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An Evaluation of Drought Tolerant Genotypes in Bread Wheat (*Triticum aestivum* L.*)* Genotypes Using Morpho-Physiological Traits and Yield Based Selection Indices

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ABSTRACT

This study aimed to evaluate the drought tolerance of fifteen bread wheat genotypes using various morpho-physiological traits, including flag leaf length (FL), flag leaf width (FW), relative water content (RWC), excised leaf water retention (ELWR), rate of water loss (RWL), leaf water content (LWC), grain yield, and biological yield. Eight drought tolerance indices were used to assess the level of sensitivity of bread wheat genotypes to drought stress, including yield stability index (YSI), yield index (YI), stress tolerance index (STI), geometric mean productivity (GMP), stress susceptibility index (SSI), mean productivity (MP), stress tolerance (TOL), and harmonic mean (HM). The STI, MP, and GMP indices were significantly and positively correlated with yield under rain-fed and irrigated conditions (0.66 to 0.90); and hence, they were identified as the best selection indices for distinguishing drought tolerance. Based on biplot analysis, Sepahan and Rowshan were superior varieties under rain-fed and irrigated conditions, making them recommendable for cultivation for their stable yield. In addition, these two genotypes had the least yield reduction (141 to 147g/m^2) between two environments.

Keywords: Bread wheat, drought tolerance, indices, principle component.

INTRODUCTION

Environmental stresses (biotic and abiotic) represent a major constraint to food production, because it limits crop yields and restricts the use of cultivated lands (Huang, 2000). Drought stress is the most prevalent environmental factor limiting crop productivity, and global climate change is increasing the frequency of severe drought conditions (Dai, 2012). From a meteorological point view, drought could be defined as the absence of adequate moisture for a plant to grow normally (Bhargava and Sawant, 2013). Improvement of crop yield under drought stress as well as normal conditions is essential for the food security of the growing global population (Basu *et al.*, 2016). Plant responses to different stresses are highly complex (Basu *et al.*, 2016) and their response to stress is related to the environmental conditions encountered (Huang, 2000).

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops grown worldwide, where it is often subjected to extreme environmental stresses that affects its yield (Li *et al.*, 2011). Improving drought tolerance of wheat is a main goal for plant breeding (Gavuzzi *et al.*, 1997; El- Rawy and Hassan, 2014). Drought stress has become an increasingly important constraint in semi-arid regions of Asia, especially the Middle East region, where wheat is exposed to drought

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at different stages of plant development (Golabadi *et al*., 2006). In Iran, the mean of wheat production is about 12.5 million tones that are harvested from 6 million hectare area (FAO, 2016). In the central and Western regions of Iran, drought stress often reduces crop yield (Golabadi *et al*., 2006, Sio- Se Marde *et al*., 2006). In general, environmental changes in arid and semi-arid regions are variable, which makes the ability of a genotype to produce high and stable yield crucial (Rashid *et al*., 2003). On the other hand, crop sensitivity to drought is influenced by the time, intensity, duration, and frequency of the stress (Clarke *et al*., 1992; Bhargava and Sawant, 2013). The basis of drought tolerance is complex, which includes diverse drought-adaptive mechanisms (Huang, 2000; Dai, 2012; Bhargava and Sawant, 2013) and involves interactions of many metabolic pathways related to stress tolerance genes (Blum, 2011).Therefore, the genotype and environment interaction is considerable for selecting suitable genotypes for cultivation in different environments (Mitra, 2001; Blum, 2011). The standard assay procedures will be the most effective strategies for the selection of drought-tolerance genotypes (Manette *et al*., 1988; Khakwani *et al*., 2011). The identification the genotypes with high potential yield under stress conditions is one of the main tasks of plant breeders (Clarke *et al*., 1992; Abdolshahi *et al*., 2012). Drought tolerance indices based on grain yield could be used as measureable indicator to identify drought tolerant genotypes (Geravandi *et al*., 2011; El- Rawy and Hassan, 2014). The optimum selection index should distinguish genotypes displaying the minimum yield loss under drought and, consequently, the most stable genotypes that perform well under stress and non-stress conditions and vice versa (Fernandez, 1992). To differentiate stress-tolerant cultivars, several selection indices (described in material and methods) have been suggested on the basis of mathematical relationships between stress and non-stress conditions (Huang, 2000, Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Huang, 2000, Sio- Se Mardeh *et al*., 2006; Drikvand *et al*., 2012). Among these, the selection indices of mean productivity (MP), geometric mean productivity (GMP), and stress tolerance index (STI) were found to be the most suitable for screening genotypes with high yield stability (Farshadfar and Shutka, 2003; Golabadi *et al*., 2006; Sio- Se- Marde *et al*., 2006). Khakwani *et al.* (2011) and Ilker *et al.* (2006) concluded that MP, GMP, and STI indices were convenient to select high yielding genotypes under stress and non-stress conditions; however, tolerance index (TOL) and stress susceptibility index (SSI) were better indices to determine tolerance levels in wheat.

Understanding the physiological basis of drought stress tolerance in plants is vital for the improvement of drought tolerance genotypes (Sheron *et al*., 1986; Rashid *et al*., 2003). Lonbani and Arzani (2011) reported that physiological traits could be exploited as an indirect selection under drought. Such secondary traits should be positively correlated with yield under stress, more stable in expression, cheaper to score (Gavuzzi *et al*., 1997; Ilker *et al*., 2011). The high RWC and rate of water loss (RWL) have been suggested as important indicators of water status under drought (Gunes *et al*., 2008). The objectives of the present study were to: 1) assess the effectiveness of selection indices, including Morpho-physiological traits as indicators of drought tolerance in bread wheat, and 2) identify high-yielding wheat drought tolerant genotypes for wheat breeding programs.

MATERIALS AND METHODS

The field experiment was conducted in 2013-2014 cropping season at the Research Field of Islamic Azad University (Isfahan Branch) located in central Iran (51º36' longitude and 32º 63' latitude). The annual rainfall and temperature was 120 mm and 16°C, respectively at this location. Fifteen Iranian bread wheat genotypes (*Triticum aestivum* L.), including Pishtaz, Arvand, Qods, Sivand, Behrang, Bahar, Sepahan, Roshan, Sardari, Mahdavi, Chamran, Aflak, Kavir, Falat, and one genotype of triticale were evaluated. Triticale was used as a tolerant to different types of marginal soils and environments (Ammar, 2004). These cultivars were released in Seed and Plant Improvement Institute (Karaj, Iran) and also in the Agricultural Research Center of Isfahan, Iran. On the other hand, these cultivars are sown in many parts of Iran. All genotypes were spring wheat and suitable for planting in temperate area. The land for the experiment was deeply plowed for two times, using disk plough followed by furrowing. Fertilizers were applied before sowing (50 kg ha^{-1} P_2O_5) and at tillering (40kg ha^{-1} N). The soil type of the surface layer was silty clay loam (0–20cm) containing 0.62% organic matter with pH 7.78. The plot area was $4m^2$ (4m×1m). Each plot consisted of five rows with a distance of 20cm between rows and 5cm within rows. The experiment was carried as Completely Randomized Block Design (CRBD) with three replications in separate conditions (normal and drought). The genotypes were grown under two moisture regimes of irrigation after 70mm evaporation from A Pan corresponding to a soil water potential of –0.5MPa (non-stress), and irrigation after 130mm evaporation from class A Pan corresponding to a soil water potential of –1.2 MPa (water stress). The moisture treatments were performed from the heading stage to physiological maturity. There was no rainfall in drought stress period. Different traits, such as physiological traits, stress indices, grain yield (was measured in maturity stage based on g/m^2), biological yield (was measured in maturity stage based on total shoot dry mater g/m^2), and length and width of flag leaf were examined (from base to tip of leaf and the withiest part of leaf (cm), respectively).

Physiological traits

Water-related variables were recorded at anthesis stage. Ten plants were randomly selected from each plot and the water-related parameters were described.

1-Relative water content (RWC) was calculated as (FW-DW) × 100%/ (TW- DW)} (Ritchie *et al*., 1990). The flag leaves were cut into two (cm) pieces and weighed (Fresh Weight = FW). The leaf pieces were then placed in distilled water for 4 hours and re-weighed to obtain Turgor Weight (TW). The leaf pieces were oven dried, weighed, and used as Dried Weight (DW).

2- Leaf water content (LWC) is an important parameter for evaluating crop health and predicting crop yield. This parameter was calculated according to the formulae: [FW-DW/DW× 100] (Ramirez and Kelly, 1998).

3- Excised leaf water retention (ELWR): The youngest leaves before anthesis stage were collected and weighed (FW), left for 4h, then wilted at 25°C and reweighed (WW4h). ELWR was calculated using the following formula: ELWR (%) = [1 – (FW –WW4h) /FW)] × 100 (Clarke *et al*., 1992).

4- Relative water loss (RWL) was determined according to Gavuzzi *et al.* (1997). Ten young fully expanded leaves were sampled for each of the three replications at anthesis stage. The leaf samples were weighed (FW), wilted for 4hours at 35°C, reweighed (WW4h), and oven dried for 24h at 72°C to obtain dry weight (DW). Then, RWL (%) was calculated using the following formula: RWL (%) = [(FM - WW4h)/(FW - DW)] × 100.

Selection indices based on grain yield

Different drought tolerance/susceptibility indices were calculated for each genotype. Rosielle and Hamblin (1981) defined stress tolerance index (TOL) as a difference in mean yield between the stress (Ys) and non-stress (Yp) environments for every genotype as follows:

$$TOL = Y_P - Y_S$$

The Mean Productivity (MP) is described as the average yield of Ys and Yp according to: $MP = (Yp + Ys)/2$, Where, Y_S and Yp are considered as the yield of every genotype under stress and normal conditions.

The Yield Index (YI) and Yield Stability Index (YSI) were calculated according to Bouslama and Schapaugh (1984), where $\overline{Y}_s$ and $\overline{Y}_P$ are the mean yield of all genotypes under drought (stress) and normal (potential) conditions, respectively.

$$Y_I = Y_s - \overline{Y}_s \quad \text{and} \quad Y_{SI} = Y_s / Y_P$$

Fischer and Maurer (1978) proposed a Stress Susceptibility Index (SSI) for genotypes as $SSI = [1-(Ys)/(Yp)]/SI$ that stress index (SI) was calculated according to:

$SI = [1-(\overline{Y}s)/(\overline{Y}p)]$ (Fischer and Maurer, 1978)

Fernandez (1992) introduced a Stress Tolerance Index (STI) that was calculated according to the following formulae:

$$STI = [(Yp)\times(Ys)/(\overline{Y}p)^2]$$

Geometric Mean Productivity (GMP) is the other yield-based estimate frequently used by breeders for drought-tolerance screening (Ramirez and Kelly, 1998):

$$GMP = \sqrt{Ys \times Yp}$$

It is often used by breeders interested in relative performance, since drought stress can vary in severity in field environment over the years. The selection index of HM (harmonic mean) was calculated by the following formulae (Kristin *et al*., 1997):

HM = 2 (Yp ×Ys) / (Yp + Ys)

Statistical analysis

The data were subjected to analyses of variances (ANOVA), using SAS computer package (SAS Institute, 2003). Mean comparisons were conducted using Fisher's (protected) least significant differences (LSD) at $p \leq 0.05$.

Correlation coefficient was performed between grain yield and susceptible and tolerance indices based on Pierson procedure. Finally, Biplot based on the first two principal component axes (PC1 and PC2), both drought indices, and bread wheat genotypes was done by SAS software so that the selection of suitable genotypes based on susceptible and tolerance indices can be done.

RESULTS AND DISCUSSION

Flag leaf related traits and grain yield

The results of the combined analysis of variance for morpho-physiological traits indicated the presence of considerable genotypic variations for grain yield, biological yield, flag leaf length, and flag leaf width as well as physiological traits, including RWC, ELWR, RWL, and LWC (Table 1). The irrigation treatment (normal irrigation and rain-fed) showed significant differences in all the studied traits except for the flag leaf length (Table 1). The genotype × environment interaction was significant for all the studied traits except for flag leave dimensions (Table 1). Therefore, the selection of suitable genotypes for different traits (with the exception of flag leave dimensions) should be done in every irrigation treatment separately. This means that high yielding genotypes or desirable traits recognized as useful under irrigation may not be useful under water stress conditions. This genotype × environment interaction for grain yield complicates the selection of genotypes suitable for a wide range of target environments. Hence, it is essential that all the experiments be conducted under appropriate field environments in target sites and repeated across seasons (Sardouie-Nasab *et al*., 2014).

Comparison of genotypes for different evaluated traits

1**. Grain yield and biological yield**

The results of mean comparisons of grain yield under irrigation and water stress conditions are presented in

Table 2. Comparison of mean yields for genotypes indicate that Aflak and Sivand with the mean values of 608.8 and 372.5 (g m^{-2}), respectively, had the highest and lowest grain yield among genotypes under irrigation. Under water stress condition, however, the highest (387) and the least (170.4) values of grain yield (gm^{-2}) were recorded for Sepahan and Triticale, respectively (Table 2). The range of grain yield between genotypes was 372.5 to 608.8 gm^{-2} under irrigation and 170.4 to 387 gm^{-2} under stress conditions, which showed the high variability. The highest biological yield under normal (1595 gm^{-2}) and drought stress (1245 gm^{-2}) conditions were found to belong to Sardari and Arvand genotypes, respectively (Table 2). The lowest biological yield under irrigation (1074 gm^{-2}) and water stress (854.9 gm^{-2}) were observed in Behrang and Sardari genotypes, respectively. Means of grain yield and biological yield decreased due to water stress in all the genotypes investigated, except for the biological yield in Behrang. The significant decline in grain yield of spring wheat was previously reported under drought stress by Li *et al.* (2011).

2. Flag leaf size

Leaf area produces dry matter before anthesis and affects balanced water use before anthesis (Ritchie *et al*., 1990). On the other hand, leaf area determines the amount of transpiration, evaporation, and photosynthesis in plants (Cedola *et al*., 1994). Leaves with lower surface areas are, therefore, more favorable in certain tolerant genotypes because narrow leaves possess the ability to roll more rapidly than wide leaves under drought stress conditions (Cedola *et al*., 1994). Flag leave size (length and width) underwent significant reductions from normal to drought stress conditions (Table 2). The longest flag l (25.83am) and widest flag (1.97cm) were found in Behrang and Kavir genotypes, respectively, in the normal treatment. The least values of flag length (27.05cm) and flag width (1.57cm) were also observed in Mahdavi and Sardari genotypes, respectively, under water stress conditions. Sheron *et al.* (1986) reported a significant correlation between flag leaf area and grain yield under rain-fed conditions. The significant effect of photosynthetic capacity of flag leaf on grain yield of wheat suggests that leaf area could influence grain yield in some ways (Blum *et al*., 2011).

3. Physiological traits

Drought was found to have significant effects on all the physiological traits under both normal to drought stress conditions (Table 2). The values of ELWR, RWC, LWC, and RWL decreased from normal to drought stress conditions (Table 2). The highest and lowest mean significant differences between normal and drought stress conditions were recorded for ELWR and RWL. The RWC values ranged from 33 (%) (Sardari) to 62 (%) (Rowshan) in drought conditions and from 60.92(%) (Bahar) to 83.39(%) (Rowshan) in normal conditions (Table 2). Schonfeld *et al.* (1988) claimed that RWC decreased when the drought stress in wheat increased. On the other hand, the resistant cultivars to drought stress exhibit higher values of RWC in drought stress conditions. It could be raised from high maintenance water capacity in tolerant genotypes (El- Rawy and Hassan, 2014).

The decline in wheat RWC due to drought stress has been reported in previous studies of wheat (Manette *et al*., 1988; Schonfeld *et al*., 1988; Lonbani and Arzani, 2011). Our results are confirmed by the findings of Geravandi *et al.* (2011) and Manette *et al.* (1988), who reported that drought tolerant genotypes show higher RWC than drought sensitive genotypes. In agreement with the findings of Geravandi *et al.* (2011), no significant relationship was detected in this study between RWC and grain yield in wheat under either treatments (data not shown). Thus, it may be claimed that the ability to maintain high water potential or relative water content under stress conditions might be an adaptive feature to drought tolerance. It has been hypothesized that genotypes that keep open their stomata under stress conditions while maintaining an adequate leaf RWC can be considered as suitable cultivars for dry regions (Liang *et al*., 2002). In the present study, the tolerant cultivars had higher values of RWC, indicating their greater ability to uptake water from the soil compared to the susceptible ones, because the plants need a deep root system to be able to maintain their internal moisture content (Hirayama *et al*., 2006). The highest and the lowest values for ELWR under drought stress conditions were observed in Sepahan (76.96) and Behrang (48.74), respectively under normal conditions. However, Aflak (57.41) and Bahar (41.8) recorded the highest and lowest values of ELWR, respectively. This indicates the high compatibility of Sepahan to drought stress (Table 2). Higher values of ELWR were recorded for tolerance cultivars than for sensitive ones as also reported by previous studies (Geravandi *et al*., 2011; Lonbani and Arzani, 2011). Occasionally, drought stress gives rise to increased excised leaf water retention (ELWR), suggesting that the mechanisms such as leaf rolling or reduced leaf area likely to be involved in leaf water retention under stress conditions failed to act and that stomata closure occurred rapidly (Manjul and Dhanda, 2005). In drought stress conditions, the stomata close rapidly to reduce water losses (Liang *et al*., 2002). In this situation, the stomatal conductance declines, leading to reduced transpiration (Liang *et al*., 2002). The increase of ELWR index in drought stress is considered as a suitable criterion for the selection of tolerant genotypes (Munjal and Dhanda, 2005). The highest value of RWL under normal treatment was recorded for Pishtaz (0.44) and that under the drought one was observed in Behrang (0.28). The least values under the drought (0.12) and normal (0.30) treatments were observed in Kavir and Aflak, respectively (Table 2). A significant decline in RWL was observed in genotypes from normal to drought stress treatments. The decline in RWL caused by drought stress might indicate certain water loss inhibiting mechanisms involved under drought stress or may be attributed to an imbalance between water loss from the leaves due to the evapotranspiration in the plant canopy and the replenishment by irrigation (Lonbani and Arzani, 2011; Bhargava and Sawant, 2013). Similar results have been reported in Lonbani and Arzani (2011) and Golestani Araghi and Asad (1998). Leaf water content (LWC) was observed to vary from 294.3 (Pishtaz) to 163.1 (Bahar) in the normal treatment and from 186.9 (triticale) to 127 (Aflak) in the drought stress one. Clearly, LWC decreased as we moved from the normal to the stress treatment, which implies the reduced capacity for water retention in the wheat genotypes studied. It may, therefore, be concluded that changes in certain physiological traits, such as RWC, RWL, LWC, and ELWR might occur depending on drought stress intensity. None of these traits, however, showed significant correlations with grain yield. They may, therefore, be exploited in genotype selection at higher drought stress intensities. Sepahan and Rowshan genotypes showed superior values of grain yield, biological yield, ELWR, and RWC in both treatments but low values of RWL under the drought stress treatment. These genotypes were, hence, identified as elite tolerant genotypes. The C.V (%) values, as an indicator of experimental error, were calculated for all traits under normal and drought stress conditions (Table 2). The highest (16.64%) and least (0.89%) value was observed at LWC (under stress) and grain yield (normal), respectively.

The drought tolerance indices based on grain yield

From the results and observations outlined above, it may be concluded that the simultaneous application of all the drought-tolerance and susceptibility indices form an appropriate approach for screening drought-tolerant genotypes. In this study, eight selection indices (SSI, TOL, MP, GMP, STI, YI, YSI, and HM) were used to evaluate the different bread wheat genotypes studied with respect to their drought tolerance. Comparison of selection indices across the genotypes are presented in Table 3. Clearly, STI varied in the genotypes from 0.14

(Sardari) to 0.38 (Sepahan). Based on STI and grain yield, the genotypes of Sepahan and Rowshan were found to be the most drought-tolerant, as they exhibited the highest STI and grain yield under drought stress. The genotype Sepahan also showed the highest values for STI, GMP, MP, YI, YSI, and HM indices (Table 3).

The results showed that the greater the TOL value representing the larger yield reduction under stress conditions is, the higher the salinity sensitivity (Rosielle and Hamblin, 1981). The TOL values ranged from 403.45(Sivand) to 133.2 (Sepahan). Sivand and Sepahan genotypes had the least grain yield reduction by drought stress (TOL) [133.2 (g) and 141.7 (g), respectively], which shows that these genotypes have some drought stress tolerant mechanisms. A selection based on minimum yield reduction under stress conditions in comparison with non-stress conditions (TOL) failed to identify the most tolerant genotypes (Rizza *et al*., 2004). Evaluation of cultivars according to stress susceptibility index (SSI) helped distinguish susceptible from tolerant cultivars regardless of their yield potential (Sio- Se Marde *et al.*, 2006). Based on the results obtained, Sepahan and Rowshan recorded the lowest SSI values (0.67 and 0.70, respectively), which allowed them to be considered as tolerant to water stress. However, the highest value of SSI (1.76) was observed in Triticale. Other genotypes were identified as either semi-tolerant or semi-sensitive to drought stress. Aflak cultivar was suitable only under normal irrigation treatment. In ranking, Rowshan and Sepahan were after Aflak genotype in normal irrigation treatment.

Correlation analysis between drought tolerance indices and grain yield under drought stress

Correlation analysis between grain yield and drought tolerance indices can be exploited in screening the best genotypes and indices used (Farshadfar and Shutka, 2003). In this study, no significant correlations were detected between Y_s and Y_p treatments (Table 4). This indicates that indirect selection for drought stress conditions based on the results obtained for normal conditions does not lead to satisfactory results. This is contrary to the results reported by Abdolshahi *et al.* (2012) and Golabadi *et al.* (2006), who found a significant positive correlation in wheat grain yield grown under supplementary irrigation and that grown under dry conditions. Thus, it will be essential to select genotypes with a high potential yield under drought conditions in order to improve yield under drought stress.. Nevertheless, Sio-Se-Mardeh *et al.* (2006) reported a negative correlation between Ys and Yp. Farshadfar and Shukla (2003) implied that the most index appropriate for selecting stress tolerant cultivars is one which has a high correlation with seed yield under stress and non-stress conditions. The good responses shown by some cultivars under stress conditions could be ascribed to adaptation mechanisms (Clarke *et al.*, 1992). The STI, MP, and GMP indices had significantly positive correlations with both Ys and Yp (Table 4). These indices are thus identified as the best selection indices for drought tolerance in wheat genotypes. These results are confirmed by those reported in Sio-Se-Mardeh *et al.* (2006), Ilker *et al.* (2011), and Abdolshahi *et al.* (2012). Among the stress tolerance indicators, larger values of TOL and SSI relatively represent more sensitivity to stress. Thus, lower values of TOL and SSI are favored as criteria for selecting drought resistant genotypes. The lower these indices are, the more genotypes are drought resistant (Sio- se Mardeh *et al.*, 2006). However, no correlation was found between SSI and grain yield under normal conditions (r= 0.39). Therefore, SSI index could not be used as a suitable index for the selection of a drought-tolerant genotype (Clarke *et al.*, 1992, El-Rawy and Hassan, 2014). Abdolshahi *et al.* (2012) used high STI and low TOL values as good indices for selecting drought tolerant genotypes. According to their report, Rowshan and Sepahan genotypes recorded the lowest values of TOL, which they used as an indicator of high drought tolerance in these genotypes. YI had the highest correlation with Ys (r= 1**) and MP had the highest correlation with SSI (r= – 0.76**). Ilker *et al.* (2011) also reported that cultivars producing high yields under both drought stress and normal treatments could be identified by STI, MP, and GMP indices. Pireivatlou *et al.* (2010) also noted that STI could be a reliable index for selecting high yielding genotypes. Ys exhibited the highest (r= 1**) and the lowest (–0.49) correlations with YI and TOL, respectively. The highest (r=0.84**) and the lowest (-0.39) correlations of Yp were observed with MP and YSI, respectively (Table 4). Based on the correlation analysis, MP, GMP, and STI could produce similar results. Since MP is the mean production under both salt stress and non-stress conditions (Rosielle and Hamblin, 1981), it was highly correlated with *Y*P and *Y*S (Table 4). Hossain *et al.* (1990) used MP as a resistance criterion for wheat cultivars under moderate stress conditions. Different indices would not result in the same outcome. To employ all indices simultaneously, multivariate statistics such as factor analysis with Varimax rotation was performed (Sardouie-Nasab ET AL., 2014). STI, MP, and GMP identified Rowshan and Sepahan as the most drought-tolerant genotypes and Sardari as the most drought-sensitive. As shown in Table 3, the greater the TOL value, the larger the yield reduction under stress conditions and the higher the drought sensitivity. The positive correlations between TOL and SSI (0.93**) and between TOL and Yp (0.7**) as well as the negative correlation between Ys and SSI (–0.77**) suggest that the selection based on SSI and TOL would result in a reduction in the yield under normal conditions.

Principal component and biplot analysis

To employ all the indices simultaneously, multivariate statistical analysis such as Principal Component Analysis (PCA) was performed. Biplot analysis was used to explain the relationship between grain yield and drought indices. It was revealed that the first PCA explained some variations in the indices of Ys, Yp, SSI, TOL, MP, GMP, STI, YI, YSI, and HM. The first PCA showed positive correlations with MP, GMP, STI, YI, YSI, and HM and negative correlations with TOL, and SSI (Figure 1). Thus, the first dimension can be designated by 'tolerance'. Considering the high and positive values of this PCA on biplot, the genotypes selected will be high yielding in both rain-fed and irrigated environments. The second PCA explained 29.43% of the total variability and established positive correlations with Ys, Y_I, and YSI. Therefore, the second component could be named 'sensitivity'. According to Figure 1, the genotypes of Sepahan and Rowshan had high yields in both normal and drought conditions, but the genotypes Pishtaz and Falat showed high yield only under normal conditions. The genotypes Sardari, Ghods, Chamran, and Kavir revealed lower yield in both (normal and drought) environments. Finally, Bahar, Behrang, Arvand, and Aflak were categorized under the same group, since they showed high yields in normal conditions.

CONCLUSION

In the present study, drought stress was shown to have significant effects on grain yield, physiological traits, and drought tolerance indices of bread wheat genotypes.

A significant reduction was observed in physiological indices moving from normal irrigation to rain-fed conditions, except in the case of ELWR. The selection indices of MP, GMP, and STI were strongly correlated with grain yield under both conditions, making them effective indicators to be used in identifying tolerant wheat genotypes. Moreover, the relative effectiveness of selection indices was shown to improve by merging two or more traits than using single traits independently. Sardari was found to be among the genotypes which are the most sensitive to drought stress. Aflak variety was the best genotype under normal conditions (608.8 g/m^2), which may be recommended for cultivation in regions with adequate irrigation in Isfahan. Thus, the genotypes

Sepahan and Rowshan were characterized as the most tolerant genotypes to be used for the improvement of drought tolerance in wheat breeding programs and identified as a suitable genotype for cultivation in dry lands with climates similar to that in Isfahan region. Because the reduction of grain yield under drought stress conditions for Sepahan and Rowshan cultivar is less than the other genotypes that may be related to tolerance mechanisms in these two genotypes, it appears that these two drought-tolerant cultivars are capable of exploiting physiological mechanisms, such as higher RWC and flag width to improve their performance under drought stress conditions.

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Table 1: Combined analysis of variance for some traits across two environments (drought stress and normal) in bread wheat genotypes.

Source of variation	D.F	GY	BY	FL	FW	RWC	ELWR	RWL	LWC
Env (E)	1	1037.1**	33815.6**	0.18ns	0.03*	1955.4**	5070.6**	0.445**	91282.1**
Rep (Env.)	4	22.9	2113.99	7.99	0.002	5.19	7.81	0.0002	255.9
Gen. (G)	14	17603.4**	55348.3**	19.3**	0.063**	149.6**	117.83**	0.006**	3085.9**
G ×E	14	1004.4**	54128.9**	5.61	0.017	143**	69.53**	0.004**	2074.6**
Error	56	41.4	4385	6.15	0.016	6.08	4.15	0.0004	380.39

Abbreviations: GY: Grain yield, BY: Biological yield, FL: Flag length, FW: Flag width, RWC: Relative water content, ELWR: Excised leaf water retention, RWL: Relative water loss, LWC: Leaf water content. Env: Irrigation treatments; Gen: Genotype. *and ** significant at 0 .05 and 0.01, respectively.

Table 2: Mean comparisons for grain yield and some morph- physiological traits of wheat genotypes under normal and drought stress.

Genotype	GY(gm^{-2})		BY(gm^{-2})		FL(cm)		FW(cm)		RWC (%)		ELWR(%)		RWL(%)		LWC (%)	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Pishtz	453.5^{f}	276.4^{d}	1488^{ab}	1054^{bc}	22.07^{a-d}	22.66^{a-e}	1.55^{de}	1.62^{cd}	78.45^{b}	51.6^{def}	60.83^{d}	45.66^{gh}	44^{a}	21^{cd}	294.3^{a}	183.8^{a}
Arvnd	528.1^{e}	257.5^{e}	1576^{a}	1245^{a}	24.23^{ab}	22.65^{a-e}	1.53^{de}	1.62^{cd}	68.21^{e}	53.9^{de}	58.07^{d}	48.42^{def}	31^{b}	24^{bc}	171.7^{jk}	181.1^{a}
Ghods	430^{h}	253.6^{e}	1503^{ab}	1049^{bc}	23.9^{abc}	24.37^{abc}	1.61^{b-e}	1.6^{cd}	73.19^{d}	58.6^{abc}	60.09^{d}	48.13^{efg}	36^{ab}	23^{bc}	228.9^{d}	170.1^{abc}
Sivand	372.5^{j}	239.3^{f}	1334^{cde}	1057^{bc}	21.86^{bcd}	25.39^{ab}	1.80^{ab}	1.93^{a}	75.47^{bdc}	62.8^{a}	61.65^{cd}	50.81^{cd}	34^{ab}	22^{bcd}	273.5^{b}	162.4^{abc}
Behrang	563.2^{c}	259.7^{c}	1074^{f}	1082b	25.83^{a}	22.93^{a-e}	1.77^{bc}	1.65^{bcd}	74.96^{bcd}	58.16^{bc}	48.74^{e}	49.71^{de}	33^{b}	28^{a}	196.7^{ghi}	175.6^{ab}
Bahar	553.9^{d}	319.2^{b}	1444^{abc}	1081b	23.67^{abc}	23.69^{a-d}	1.76^{bc}	1.8^{ab}	60.92^{f}	49.74^{efg}	65.17^{bc}	41.8i	32^{b}	19^{d}	163.1^{k}	144.5^{abc}
Sepahan	528.7^{e}	387^{a}	1416^{bcd}	880.9f	22.80^{a-d}	22.74^{a-e}	1.6^{bde}	1.66^{bcd}	76.23^{bcd}	33.02^{i}	76.96^{a}	50.82^{cd}	31^{b}	21^{cd}	185.6^{ij}	137.4^{bc}
Rowshan	525.1^{e}	377.9^{a}	1193de	859.1f	20.16^{cd}	19.63^{de}	1.72^{bcd}	1.69^{bcd}	83.39^{a}	62^{ab}	66.03^{b}	53.18^{bc}	36^{ab}	15^{e}	209.2^{fgh}	135.3^{bc}
Sardari	372.5^{j}	208.3^{g}	1595^{a}	854.9f	19^{d}	20.75^{cde}	1.5^{e}	1.57^{d}	74.39^{bcd}	47.59^{fgh}	65.48^{bc}	47.11^{fgh}	36^{ab}	19^{d}	227.7^{de}	162.9^{abc}
Mahdvi	445.8^{g}	190.6^{h}	1511^{ab}	997.7^{d}	23.4^{abc}	27.05^{a}	1.64^{b-e}	1.82^{abc}	72.49^{d}	55.77^{cd}	74.35^{a}	53.28^{bc}	0.31^{b}	0.13e	224.8^{def}	156.4^{abc}
Chamran	433.2^{h}	249.3^{ef}	1410^{bcd}	856.4^{f}	22.46^{a-d}	21.9^{b-e}	1.69^{b-e}	1.63^{cd}	77.36^{bc}	46.04^{gh}	67.2^{b}	53.67^{b}	0.33^{b}	0.21^{cd}	217.8^{def}	128.3^{c}
Triticale	573.8^{b}	170.4^{i}	1265de	940.9^{e}	21.29^{bcd}	19.1^{e}	1.6^{cde}	1.7^{bcd}	72.5^{d}	51.92^{def}	59.87^{d}	46.02^{fgh}	0.38^{ab}	0.25^{ab}	228.5^{de}	186.9^{a}
Kavir	422.2^{i}	272.7^{d}	1500^{ab}	929.7^{e}	24.26^{ab}	22.4^{b-e}	1.97^{a}	1.76^{a-d}	78.06^{bc}	37.28^{i}	65.5^{bc}	50.58^{de}	0.32^{b}	0.12^{e}	253.6^{c}	130.6^{c}
Falat	456.3^{f}	259.8^{c}	1336^{cde}	1027^{cd}	20.37^{cd}	22.14^{b-e}	1.66^{b-e}	1.81^{abc}	72.79^{c}	44.45^{h}	68.87^{b}	45.3^{h}	0.33^{b}	0.14^{e}	195.9^{hi}	145.9^{abc}
Aflak	608.8^{a}	252.3^{ef}	1311^{cde}	1233^{a}	25.72^{a}	24.8^{abc}	1.59^{cde}	1.66^{bcd}	74.53^{cd}	55.74^{cd}	68.38^{b}	57.41^{a}	0.30^{b}	0.23^{bc}	212.5^{efg}	127^{c}
CV(%)	0.89	2.98	6.5	2.58	10.05	11.66	7.1	7.85	3.1	5.12	3.13	3.77	5.89	10.59	4.42	16.64

¥: Abbreviations: GY: Grain yield, BY: Biological yield, FL: Flag length, FW: Flag width, RWC: Relative water content, ELWR: Excised leaf water retention, RWL: Relative water loss, LWC: Leaf water content. N: non-stress, S: drought stress

Table 3: The mean comparison of different selection indices, grain yield (at normal and drought stress) among different genotypes of bread wheat

Genotype	Ys	Yp	SSI	TOL	MP	GMP	STI	YI	YSI	HM
Pishtaz	276.38	453.52	0.98	177.14	364.95	354.04	0.23	0.37	0.61	343.45
Arvand	257.53	528.07	1.28	270.54	392.80	368.77	0.25	0.35	0.49	346.21
Ghods	253.56	430.02	1.03	176.46	341.79	330.21	0.20	0.34	0.59	319.02
Sivand	239.33	371.53	0.89	133.20	305.93	298.59	0.16	0.32	0.64	291.43
Behrang	295.73	563.24	1.19	267.51	429.48	408.12	0.31	0.40	0.53	387.83
Bahar	319.20	553.92	1.06	234.73	436.56	420.49	0.32	0.43	0.58	405.01
Sepahan	387.02	528.67	0.67	141.65	457.80	452.34	0.38	0.52	0.73	446.89
Rowshan	377.87	525.10	0.70	147.22	451.49	445.44	0.36	0.51	0.72	439.48
Sardari	208.31	372.25	1.1	164.22	290.42	278.57	0.14	0.28	0.56	267.20
Mahdavi	190.61	445.75	1.43	255.14	318.18	291.48	0.16	0.26	0.43	267.03
Chamran	249.28	433.22	1.06	183.93	341.25	328.62	0.20	0.34	0.58	316.47
Triticale	170.39	573.84	1.76	403.45	372.11	312.69	0.18	0.23	0.30	262.76
Kavir	272.72	422.16	0.88	149.43	347.44	339.31	0.21	0.37	0.65	331.37
Falat	295.80	456.29	0.88	160.49	376.04	367.38	0.25	0.40	0.65	358.92
Aflak	252.32	608.82	1.46	356.50	430.57	391.94	0.28	0.34	0.41	356.78

stress tolerance index (TOL), yield under stress conditions (Ys), yield under non-stress conditions (Yp) , mean productivity (MP), yield index (YI), yield stability index (YSI), stress susceptibility index (SSI), stress tolerance index (STI),geometric mean productivity (GMP), harmonic mean (HM)

Table 4: Correlation coefficients among various indices under normal and drought stress in bread wheat genotypes

	¥Ys	Yp	SSI	TOL	MP	GMP	STI	YI	YSI	HM
Ys	1						.			
Yp	0.28	1								
SSI	-0.77**	0.39	1							
TOL	-0.49	0.70**	0.93**	1						
MP	0.75**	0.84**	-0.16	0.21	1					
GMP	0.90**	0.67**	0-.41	-0.05	-0.05	1				
STI	0.90**	0.66**	-0.42	-0.06	-0.06	1**	1			
YI	1.00**	0.28	-0.76**	-0.48	-0.48	0.9**	0.9**	1		
YSI	0.77**	-0.39	-1.0**	-0.93**	-0.93**	0.41	0.42	0.77**	1	
HM	0.97**	0.51	-0.58*	-0.25	-0.25	0.98**	0.98**	0.97**	o.58*	1

* and ** are significant at 0.05 and 0.01, respectively. ¥: yield under stress conditions (Ys), yield under non-stress conditions (Yp), tolerance index (TOL), mean productivity (MP), yield index (YI), yield stability index (YSI), stress susceptibility index (SSI), stress tolerance index (STI),geometric mean productivity (GMP), harmonic mean (HM).

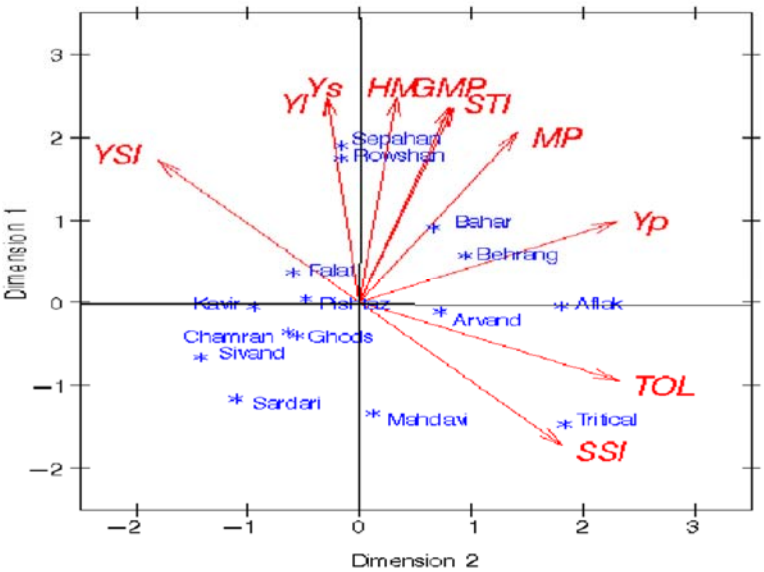

Figure 1: Biplot based on first two principal component axes (PC1 and PC2) both drought indices and bread wheat genotypes.

Abbreviations in Figure 1: yield under stress conditions (Ys), yield under non-stress conditions (Yp), tolerance index (TOL), mean productivity (MP), yield index (YI), yield stability index (YSI), stress susceptibility index (SSI), stress tolerance index (STI),geometric mean productivity (GMP), harmonic mean (HM).

تقييم التراكيب الوراثية لتحمل الجفاف في قمح الخبز (*Triticum aestivum* L.) باستخدام الصفات الشكلية– الفسيولوجية ومؤشرات الانتقاء المعتمدة على المردود

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ملخص

تهدف هذه الدراسة إلي تقييم مدى فعالية مؤشرات تحمل الجفاف لخمسة عشر نمطاً وراثياً من قمح الخبز وذلك باستخدام مختلف الصفات الشكلية– الفسيولوجية، بما في ذلك طول ورقة العلم (FL)، عرض ورقة العلم (FW)، المحتوى المائي (RWC)، الاحتباس المائي للورقة (ELWR)، معدل فقدان الماء (RWL)، المحتوى المائي للورقة (LWC)، المردود الحبي والمردود البيولوجي. خلال البحث تم استخدام ثمانية مؤشرات من مؤشرات تحمل الجفاف لاختبار مستوى حساسية الأنماط الوراثية لقمح الخبز وعلاقته باجهاد الجفاف، بما في ذلك مؤشر ثبات المردود (YSI)، مؤشر المردود (YI)، مؤشر تحمل الجفاف (STI)، متوسط الانتاجية الهندسي (GMP)، مؤشر الحساسية للجفاف (SSI)، متوسط الإنتاجية (MP)، تحمل الجفاف (TOL)، والمتوسط التوافقي (HM). أظهرت الدراسة وجود ارتباط معنوي وإيجابي بين المؤشرات STI، MP، GMP والمردود الحبي في ظروف الري التكميلي والإجهاد المائي (0.66–0.90)، ويوحي هذا بفعالية هذه المؤشرات في تحديد الأصناف المتحملة للجفاف. كما أظهرت الدراسة استناداً إلى تحليل biplot تفوق صنف سباهان وروشن من حيث ثبات المردود وامتلاك أقل معدل انخفاض للمردود (141–147 غ/م2) في ظروف الري التكميلي والاجهاد المائي، بالتالي توصي هذه الدراسة بالاهتمام بزراعة هذه الأصناف.

الكلمات الدالة: قمح الخبز، تحمل الجفاف، مؤشرات التحمل.

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