genotypes did not respond similarly to different years (Table 3).

Ys (yield under stress conditions), Yp (yield under non-stress conditions), MP (mean productivity), GMP (geometric mean productivity), TOL (tolerance), STI (stress tolerance index), SSI (stress susceptibility index), YSI (yield stability index), SSSI (modified susceptibility stress index), MRP (mean relative performance), REI (relative efficiency index) and DRI (drought response index).

Table 3. Correlation between drought indices and grain yield in two datasets – A: Y2 as non-stress conditions and Y1 as stress conditions; and B: Y2 as non-stress conditions and Y3 as stress conditions.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Data  set |  | Ys | Yp | MP | GMP | TOL | STI | SSI | YSI | SSSI | MRP | REI |
| A | Yp | 0.203 |  |  |  |  |  |  |  |  |  |  |
| B |  | 0.405 |  |  |  |  |  |  |  |  |  |  |
| A | MP | 0.593\*\* | 0.909\*\* |  |  |  |  |  |  |  |  |  |
| B |  | 0.596\*\* | 0.976\*\* |  |  |  |  |  |  |  |  |  |
| A | GMP | 0.938\*\* | 0.523\* | 0.829\*\* |  |  |  |  |  |  |  |  |
| B |  | 0.805\*\* | 0.868\*\* | 0.956\*\* |  |  |  |  |  |  |  |  |
| A | TOL | -0.306 | 0.870\*\* | 0.585\*\* | 0.035 |  |  |  |  |  |  |  |
| B |  | 0.142 | 0.963\*\* | 0.880\*\* | 0.701\*\* |  |  |  |  |  |  |  |
| A | STI | 0.940\*\* | 0.523\* | 0.831\*\* | 0.996\*\* | 0.035 |  |  |  |  |  |  |
| B |  | 0.829\*\* | 0.844\*\* | 0.940\*\* | 0.997\*\* | 0.668\*\* |  |  |  |  |  |  |
| A | SSI | -0.829\*\* | 0.371 | -0.048 | -0.588\*\* | 0.778\*\* | -0.592\*\* |  |  |  |  |  |
| B |  | -0.304 | 0.736\*\* | 0.573\*\* | 0.315 | 0.886\*\* | 0.263 |  |  |  |  |  |
| A | YSI | 0.828\*\* | -0.373 | 0.046 | 0.586\*\* | -0.779\*\* | 0.591\*\* | -1.00\*\* |  |  |  |  |
| B |  | 0.302 | -0.737\*\* | -0.575\*\* | -0.317 | -0.888\*\* | -0.266 | -1.00\*\* |  |  |  |  |
| A | SSSI | -0.850\*\* | 0.247 | -0.159 | -0.673\*\* | 0.668\*\* | -0.652\*\* | 0.932\*\* | -0.932\*\* |  |  |  |
| B |  | -0.415 | 0.657\*\* | 0.477\* | 0.2 | 0.834\*\* | 0.152 | 0.982\*\* | -0.983\*\* |  |  |  |
| A | MRP | 0.939\*\* | 0.528\* | 0.834\*\* | 0.998\*\* | 0.04 | 0.999\*\* | -0.588\*\* | 0.587\*\* | -0.650\*\* |  |  |
| B |  | 0.817\*\* | 0.858\*\* | 0.950\*\* | 1.00\*\* | 0.687\*\* | 0.998\*\* | 0.294 | -0.296 | 0.181 |  |  |
| A | REI | 0.940\*\* | 0.522\* | 0.830\*\* | 0.996\*\* | 0.034 | 1.00\*\* | -0.593\*\* | 0.592\*\* | -0.652\*\* | 0.999\*\* |  |
| B |  | 0.830\*\* | 0.843\*\* | 0.940\*\* | 0.997\*\* | 0.667\*\* | 1.00\*\* | 0.262 | -0.265 | 0.151 | 0.998\*\* |  |
| A | DRI | 0.925\*\* | 0.0 | 0.394 | 0.805\*\* | -0.466\* | 0.801\*\* | -0.861\*\* | 0.860\*\* | -0.869\*\* | 0.802\*\* | 0.802\*\* |
| B |  | 0.978\*\* | 0.552\*\* | 0.720\*\* | 0.890\*\* | 0.307 | 0.904\*\* | -0.129 | 0.127 | -0.253 | 0.897\*\* | 0.904\*\* |

This can be supported by the significant G ×Y interactions for grain yield (Table 1). Thus, there is no guarantee that a genotype selected in a year with high rainfall will produce high yields in years with low rainfall (severe and mild drought stresses) and vice versa. Therefore, indirect selection in a drought-prone environment based on the results of optimum conditions will not be efficient. These results are in agreement with those of Ceccarelli and Grando (1991), Bruckner and Frohberg (1987), and Sio-Se Mardehet al. (2006), who found that landraces of barley and wheat with a low yield potential were more productive under stress conditions. The lack of response to improved environmental conditions may be related to a lack of adaptation to high-moisture conditions (Clarke et al., 1992). These interactions complicate the breeding process by introducing unknown factors that modulate the yield response depending on the availability of water. It is important, therefore, to differentiate between genotypes that have high yields in drought conditions simply because of their high inherent yield potential and those that have greater drought tolerance per se.

A linear regression model was fitted to the relationship between genotypic mean yields and total annual rainfall which showed that genotypic mean yield increased with increasing rainfall (R2= 0.82) (Figure 2). Among genotypes, the grain yield of the old cultivar Zardak was found to be the lowest, and that of the new cultivar Saji was equal or superior to the breeding lines in a low rainfall year, while under high rainfall conditions Saji was not superior to the breeding lines. It can be concluded that the breeding lines were better than the new cultivar in favorable conditions, whereas they were not better than the new cultivar in stress conditions. A similar result for oat (*Avena sativa*) was reported by Akcura and Ceri (2011).

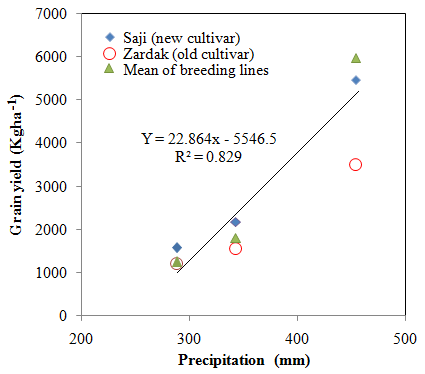


Fig. 2. Regression between genotype (mean of breeding lines and cultivars) grain yield and total annual rainfall in different years.

The drought tolerance indices take into account yield potential and yield under drought conditions in different formulas. Using one drought index may not lead the breeder to the best selection. Therefore, selection based on a combination of several indices may provide a more useful criterion for drought tolerance improvement. Principal component analysis and biplot technique were used to identify superior genotypes based on the indices for each dataset. For the two A and B datasets, the stress intensity (SI) values were 0.79 and 0.69, respectively, which provides an opportunity to evaluate the durum genotypes under both mild and severe stresses under rainfed conditions. The first two PCs accounted for 98.2% and 99.4% of total variation for datasets A and B, respectively. PC analysis in different datasets showed that the dataset A with the highest SI value was the best one for distinguishing genotypes by indices (Figures 3 and 4). In the dataset A, the indices were separated into two groups: TOL, SSI and SSSI (Group G1), and Ys, REI, STI, MRP, GMP, DRI and YSI (Group G2) (Figure 3).

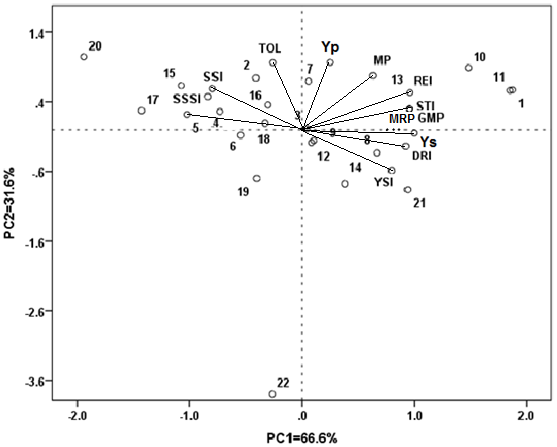


Figure 3. Biplot based on the first two principal component axes (PC1 and PC2) for 22 genotypes across drought indices in the dataset A. Ys (yield under stress conditions), Yp (yield under non-stress conditions), MP (mean productivity), GMP (geometric mean productivity), TOL (tolerance), STI (stress tolerance index), SSI (stress susceptibility index), YSI (yield stability index), SSSI (modified susceptibility stress index), MRP (mean relative performance), REI (relative efficiency index) and DRI (drought response index). The numbers represent genotypes.

Concerning the group G1, the genotype nos. 16, 2, 18, 4, 5, 15, 17, 20 were found to be susceptible to drought conditions, while the genotype nos. 1, 11, 10, 13, 8, 9, and 12 belonging to the group G2 were tolerant. Raman et al. (2012) found a strong positive correlation between the indices REI, MRP, STI, GMP and MPI belonging to the same group and the indices DYI, TOL, SSI and SSSI were classified in another group. They reported a highly negative correlation between these two groups. Sio-Se Mardeh et al. (2006) concluded that GMP and STI were able to discriminate a group of cultivars only under moderate drought stress conditions.

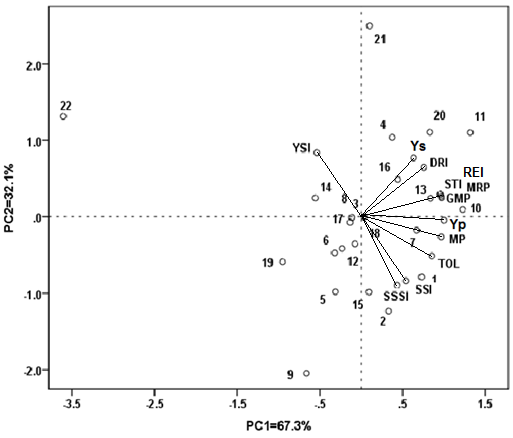


Figure 4. Biplot based on the first two principal component axes (PC1 and PC2) for 22 genotypes across drought indices in the dataset B. Ys (yield under stress conditions), Yp (yield under non-stress conditions), MP (mean productivity), GMP (geometric mean productivity), TOL (tolerance), STI (stress tolerance index), SSI (stress susceptibility index), YSI (yield stability index), SSSI (modified susceptibility stress index), MRP (mean relative performance), REI (relative efficiency index) and DRI (drought response index). The numbers represent genotypes.

A positive correlation between TOL and Yp in the A and B datasets, and a negative correlation between TOL and Ys in the dataset A suggests that selection based on TOL will result in increased yield under optimal conditions (Table 3). Similar results were reported by Sio-Se Mardeh et al. (2006), Clarke et al. (1992) and Rosielle and Hamblin (1981). Hossain et al. (1990) used MP as a resistance criterion for wheat cultivars in moderate stress conditions. Correlations of MP and GMP with Yp and Ys were positive in the two datasets (Table 3). As described by Hohls (2001), selection for MP should increase yield in both stress and non-stress environments unless the correlation between yields in contrasting environments is highly negative. In our experiment, there was no significant correlation between genotypic yields in different conditions. SSI has been widely used by researchers to identify sensitive and resistant genotypes (Clarke et al., 1992; Fischer and Maurer, 1978). SSI showed a negative correlation with Ys in both datasets (Table 3). Similar results were reported by Sio-Se Mardeh et al. (2006).

The results showed yield ranks in each year indicating that G11, G10, G13 and G1 had mean ranks below 5 during three years (Table 2). These genotypes were already identified by the group G2 of indices as the most drought tolerant (Fig. 3). Therefore, selection based on this group of indices will enhance yield productivity in durum genotypes under different levels of drought stress.

**Conclusion**

Screening of durum wheat genotypes for drought tolerance in environments with a higher value of stress intensity (SI) proved to be more efficient for grouping of drought tolerance indices and genotype selection. The group G1 of indices (Ys, REI, STI, MRP, GMP, DRI and YSI) distinguished genotypes with higher yields under different levels of drought stress. The studied genotypes showed considerable variability in yield and tolerance to different levels of drought stress, which could be exploited for crop improvement. Among the examined materials, the breeding line nos. 1, 11, 10, 13, 8, 9, and 12 with higher yield productivity under different levels of stress can be included in further considerations for durum wheat breeding programs for drought-prone environments.

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PROCENA GENOTIPOVA DURUM PŠENICE NA OSNOVU INDEKSA TOLERANTNOSTI NA SUŠU PRI RAZLIČITIM NIVOIMA STRESA IZAZVANOG SUŠOM

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R e z i m e

Ciljevi ovog istraživanja bili su da se procene genetipovi durum pšenice za tolerantnost na sušu i da se prouče veze između različitih indeksa tolerantnosti na sušu u različitim uslovima stresa uslovljenog sušom. Ukupno dvadeset i dve linije durum pšenice procenjene su u ogledu po slučajnom blok sistemu u tri ponavljanja za tri vegetacione sezone (2008–2009; 2009–2010 i 2010–2011). Različiti indeksi suše kao što su tolerantnost (engl. *tolerance* [TOL]), srednja produktivnost (engl. *mean productivity* [MP]), srednji relativni učinak (engl. *mean relative performance* [MRP]), indeks osetljivosti na stres (eng. *stress susceptibility index* [SSI]), indeks promenjenog intenziteta stresa (engl. *modified severity stress index* [SSSI]), geometrijska srednja produktivnost (engl. *geometric mean productivity* [GMP]), indeks tolerantnosti na stres (engl. *stress tolerance index* [STI]), indeks stabilnosti prinosa (engl. *yield stability index* [YSI]), indeks relativne efikasnosti (engl. *relative efficiency index* [REI]) i indeks odgovora na sušu (engl. *drought response index* [DRI]) određeni su na osnovu prinosa u sušnim uslovima i u odsustvu suše. Ispitivani genotipovi su pokazali značajnu varijaciju u učinku i tolerisali su različite sušne uslove, koji se mogu iskoristiti u programu oplemenjivanja durum pšenice. Ispitivanje genotipova za tolerantnost na sušu u sredinama sa višom vrednošću intenziteta stresa (SI) biće efikasnije pri grupisanju indeksa i selekciji genotipova. Indeksi su bili klasifikovani u grupe (G1 i G2). Grupa G1, koja se sastojala od indeksa REI, STI, MRP, GMP, DRI i YSI istakla je genotipove sa višim prinosom pri različitim nivoima stresa izazvanog sušom. Oplemenjivačke linije durum pšenice brojeva 1, 11, 10, 13, 8, 9, i 12 bile su superiornije na osnovu grupe G1 i mogle bi se uzeti u obzir za dalju evaluaciju u sredinama izloženim suši.

**Ključne reči:** durum pšenica, indeksi tolerantnosti na sušu, intenzitet stresa.

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