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RESEARCH ARTICLE

# Genetic diversity evaluation for drought stress tolerance in bread and durum wheat genotypes using common and new drought tolerance indices

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**ABSTRACT:** To evaluate the genetic diversity and the effect of drought stress on grain yield of wheat, 56 wheat genotypes were evaluated for terminal drought stress tolerance in field environments in the Kermanshah of Iran during the 2010-2011 cropping season. The experiments were conducted at the Campus of Agriculture and Natural Resources, Razi University using alpha-lattice design with two replicates under two different water regimes included non-stress (normal irrigation at all stages of growth) and drought stress (end-season after flowering stage) conditions. Several new stress tolerance indices were evaluated. So that, ten drought tolerance indices including stress tolerance index (STI), relative drought index (RDI), yield index (YI), yield stability index (YSI), drought resistance index (DI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), sensitive drought index (SDI), modified stress tolerance index in normal irrigation ($K_1STI$), and modified stress tolerance index in stress irrigation ($K_2STI$) were calculated based on grain yield under drought (GYs) and irrigated (GYp) conditions. The result of analysis of variance indicated high significant differences among genotypes for grain yield trait. In general, terminal drought stress reduced 27.2% of grain yield. The Shiroudi, Rassoul, Darab-2, Marvdasht, Argh, and Shiraz genotypes which are high reduction of grain yield (61.1, 51.3, 48.4, 44.1, 43.1, and 43.0%, respectively) and also genotypes 318, Ghohar, 330, Mahdavi, and Alamout which are low reduction of grain yield with drought stress (4.1, 4.7, 7.0, 7.5, and 10.2%, respectively). Furthermore, results showed that wheat genotypes can be classified as normal and stress situations using cluster analysis. The correlation analysis among grain yield under non-stress and drought stress conditions with different drought tolerance indices showed that STI, YI, $K_1STI$, and $K_2STI$ indices were appropriate indicators to identify the high grain yield genotypes. Based on these indicators, Mughan-1, Golestan, Navid, 330, Darab-2, and Bahar genotypes had the highest grain yield under both experimental conditions. Therefore, these wheat genotypes are suitable for cultivation in Mediterranean regions that are constantly exposed to drought stress at the end of the growing season, and areas with similar climatic conditions. Also, they are recommended to be used as parents for the improvement of drought tolerance in other wheat genotypes.

**KEYWORDS**: Grain yield, Genetic variations, Water deficit stress, Wheat, Stress tolerance indices

## INTRODUCTION

Environmental stresses including abiotic and biotic stresses are the major constraints to food production in world. In between, drought stress is one of the most important abiotic stresses directly affecting crop production. In arid and semi-arid areas, drought stress is one of the most important production challenges for cereal [1]. The effects of drought stress on cereal depend on the capacity of genetic resistance of plant, intensity and continuity of drought stress, and stage of plant growth that experiences the water deficit [2]. It is a common

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constraint after anthesis/flowering and grain filling stages in many cereal crops of Mediterranean regions.

Among cereals, wheat (*Triticum aestivum* L.) is a major dietary source and provides more than 70% of daily calories to people of world, as well as it is widely cultivated in the majority of the world regions [3]. Furthermore, this plant is a major crop in global, and there is a dynamic commercial breeding industry producing new wheat genotypes for farmers. Despite the potential and multitude uses of wheat, however, the full genetic potential of the wheat cannot be harnessed particularly in arid and semi-arid areas because of limitations of water deficit. Improved different stress tolerance such as drought and/or water deficit stress in wheat genotypes is of increasing importance, but it is arduous to detect.

Genetic diversity can be estimated using cytogenetic characters and molecular markers [4, 5], in addition, physiological, morphological, and agricultural traits or grain yield can be used for this purpose [6, 7]. Evaluation of germplasm will be of great significance for selection of drought tolerant genotypes of wheat and for improving grain yield under water deficit. Drought stress indices that provide a measure of drought based on yield loss under drought situations in comparison to normal situations were used for screening genotypes of drought-tolerant. Fernandez [8] stated that the genotypes can be divided into four groups based on their yield response to stress situations: genotypes producing high yield under both drought stress and normal situations (group I), genotypes with high yield under normal (group II) or drought stress situations (group III) and genotypes with poor yield under both drought stress and normal situations (group IV). Several stress indices have been developed, aiming to assist identification and selection of stable, high-yielding, drought tolerant genotypes [8-10]. These indices are indicator for drought tolerance such as tolerance index (TOL), stress susceptibility index (SSI), harmonic productivity (HM), mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) which used in investigations. Stress tolerance index (STI) identified genotypes which produce high performance in both favorable and unfavorable water situations [11, 12]. It is generally presumed that good performance of genotypes under both irrigated and drought situations leads to high values of STI, MP, HM, GMP, and mean relative performance (MRP) and generally low values of TOL and SSI [13].

In addition to the common indicators, there are new indicators that can be used to identify resistant genotypes. Little information is available on the study of wheat genotypes using new indicators such as relative drought index (RDI), yield index (YI), yield stability index (YSI), drought resistance index (DI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), sensitive drought index (SDI), and modified stress tolerance index (MSTI). Therefore, the objectives of this study were (i) to selection drought tolerant wheat genotypes based on grain yield trait, (ii) to assess new stress tolerance indices in screening of tolerance wheat genotypes across multi-environments, and (iii) to investigate of relationships between tolerance indices and grain yield.

## MATERIALS AND METHODS

### Plant material, design and experimental site

Plant materials of this research comprised of 56 wheat genotypes with a wide range of genetic backgrounds (49 commercial bread cultivars released from 1930 to 2010, 4 superior elite lines and 3 durum cultivars) were which seeds of these wheat genotypes were obtained from Karaj Agricultural and Natural Resources Research and Education Center, Karaj, Iran. The names and codes of wheat genotypes are given in Supplementary File 1 (Table S1). This research was conducted during 2010-2011 cropping season at the research field of Campus of Agriculture and Natural Resources, Razi University, Kermanshah located on the western part of Iran (latitude 34° 21' N, longitude 47° 9' E, and altitude 1319 m above sea level) with 367 mm average annual precipitation at the cropping season of the experiment. More information of meteorological data such as monthly average minimum and maximum temperatures and rainfall are shown in Supplementary File 2 (Fig. S1). The soil texture at study site was clay with pH 7.4, soil organic matter 1.14%, total nitrogen 0.098%, available phosphorus 8.0 mg/kg and total exchangeable potassium 329 mg/kg.

Experimental layout design was based on an alpha-lattice (7×8; in each replicate, there were 7 incomplete blocks and in each incomplete block, there were 8 genotypes) with two replicates at two adjacent sites as control (normal; irrigation at all stages of growth based on plant needs and climatic conditions) and terminal drought stress. Terminal (end-season) drought stress was imposed after flowering stage on May 18, 2011 at stressed plots till physiological maturity. Meanwhile, non-stressed plots were irrigated thrice more. Seed sowing was done by hand on November 6, 2010 at five row plots, 4 m length, and

0.23 m row spacing as 400 seeds per square meter density. The land was left as fallow in the previous years, and nitrogen (N) fertilizer were added to the soil before planting (50 kg/ha urea) and at stem elongation stage (50 kg/ha urea), and no phosphorus (P) or potassium (K) was required in both sites (normal and terminal drought stress). Crop management practices such as weed control and plant nutrition were practiced as needed during the growing season. The herbicides and pesticides were not used at both sites.

### Determining grain yield

At physiological maturity stage, one square meter (each of 1m×1m) of each plot was harvested by hand to determine grain yield trait.

### Estimation of grain yield loss due to drought stress

The relative changes caused by drought stress on grain yield trait were calculated as follows:

Grain yield loss due to drought stress = [(Yp –Ys)/ Yp]×100

Where, Yp and Ys are grain yield of each genotype under normal and drought stress treatments, respectively [29, 42].

### Calculation of stress tolerance indices

Ten drought resistance indices including stress tolerance index (STI), relative drought index (RDI), yield index (YI), yield stability index (YSI), drought resistance index (DI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), sensitive drought index (SDI), modified stress tolerance index in normal irrigation ($K_1$STI), and modified stress tolerance index in stress irrigation ($K_2$STI) were calculated using the Supplementary File 1, Table S2 equations [8, 9, 10, 14, 15, 16, 17, 18, 19].

### Data analysis

All data collected were subjected to analysis of variance and the means were compared by LSD test at the $P < 0.05$ using SAS software version 9.1 [20]. The data were analyzed using SPSS software version 16.0 [21] for cluster analysis of wheat genotypes based on Square Euclidean distance. Pearson's correlation coefficient was calculated for each pair of traits, as well as drought stress tolerance indices using SAS software version 9.1. Excel software version 10.0 was used to draw figures.

## RESULTS

### Grain yield

Analysis of variance showed significant differences among wheat genotypes for grain yield and 10 stress tolerance indices. Ranges of variability and amount of mean for the different traits are presented in Table 1.

Yield performance of wheat genotypes in normal condition ranged from 0.419 to 0.760 kg/m$^2$ (with an average 0.544 kg/m$^2$), while under drought stress condition it varied from 0.187 to 0.542 kg/m$^2$ (with an average 0.396 kg/m$^2$) (Table 1). Our findings indicated that drought stress significantly reduced grain yield by 27.2% (Fig. 1 and Fig. 2). The interaction between genotypes and water regime conditions was significant for grain yield (Fig. 1). In among, bread wheat genotypes B3, B34, B22, B56, B21, and B9 had the highest decrease (61.1, 51.3, 48.4, 44.1, 43.1, and 43.0%, respectively) and genotypes B53, B39, B54, B20, and B6 had the lowest decrease of yield due to drought stress (4.1, 4.7, 7.0, 7.5, and 10.2%, respectively) (Fig. 2). Among durum wheat genotypes, genotype D48, in addition to having lower grain yield than D41 and D45 genotypes

**Table 1.** Minimum, maximum, mean, ranges and standard deviation for grain yield and 10 stress tolerance indices recorded over 56 wheat genotypes.

| Traits | Minimum | Maximum | Mean | ± Standard deviation (SD) | F-value |
|---|---|---|---|---|---|
| GYp (kg/m$^2$) | 0.419 | 0.760 | 0.544 | 0.079 | ** |
| GYs (kg/m$^2$) | 0.187 | 0.542 | 0.396 | 0.068 | * |
| STI | 0.305 | 1.275 | 0.733 | 0.191 | ** |
| RDI | 0.534 | 1.317 | 1.010 | 0.180 | ** |
| YI | 0.473 | 1.368 | 0.999 | 0.172 | ** |
| YSI | 0.389 | 0.959 | 0.735 | 0.131 | ** |
| DI | 0.184 | 1.273 | 0.750 | 0.226 | ** |
| ATI | 0.006 | 0.146 | 0.050 | 0.030 | ** |
| SSPI | 1.70 | 33.8 | 13.6 | 7.57 | ** |
| SDI | 0.041 | 0.611 | 0.265 | 0.131 | ** |
| $K_1$STI | 1.44 | 7.83 | 3.34 | 1.42 | ** |
| $K_2$STI | 0.51 | 7.11 | 3.37 | 1.40 | ** |

* and ** indicate significance at $P < 0.05$ and $P < 0.001$, respectively.

Grain yield potential (GYp), Grain yield stress (GYs), Stress tolerance index (STI), Relative drought index (RDI), Yield index (YI), Yield stability index (YSI), Drought resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive drought index (SDI), Modified stress tolerance index in normal irrigation ($K_1$STI), and Modified stress tolerance index in stress irrigation ($K_2$STI).

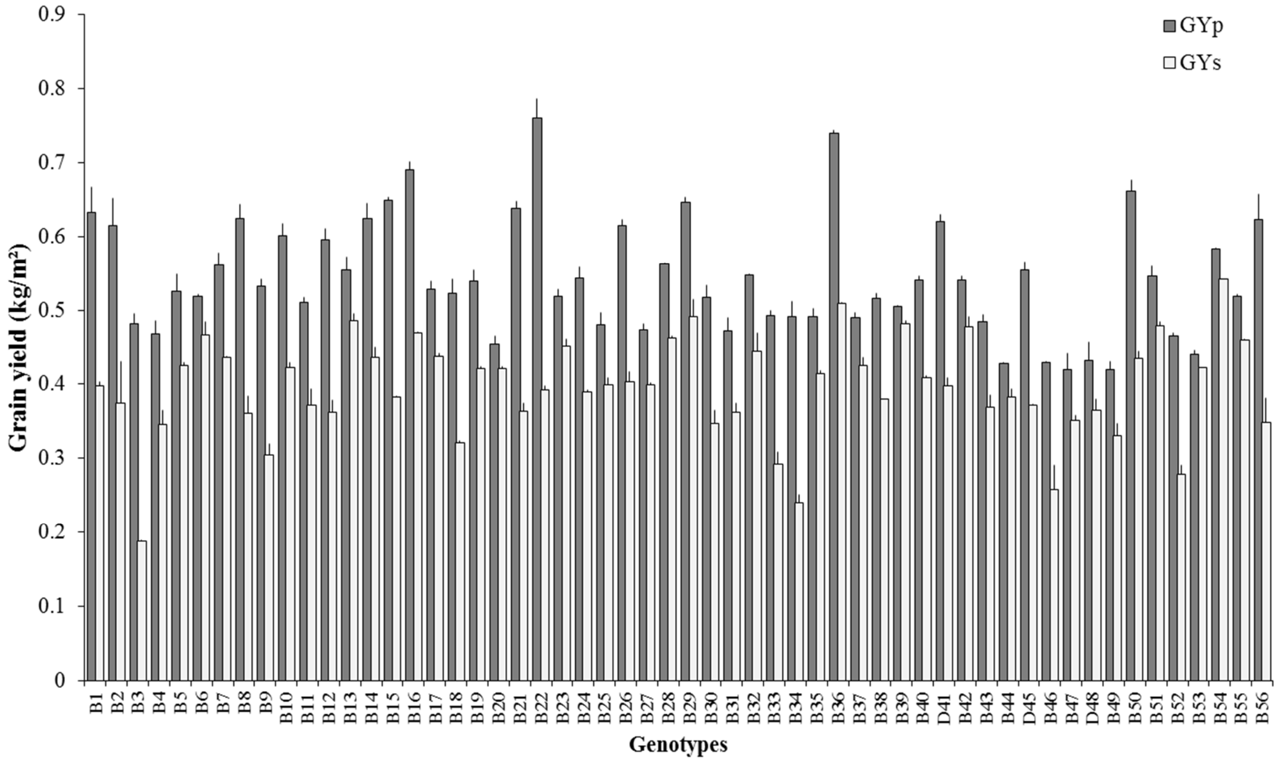


**Figure 1.** The amounts of yields in normal (grain yield potential, GYp) and drought (grain yield stress, GYs) conditions in 56 wheat genotypes. Vertical lines indicate standard error (SE). Numbers inside the figure are genotypes code (see Supplementary File 1, Table S1). Bread wheat (B) and Durum wheat (D).

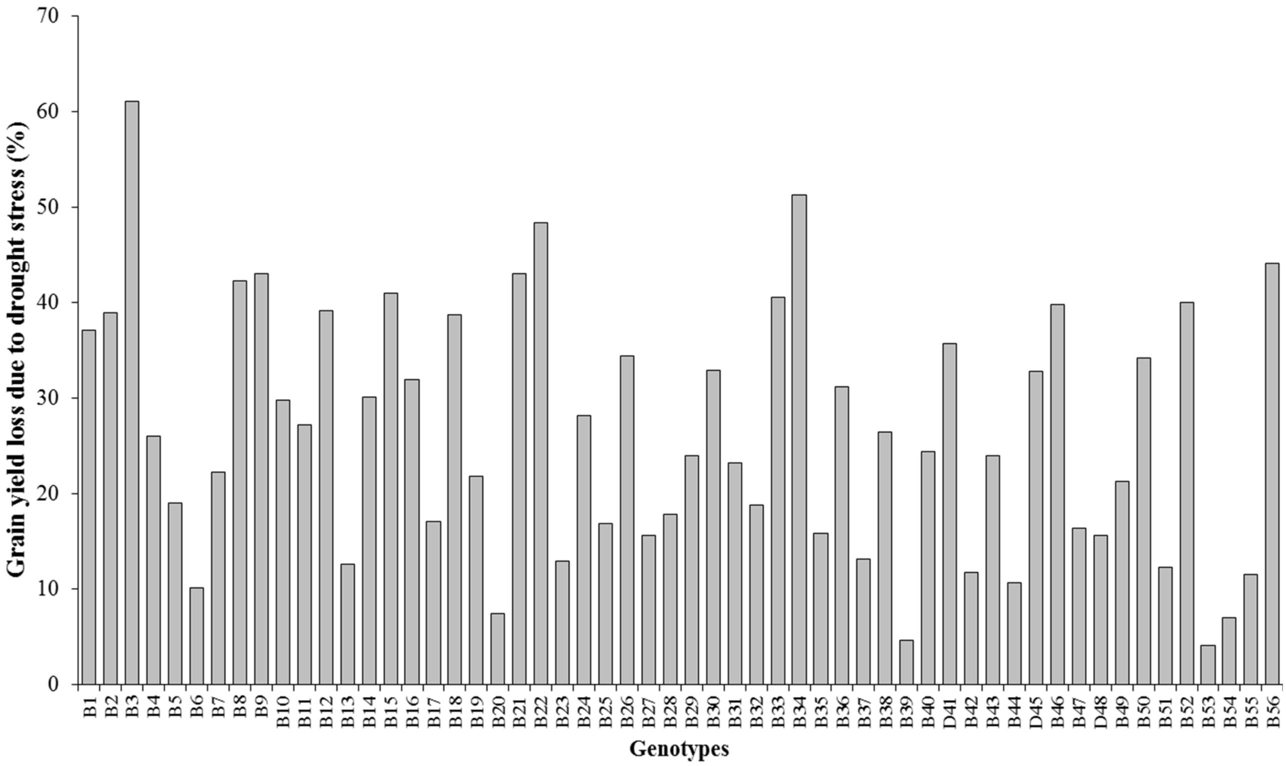


**Figure 2.** Percent of grain yield (GY) loss due to drought stress in 56 wheat genotypes. Numbers inside the figure are genotypes code (see Supplementary File 1, Table S1). Bread wheat (B) and Durum wheat (D).

**Table 2.** Pearson's correlation coefficients between drought stress tolerance indices and grain yield in normal and drought stress conditions.

| Traits | GYp | GYs | STI | RDI | YI | YSI | DI | ATI | SSPI | SDI | $K_1STI$ | $K_2STI$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GYp | 1 | | | | | | | | | | | |
| GYs | 0.38** | 1 | | | | | | | | | | |
| STI | 0.81** | 0.85** | 1 | | | | | | | | | |
| RDI | -0.40** | 0.69** | 0.20 | 1 | | | | | | | | |
| YI | 0.38** | 1.00** | 0.85** | 0.68** | 1 | | | | | | | |
| YSI | -0.40** | 0.69** | 0.20 | 1.00** | 0.68** | 1 | | | | | | |
| DI | -0.05 | 0.90** | 0.54** | 0.92** | 0.90** | 0.92** | 1 | | | | | |
| ATI | 0.83** | -0.19 | 0.35** | -0.82** | -0.19 | -0.82** | -0.59** | 1 | | | | |
| SSPI | 0.64** | -0.46** | 0.07 | -0.95** | -0.46** | -0.95** | -0.79** | 0.95** | 1 | | | |
| SDI | 0.40** | -0.69** | -0.20 | -1.00** | -0.68** | -1.00** | -0.92** | 0.82** | 0.95** | 1 | | |
| $K_1STI$ | 0.98** | 0.48** | 0.87** | -0.28* | 0.48** | -0.28* | 0.07 | 0.76** | 0.54** | 0.28* | 1 | |
| $K_2STI$ | 0.54** | 0.96** | 0.93** | 0.50** | 0.96** | 0.50** | 0.79** | -0.01 | -0.27* | -0.50** | 0.64** | 1 |

* and ** indicate significance at $P < 0.05$ and $P < 0.001$, respectively.

Grain yield potential (GYp), Grain yield stress (GYs), Stress tolerance index (STI), Relative drought index (RDI), Yield index (YI), Yield stability index (YSI), Drought resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive drought index (SDI), Modified stress tolerance index in normal irrigation ($K_1STI$), and Modified stress tolerance index in stress irrigation ($K_2STI$).

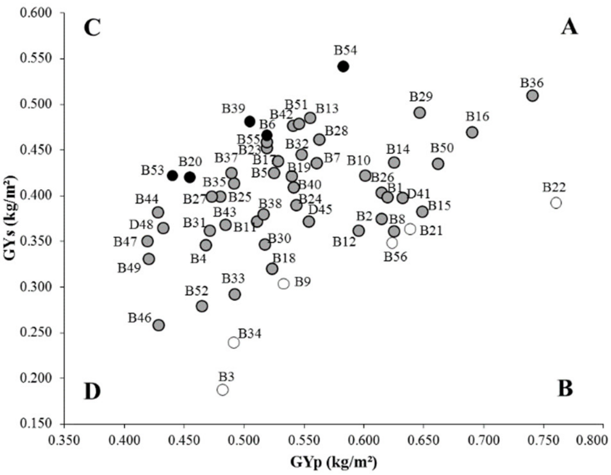


**Figure 3.** The relationship between grain yields produced under non-stress (GYp) and drought stress (GYs) environments in 56 wheat genotypes. The B3, B9, B21, B22, B34, and B56 genotypes which are high reduction of grain yield with drought stress (white circles) and the B6, B20, B39, B53, and B54 genotypes which are low reduction of grain yield with drought stress (black circles) and also the other genotypes used in this study (gray circles). Numbers inside the figure are genotypes code (see Supplementary File 1, Table S1). Bread wheat (B) and Durum wheat (D).

in both environmental conditions, also had the lowest decrease of grain yield with 15.6% due to drought stress. In the present study, we found that grain yield under non-stress conditions was significantly correlated with grain yield under drought stress conditions (Fig. 3 and Table 2). Genotype B36 followed by B29 and B16 genotypes had the highest grain yield under both conditions. Genotypes B46 and B52 had poor performance under non-stress and drought stress conditions, while genotype B3 was highly adapted to the non-stressed conditions. On the other hand, genotypes B20, B39, B53, and B54 had a similar response to drought-stress conditions. The biggest difference in yield performance under non-stress conditions was showed between B3, B34, and B22 genotypes (Fig. 1 and Fig. 3). These variations among genotypes for grain yield reflect their different genetic backgrounds.

## Stress tolerance indices

Results showed that genotypes differed significantly in drought stress tolerance indices (Fig. 4, Supplementary File 1, Tables S3, and S4). Taking into account of means comparison of stress tolerance indices, we identified the best wheat genotypes for each index (Fig. 4 and Table S3).

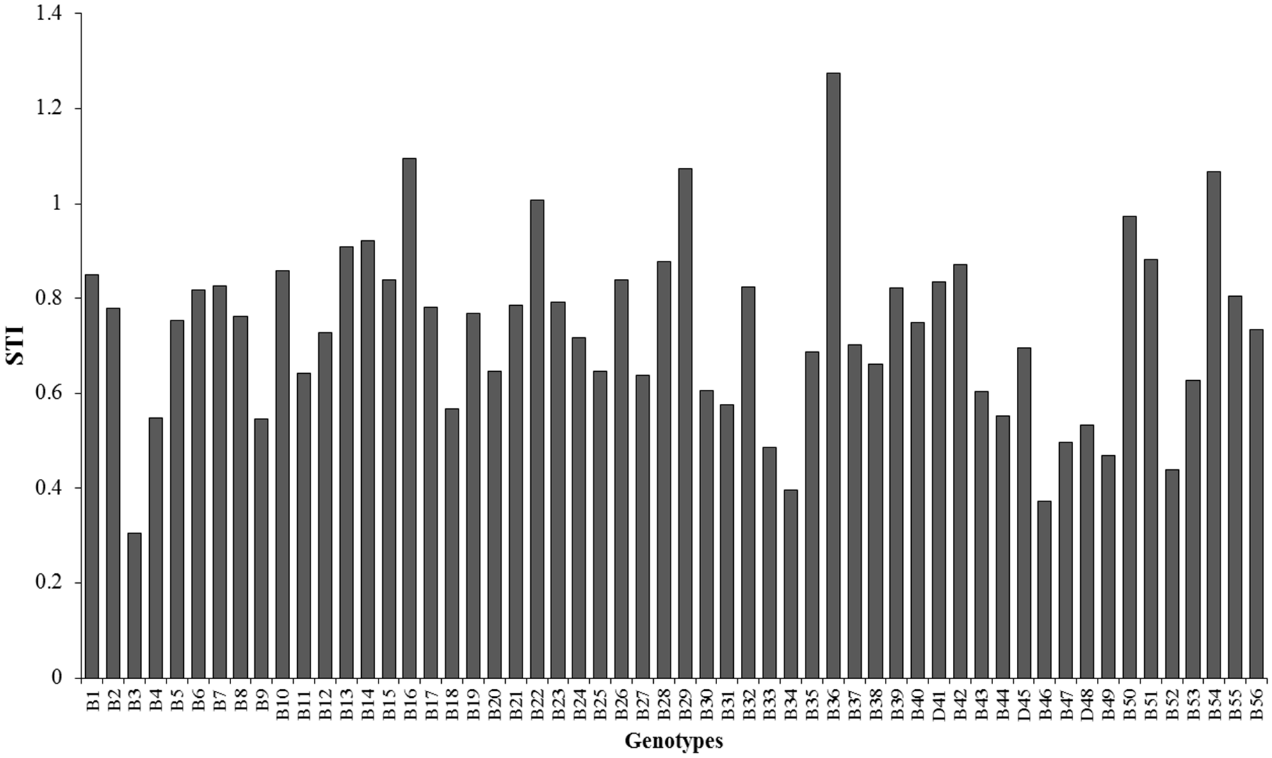


**Figure 4.** Stress tolerance index (STI) for 56 wheat genotypes. Numbers inside the figure are genotypes code (see Supplementary File 1, Table S1). Bread wheat (B) and Durum wheat (D).

For instance, stress tolerance index (STI) ranged from 0.305 to 1.275 with an average 0.733 (Table 1). A high value of STI implies higher tolerance of stress. The greatest amount of STI belonged to the B36, B16, B29, B54, and B22 bread wheat genotypes as well as greatest amount of this index belonged to the D41 durum wheat genotype (Fig. 4). Also, the highest relative drought index (RDI) and yield stability index (YSI) recorded for genotypes B53, B39, B54, B20, and B6 and were suggested as the most drought-tolerant genotypes under drought stress, but lowest these indexes recorded for genotypes B3, B34, B22, B56, and B21 (Table S3).

Of the 53 bread wheat genotypes used in this study, genotypes B3, B34, B46, B52, and B33 had the lowest values of yield index (YI), as well as genotypes B54, B36, B29, B13, and B39 had the highest values of this index (Table S3). Also, in the three durum wheat genotypes used in this research, genotypes D41 and D48 had the highest and lowest values of this index, respectively (Table S3). The genotypes with high value of YI will be suitable for stress condition.

Our results revealed that drought resistance index (DI) ranged from 0.184 to 1.273 (Table 1). Genotypes B54, B39, B13, B42, and B51 by 1.273, 1.159, 1.071, 1.062, and 1.061 had the highest and genotype B3 by less than 0.184 had the lowest DI, respectively (Tables S3 and S4). For abiotic tolerance index (ATI), the range was between 0.006 and 0.146 (Table 1). The highest ATI was obtained from genotypes B22, B36, B21, B15, and B56, by 0.146, 0.103, 0.096, 0.096, and 0.093, while the lowest was belonged to genotypes B53, B39, B20, B44, and B54 by 0.006, 0.008, 0.011, 0.013, and 0.017, respectively (Tables S3 and S4).

The genotypes with low values of stress susceptibility percentage index (SSPI) are more stable in two different (non-stress and drought stress) conditions. Maximum SSPI was obtained from genotypes B22, B3, B56, B21, and B15 by more than 24.4, while the minimum value was observed for genotypes B53, B39, B20, B54, and B44 by less than 4.2 (Tables S3 and S4).

A wide range of variation was observed for the other studied indexes which are presented in Table S3. For example, sensitive drought index (SDI) ranged from 0.041 to 0.611 which was recorded for genotypes B53 and B3, respectively (Table 1, Tables S3 and S4).

Regarding to the drought tolerance indices data manifested in Table 1, the obtained results of the $K_1STI$ ranged from 1.44 to 7.83 (Table 1). Genotypes B36, B22, B16, B50, and B29 by 7.83, 7.61, 6.31, 5.49, and 5.43 had the highest and genotypes B46, B49, B47, and B44 (bread wheats) and D48 (durum wheat) by less than 1.70 had the lowest $K_1STI$, respectively (Tables S3 and S4).

The $K_2STI$ ranged from 0.51 to 7.11 which were recorded for bread wheat genotypes B3 and B54, respectively (Table 1 and Table S3). Maximum $K_2STI$ was obtained from genotypes B54, B36, B29, B16, and B13 by more than 5.28, while the minimum value was observed for genotypes B3, B34, B46, B52, and B33 by less than 1.45 (Tables S3 and S4).

### Correlation analysis

Simple correlation coefficient analysis also revealed the existence of significant positive or negative correlations among grain yield under normal and drought stress conditions and 10 stress tolerance indices (Table 2).

High positive significant correlations were observed between grain yield with these traits, GYs, STI, YI, ATI, SSPI, SDI, $K_1STI$, and $K_2STI$ under normal conditions (Table 2). But, in this condition, negative significant correlations were observed between grain yield with RDI ($r = –0.40$, $P < 0.001$) and YSI ($r = –0.40$, $P < 0.001$) indexes.

On the other hand, high positive significant correlations were observed between grain yield with these traits, GYp, STI, RDI, YI, YSI, DI, K1STI, and K2STI under drought stress conditions (Table 2). However, negative significant correlations were observed between grain yield with SSPI ($r = –0.46$, $P < 0.001$) and SDI ($r = –0.69$, $P < 0.001$) in drought stress environments (Table 2).

According to our data, grain yield in drought stress (GYs) and non-stress (GYp) conditions were significantly and positively correlated with SSTI, YI, K1STI, and K2STI (Table 2). Therefore, the above indicators are suitable for evaluating genotypes.

It was found a strong and positive correlation ($P < 0.001$) of relative drought index (RDI) with all indices, except GYp, ATI, SSPI, SDI, and $K_1STI$ (Table 2).

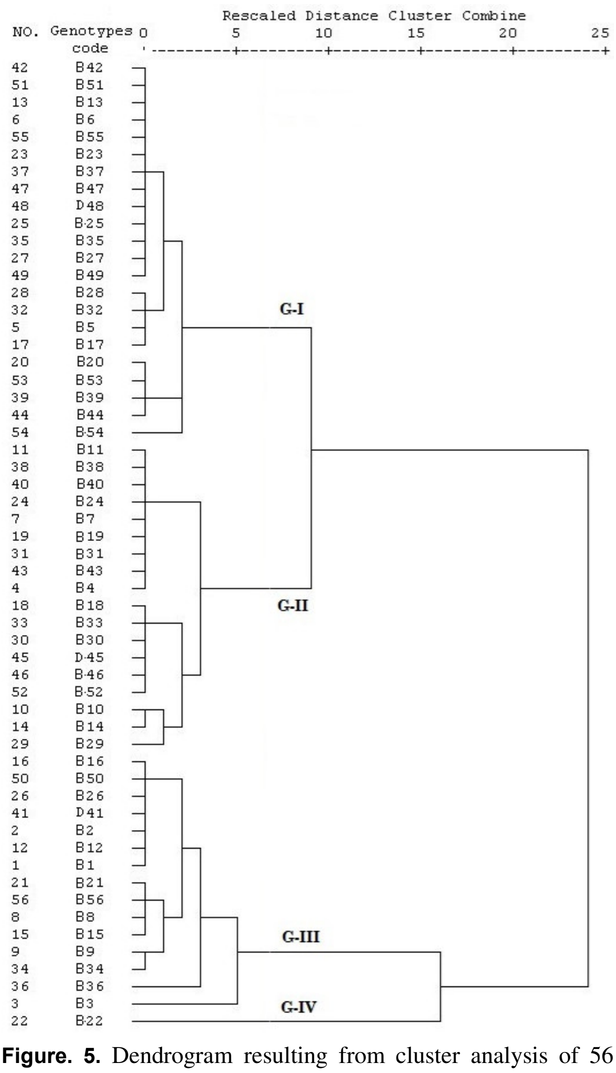


**Figure. 5.** Dendrogram resulting from cluster analysis of 56 wheat genotypes based on STI, RDI, YI, YSI, DI, ATI, SSPI, SDI, $K_1STI$, and $K_2STI$ indices for grain yield in normal (GYp) and drought stress (GYs) conditions. Numbers inside the figure are genotypes code (see Supplementary File 1, Table S1). Bread wheat (B) and Durum wheat (D).

### Cluster analysis

The grain yield and 10 stress tolerance indices cluster analysis divided the wheat genotypes into four main groups (Fig. 5). The first cluster (G-I) with 22 genotypes had the largest number of genotypes, and genotypes in this cluster had high grain yield both under non-stressed and drought stressed conditions and had the highest value of STI, RDI, YI, YSI, and DI, while lower values of ATI, SSPI, and SDI. On the other hand, 18 genotypes were located in second cluster (G-II). These genotypes had average value of the most traits. The third cluster (G-III) included 15 genotypes which had highest reduction of grain yield with drought stress as well as the highest SDI and had lowest STI, RDI, YI, YSI, and DI. The cluster constituted those genotypes characterized by overall inferior yield. The fourth cluster (G-IV) included 1 wheat genotype. The fourth cluster had the lowest number of genotypes and was characterized by high and medium grain yield under normal and drought stress conditions, respectively. This cluster also showed higher values of STI, while lowest values of mean ATI, SSPI, SDI, and $K_1STI$.

## DISCUSSION

Drought stress due to low ambient water is a serious threat to crop production such as wheat worldwide especially at arid and semi-arid regions (such as Iran). This study was carried out to assess the effect of drought stress on wheat yield grain and to better understand and identification of resistant wheat genotypes was using new stress tolerance indicators. This study confirmed that drought stress after flowering stage reduced grain yield in all tested wheat genotypes and under drought stress the main grain yield declined by 27.2% across all wheat genotypes than the control condition (Fig. S1). Also, highly significant differences were found for yield in the genotypes under non-stress and drought stress conditions (Fig. S1 and Fig. 1). In general, in this study, bread wheat genotypes (mean yield of 53 genotypes) had a relative superiority of yield over durum wheat genotypes (mean yield of 3 genotypes). So that, bread wheat and durum wheat had a yield drop of about 26.4% and 28.1% due to drought stress. According to a survey, drought reducing more than 50% of average yields for most major crops at arid and semi-arid regions [22]. The reason for lower grain yield under water deficit condition was mainly due to a reduction in 1000-grains weight, number of grain per spike and number of spike per area [6, 23-25]. In wheat, negative effects of drought stress on yield and performance components had been reported by many researchers [26, 27]. On the other hand, drought stress at the stage of flowering and grain filling led to shorten the filling period, which eventually leads to loss of grain weight. It is stated that the grain filling rate is increased under drought stress compared to normal conditions, but this increase does not completely compensate for diminution in the length of grain filling period [28]. Another factor in declining performance under drought stress is the reduction of physiological and biochemical traits [29].

Knowledge of genetic variation and genetic relationships between genotypes are crucial for wheat performance improvement. In this research, wheat genotypes responded to drought stress differently. So that, bread genotypes B36, B16, B29, and B50 were the most productive in both environments, thus these genotypes stayed into group A. Also, the B22, B21, and B15 bread genotypes were the high yield response in non-stress (normal) environments, therefore these genotypes stayed into group B. Furthermore, genotypes B54, B39, and B6 were the most productive in drought stress situation, hence these genotypes stayed into group C. Moreover, the B3, B34, B33, B46, and B52 genotypes were the low yield performance in both conditions, so these genotypes stayed into group D (Fig. 3). Fernandez [8] stated that genotypes can be divided in to four groups according to their performance in non-stress and drought stress situations.

Drought stress is the most significant environmental calamity on wheat in world and hence identifies resistant genotypes and improving yield under drought stress is a major goal of plant breeding. In this study, drought tolerance indices were calculated on the basis of grain yield of the 56 wheat genotypes. Selection of wheat genotypes with better adaptation to drought stress should increase the productivity of wheat [30]. Fernandez [8] defined a stress tolerance index (STI) which can be used to identify genotypes that produce high yield under both stress and non-stress situations. A high STI amount indicates higher stress tolerance and high yield potential [31]. The highest value of STI was observed for B36, B16, B29, B54, and B22 bread wheat genotypes and D41 durum wheat genotype (Fig. 4). Thus, they were identified as the most stable and productive genotypes among the cultivated genotypes under both environmental conditions. In fact, the tolerance of different genotypes was because of their physiological and biochemical properties and ability to control water loss in drought stress situations. Abdoli and Saeidi [32] and Esmaeilpour et al. [33] proposed that STI can be used to identify wheat genotypes that produce high yield under both non-stress and drought stress environments. Several studies also showed a high and positive correlation between STI and GY [6, 12, 13, 34].

The genotypes with high values of yield index (YI) found suitable for drought stress conditions [35]. Based on this, the genotypes B54, B36, B29, B13, and B39 (bread wheats) and D41 (durum wheat) are suitable for drought stress environments. It is generally presumed that good yield under both normal and drought stress conditions leads to high values of STI, YSI, and YI. In this study significant differences were found amongst the wheat genotypes for YSI and RDI. Finding of this experiment showed that the genotype B53 had the highest YSI and RDI followed by B39, B54, B20, and B6 exhibited stability to stress while, genotype B3 followed by B34, B22, B56, and B21 had lower values these indexes (Tables S3 and S4). Yield stability index (YSI) evaluates the grain yield under stress condition of a genotype relative to its non-stress yield, hence the wheat genotypes with a high YSI are expected to have high grain yield under both stress and non-stress conditions. Whereas, Mohammadi et al. [36] reported that the genotypes with high YSI is expected to have high grain yield under stress, but low grain yield under non-stress situations. Lan [17] defined a new drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both non-stress and stress environments. Based on this index, genotypes B54, B39, B13, B42, and B51 were superior to other genotypes. Significant differences among the tested wheat genotypes for ATI, SSPI, SDI, $K_1$STI, and $K_2$STI indexes were found (Table S3). In our study, the estimates of ATI, SSPI, and SDI indices revealed that the genotypes B22, B56, B21, B15, and B3 had the highest and the genotypes B53, B39, B20, B54, and B44 had the lowest this indexes values (Tables S3 and S4). Furthermore, genotypes B36, B22, B16, B50, and B29 scored the highest values for $K_1$STI indicator and the opposite was true in case of the B54, B36, B29, B16, and B13 genotypes for $K_2$STI. In terms of both indices ($K_1$STI and $K_2$STI), genotype D41 was superior to the other two durum genotypes. Farshadfar and Sutka [10] stated that the $K_1$STI and $K_2$STI are the optimal selection indices for stress and non-stress environments, respectively. Large differences in stress tolerance were seen in the genotypes, and certain genotypes are recommended as candidates for further investigation. These results were in agreement with those of Amiri et al. [26] and Saeidi et al. [6].

The correlation analysis among grain yield under non-stress and drought stress conditions with different drought tolerance indices showed that STI, YI, $K_1$STI, and $K_2$STI indices were appropriate indicators to identify the high grain yield genotypes (Table 2). On the basis of these indicators, B36, B29, B16, B54, B22, and B13 genotypes had the highest grain yield under both experimental conditions. In this case, Khalili et al. [37] reported that these indices of stress tolerance such as $K_1$STI, $K_2$STI, SSPI, RDI, and DI can be used as the most suitable indicators for screening drought tolerant canola cultivars. Similar results reported by Akta [38] indicated that STI, GMP, MP, HM, YSI, and YI indexes were suitable drought indices to identify wheat producing high performance in stress and non-stress environments. In other research, Amiri et al. [26] reported that the positive and significant correlation was observed between grain yield in both non-stress and stress conditions with MP, GMP, STI, YI, HM, SDI, $K_1$STI, and $K_2$STI indicated that these indices are the most suitable indices to screen bread wheat genotypes in drought stress environments.

Cluster analysis based on grain yield under non-stressed and drought stressed environments and new drought tolerance indices were classified into four clusters (Fig. 5). Clusters I, II, III, and IV with 22, 18, 15, and 1 wheat genotypes encompassed 39.9, 32.1, 26.8, and 1.8% of the wheat genotypes, respectively. Cluster analysis has been widely used for description of diversity of genetic and grouping based on similar attributes [39]. In this study, genotypes in cluster I was superior to grand mean of indexes averaged over all clusters, indicating that this cluster contained desirable genotypes according to yield obtained from both situations and selection indices (such as B6, B13, B20, B39, B53, and B54 bread wheat genotypes and also durum genotype of D48 was included in this group). But cluster III constituted genotypes characterized by overall inferior yield (such as bread wheat genotypes B3, B9, B21, B34, and B56 and also D41 durum wheat genotype). This study is in aligned with previous studies that genotypes can be classified adapted to normal and stress situations using cluster analysis in different crops such as safflower [40], sorghum [13, 41], rice [34], barley [42, 43] etc.

## CONCLUSION

Based on the results of this study, grain yield was significantly decreased by drought stress after flowering in durum and bread wheat. Also, high genetic diversity was found among 56 wheat genotypes for grain yield as well as new stress tolerance indices. However, generally bread wheat had the higher grain yield and common and new drought tolerance indices than durum wheats. The results suggest that the STI, YI, $K_1$STI, and $K_2$STI indices are to identify drought sensitive and tolerant genotypes, and these indices are an effective selection criterion for high yielding genotypes with stable yield under variable environmental conditions. Furthermore, results showed that genotypes can be classified adapted to normal and stress situations using cluster analysis. The cluster analysis indicated that bread and durum wheat genotypes could be clustered into four major groups, with group I being, in general, drought sensitive, group II being slightly-medium drought tolerant, group III being highly drought tolerant, group IV being highly drought sensitive. According to all statistical procedures, bread wheat genotypes Alamout, Bahar, Navid, Mahdavi, Darab-2, Golestan, Mughan-1, Ghohar, 318, and 330 as well as durum wheat genotype Seimareh were known as superior genotypes under both stressed and non-stressed conditions with high stability to drought stress. The potential of these wheat genotypes offers further opportunities for analysis at the molecular and cellular levels to confront with drought stress through a physiological mechanism.

## ABBREVIATIONS

Nitrogen (N), Phosphorus (P), Potassium (K), 1000-grains weight (TGW), Grain yield (GY), Grain yield potential (GYp), Grain yield stress (GYs), Tolerance index (TOL), Stress susceptibility index (SSI), Mean productivity (MP), Geometric mean productivity (GMP), Harmonic productivity (HM), Mean relative performance (MRP), Stress tolerance index (STI), Relative drought index (RDI), Yield index (YI), Yield stability index (YSI), Drought resistance index (DI), Abiotic tolerance index (ATI), Stress susceptibility percentage index (SSPI), Sensitive drought index (SDI), Modified stress tolerance index (MSTI), Modified stress tolerance index in normal irrigation ($K_1$STI), Modified stress tolerance index in stress irrigation ($K_2$STI).

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# ارزیابی تنوع ژنتیکی تحمل به تنش خشکی در ژنوتیپ‌های گندم نان و دوروم با استفاده از شاخص‌های متداول و جدید تحمل به خشکی

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## چکیده

به منظور ارزیابی تنوع ژنتیکی و تأثیر تنش خشکی بر عملکرد دانه گندم، ۵۶ ژنوتیپ گندم از نظر تحمل به تنش خشکی انتهای فصل در شرایط مزرعه‌ای در کرمانشاه طی فصل زراعی ۹۰-۱۳۸۹ مورد ارزیابی قرار گرفتند. این آزمایش در پردیس کشاورزی و منابع طبیعی دانشگاه رازی با استفاده از طرح آلفا-لاتیس با دو تکرار در دو رژیم مختلف آبی شامل بدون تنش (آبیاری نرمال در تمام مراحل رشد) و تنش خشکی (انتهای فصل پس از گلدهی) انجام شد. چندین شاخص جدید تحمل به تنش مورد ارزیابی قرار گرفتند. به طوری که ۱۰ شاخص تحمل به خشکی شامل شاخص تحمل تنش (STI)، شاخص خشکی نسبی (RDI)، شاخص عملکرد (YI)، شاخص پایداری عملکرد (YSI)، شاخص مقاومت به خشکی (DI)، شاخص تحمل غیرزنده (ATI)، شاخص درصد حساسیت به تنش (SSPI)، شاخص حساسیت به خشکی (SDI)، شاخص تحمل تنش اصلاح شده در آبیاری نرمال ($K_1STI$) و شاخص تحمل تنش اصلاح شده در تنش ($K_2STI$) بر اساس عملکرد دانه در شرایط تنش (GYs) و آبیاری (GYp) برآورد شدند. نتایج تجزیه واریانس نشان داد که اختلاف معنی‌داری بین ژنوتیپ‌ها از نظر صفت عملکرد دانه وجود دارد. به طور کلی، تنش خشکی انتهای فصل سبب کاهش ۲۷/۲ درصدی عملکرد دانه شد. ژنوتیپ‌های شیرودی، رسول، داراب-۲، مرودشت، ارگ و شیراز بیشترین کاهش عملکرد دانه (۶۱/۱، ۵۱/۳، ۴۸/۴، ۴۴/۱، ۴۳/۱ و ۴۳/۰ درصد) و همچنین ژنوتیپ‌های ۳۱۸، گوهر، ۳۳۰، مهدوی و الموت کمترین کاهش عملکرد دانه (۴/۱، ۴/۷، ۷/۰، ۷/۵ و ۱۰/۲ درصد) را در اثر تنش خشکی داشتند. بعلاوه، نتایج نشان داد که می‌توان ژنوتیپ‌های گندم را با استفاده از تجزیه و تحلیل خوشه‌ای در شرایط نرمال و تنش طبقه‌بندی کرد. تجزیه و تحلیل همبستگی بین عملکرد دانه در شرایط بدون تنش و تنش خشکی با شاخص‌های مختلف تحمل به خشکی نشان داد که شاخص‌های STI، YI، $K_1STI$ و $K_2STI$ شاخص‌های مناسبی برای شناسایی ژنوتیپ‌های با عملکرد دانه بالا بودند. بر اساس این شاخص‌ها، ژنوتیپ‌های مغان-۱، گلستان، نوید، ۳۳۰، داراب-۲ و بهار در هر دو شرایط آزمایشی بیشترین عملکرد دانه را داشتند. بنابراین، این ژنوتیپ‌های گندم برای کشت در مناطق مدیترانه‌ای که در پایان فصل رشد دائماً با تنش خشکی مواجه هستند و در مناطقی با شرایط آب و هوایی مشابه، مناسب هستند. همچنین، توصیه می‌شود از آنها بعنوان والدین برای بهبود تحمل به خشکی در سایر ژنوتیپ‌های گندم استفاده شود.

**کلمات کلیدی:** عملکرد دانه، تنوع ژنتیکی، تنش کمبود آب، گندم، شاخص‌های تحمل تنش