Turkish Journal of FIELD CROPS

Turk J
Field Crops
2018, 23(2), 135-145
DOI: 10.17557/tjfc.471686

SCREENING OF NORTH AFRICAN BARLEY GENOTYPES FOR DROUGHT TOLERANCE BASED ON YIELDS USING TOLERANCE INDICES UNDER WATER DEFICIT CONDITIONS

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Received: 10.04.2018

ABSTRACT

Water deficit is one of the most constraining factors for the growth, development and yields of plants in arid and semi-arid regions of the world. The objective of this study is to evaluate North African barley collection for drought tolerance and to study the tolerance indicators of water deficit in order to select the most relevant ones that could be used for assessing any large scale plant population. For this purpose, two trials were conducted: first one was conducted in the laboratory to evaluate the germination characteristics of sixteen North African barley genotypes under physiological stress conditions induced by polyethylene glycol-6000 and the second one was conducted in the field on the same genotypes, under favorable and water deficit conditions. In the first experiment, germination parameters showed significant differences between genotypes within the same water regime and between different water regimes and revealed the tolerance of the majority of the Egyptian genotypes to drought. In the second experiment, yields, relative water content (RWC) and drought tolerance indicators also showed the same trend where the majority of Egyptian genotypes as well as one Tunisian genotype tolerated drought more than others do. STI (Stress Tolerance Index), SSI (Stress Sensitivity Index), YSI (Yield Stability Index) and TOL (Stress Tolerance) indices showed different correlations to conclude that (STI) and (YSI) are the best predictors of drought tolerance compared to other indices. On the other hand, a positive correlation between root length under physiological stress and field yield under water deficit conditions has been established, allowing selection of the most drought-tolerant genotypes at an early stage (germination) before evaluating them in the field.

Key words: Barley, drought, polyethylene glycol, relative water content, tolerance index

INTRODUCTION

Water deficit is an important factor limiting crop production in many countries around the world. It is revealed in the plant by a series of changes that affect the morphological, physiological, biochemical, genetic and even the gene expression levels induced by drought (Gerszberg and Hnatuszko-Konka, 2017). The changes are often expressed in the leaf area index (Bashir et al., 2017) and the global leaf level by the accumulation of compatible compounds such as proline, glycine betaine and soluble sugars in order to keep the turgor potential as high as possible and allow the plant to survive. These changes may occur in roots that form wilts storing moisture and allow the plant to survive until water conditions become favorable again (Minocha et al., 2014).

Improving plant resistance to drought is complex due to the lack of fast and reproducible screening techniques. Nevertheless, in spite of this complexity, screening for drought tolerance was conducted by different manners. Tembe et al. (2017) measured the plant relative water content and the canopy temperature to identify the most tolerant variety to drought. Geetha et al. (2017) focused on the accumulation of osmotic components and the membrane integrity. Lalić et al. (2017) interested on root system development (length, number, diameter and root architecture). Ilker et al. (2011a) and Karimizadeh et al. (2016) have used the Additive Main effects and Multiplicative Interactions (AMMI) approach to select the most stable genotype in arid region, where the environment is variable and unpredictable and EL-Shawy et al. (2017) measured the yield components and the stress tolerance indices.

Golabadi et al. (2006) stated drought tolerance indices provide measures based on yield loss under drought comparatively to that obtained under favorable conditions. Many scientists have defined stress tolerance (TOL) as the yield differences between the yields obtained under favorable conditions (Yp) and those obtained under stress conditions (Ys) and have defined the average productivity in both conditions as $\bar{Y}s$ and $\bar{Y}p$. However, Fischer and Maurer (1978) and Ayranci et al. (2014) recommended the stress susceptibility index (SSI) as another index to assess the sensitivity of genotypes in variable environments. Gavuzzi et al. (1997) suggested yield index (YI) and yield stability index (YSI) to assess the yield stability of genotypes under stress and non-stress conditions. However, Fernandez (1992) proposed another stress tolerance index (STI) for identifying high-yielding genotypes under both conditions. Other modified indices have recently been used by other researchers (Farshadfar and Sutka, 2002; Moosavi et al., 2008).

In this study, we intend to identify the most tolerant North African barley genotypes to water deficit and that can be used as brood stock in the barley improvement programs of tolerance to drought. We try to identify the most discriminating and robust criteria that breeders can use to assess a large plant population for drought tolerance. We also plan to establish any correlations between germination characteristics and field yield that would be useful for the identification of the most drought tolerant genotypes at an early stage.

MATERIALS and METHODS

Plant Material and Germination Parameters

In frame of a previous research project (New Partnership for African Development=NEPAD), 31 North African barley genotypes were characterized on the molecular level and showed high genetic diversity allowing to cluster them according to their eco-geographical origin or according to the caryopsis character (hulled or naked caryopsis) (Ben Naceur et al., 2012). Among these genotypes, sixteen ones were selected on the base of greater genetic distance or on the base of contrasting characters (early/late; hulled/hulless; erected/prostrate; productive/less productive) and used for evaluation to drought tolerance.

Five genotypes from Tunisia [Kairouan (V4), Rihane (V7), Sidi-Bouzid (V8), Sabra (V9), Tombari (V10)], five genotypes from Algeria [Techedrette (V15), Saïda (V17), Sidi-Mehdi (V18), Ras-El-mouche (V19), Naïlia (V20)] and six genotypes from Egypt [Giza 123 (V23), El Arich (V24), Ksar (V25), Giza 2000 (V26), Giza 125 (V29) and Giza 131 (V30)].

For each genotype, 20 grains of barley were placed into 90 mm diameter Petri dishes lined with filter paper containing either distilled water (Control) or a polyethylene glycol solution (PEG-6000) at a concentration of 10% (Stress). Each treatment (stressed or not) is repeated 4 times. The germination is carried out in a germination room (temperature: 25°C day/18°C night and 12h light). According to Michel and Kaufmann (1973), osmotic potential generated by the PEG-6000 can be obtained by the following formula:

$$\psi_s = -(1.18 \times 10^{-2})\, C - (1.18 \times 10^{-4})\, C + (2.67 \times 10^{-4})\, CT + (8.39 \times 10^{-7})\, C^2T$$

Where C: is the concentration of PEG-6000 and T is the temperature. In this case the osmotic potential of the solution used is -1.48 bars. After the incubation of the Petri dishes in the germination room during seven days, we have measured the following parameters:

- The root length was measured in cm.

- The coleoptiles length was measured in cm

- The stress tolerance index (STI) was assessed based on root length

Field Experimental Design

The trial for drought tolerance assessment was conducted at the National Agronomic Research Institute of Tunisia for two consecutive growing seasons (2014 and 2015). Sixteen barley genotypes previously selected as part of a research project, were assessed in the field using a split plot experimental design with three replications under two water regimes (Control and Stressed). The soil on which the tests were carried out showed the following characteristics: clay 22.5%, silt 31.5%, very fine sand 12.0%, fine sand 20%, coarse sand 12% and organic matter 2%. The fertilization consisted of 80 kg P_2O_5 ha^{-1}, just before sowing date and a 20kg (N) ha^{-1}, at full tilling stage was applied each year. The seeding density was calculated based on 250 grains.m^{-2}.

Each barley genotype was represented by an elementary plot of $4m^2$ (two meters wide and two meters long), replicated three times for each water regime. The control was subjected to the rainfall regime whereas the stressed trial was carried out in the same place but it was covered by plastic sheet since the tilling stage (February) to prevent precipitation.

At harvest time, the control yield (Yp) and stress yield (Ys) were measured.

The rainfall recorded during the two years of experimentation (September to June) were shown in Table 1.

Table 1: Monthly rainfall (mm), during two cropping seasons (2014 and 2015)

Cropping seasons	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Total
2014	47	39	51	44	64	60	59	52	14	424
2015	30	76	38	81	47	38	50	25	16	401

Leaf Relative Water Content (RWC)

The relative water content (RWC) of leaf is a measurement of its hydration status relative to its maximal water holding capacity at full turgidity. It provides a measurement of the plant water status and gives a strong indication of the plant's response to different environmental conditions.

RWC (%) = [(W-DW) / (TW-DW)] x 100,

Where,

W – Sample fresh weight

TW – Sample turgid weight

DW – Sample dry weight.

During the grain filling period (The end of April), four terminal leaf samples from plants in each plot (Stressed and none stressed) were used to assess their relative water content. It is clear that genotype which is able to maintain turgid leaves in stressed environments will maintain also its physiological activities such as photosynthesis, growth, and grain filling, and therefore maintain a grain yield slightly affected by stress.

Yields Obtained in the Field and Calculate Indices

At the maturity stage, grain yield (Qha^{-1}) was estimated after harvesting of the elementary plots and the collected data were used to calculate several drought indices in order to evaluate the tolerance of barley genotypes to drought:

- The stress susceptibility index (SSI): SSI = [1- (Ys) / (Yp)] / [1- ($\bar{Y}$s) / ($\bar{Y}$p)]

- The stress intensity (SI): SI = [1- ($\bar{Y}$s) / ($\bar{Y}$p)]

- The stress tolerance index (STI): STI = [(Yp) X (Ys) / $\bar{Y}p^2$]

- The stress tolerance (TOL): TOL = (Yp - Ys)

- The yield stability index (YSI) = Ys/Yp

Where Ys and Yp are the grain yields, respectively, under stressed and no-stressed conditions, $\bar{Y}$s and $\bar{Y}$p are the mean yield of all genotypes under stressed and favorable conditions, respectively.

Statistical Analysis

Data collected from all measured parameters over two cropping seasons and the correlation among indices and grain yield under stress conditions were analyzed (ANOVA) using Statistical Analysis System Software (SAS, 1985). This analysis was completed by "multiple comparisons of means" with Newman Keuls test. Treatment means with the significant effects were separated by the test of Least Significant Difference (LSD) at the probability level of 5%.

RESULTS AND DISCUSSION

Effects of Physiological Stress, Induced by PEG-6000, on Seedling Growth

The germination rate, which expresses the percentage of germinated grains on the total grain number, does not always indicate the most tolerant genotype to stress. It gives only a trend of ones that could tolerate stress. In this case, physiological stress induced by PEG-6000 did not impose a significant change in the final germination of the different barley genotypes (Figure 1). However, a significant delay in the beginning and in the end of germination was observed in the case of stress. This delay is a common answer, as the kernels require more time to absorb enough water and initiate germination. This observation was also reported by Hogon and Chan (1977).

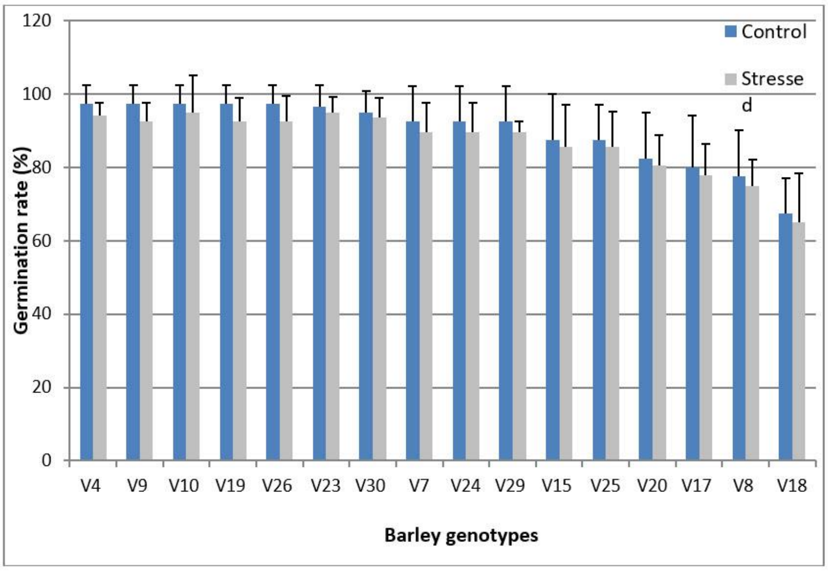

Figure 1: Germination rate of barley seeds as affected by genotype and PEG

Legend: V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131

Although most seeds germinated in both favorable and stressful conditions, some of them cannot give viable seedlings under stress conditions. Therefore, we focused particularly on root and coleoptiles length rather than the germination rate itself (Table 2). This Table reveals variability in root length both under favorable and stress conditions induced by PEG-6000. Variance analysis of this parameter showed a significant difference ($p<0.05$) in both cases of water regime, indicating that genotypes reacted differently to the drought.

Table 2: Effects of Physiological Stress Induced by PEG-6000 on Seedling Growth

	T0		T10	
	Root Length	**Shoot Length**	**Root Length**	**Shoot Length**
V4	5,97 fgh	9,47 b-e	4,08 a-d	6,45 ab
V7	6,58 bc	9,00 def	5,012 a	6,02 a-d
V8	6,16 gh	6,17 hij	4,11 abc	7,02 a
V9	3,92 h	5,82 ij	3,69 f	4,97 fg
V10	7,99 a	8,64 efg	3,10 def	5,77 a-e
V15	5,27 def	6,12 hij	3,49 c-f	4,43 efg
V17	5,00 e-h	7,74 fgh	3,76 b-e	4,77 d-g
V18	5,98 b-e	4,93 j	4,50 ab	5,02 c-f
V19	4,79 fgh	7,03 ghi	3,64 b-f	5,37 b-e
V20	5,14 efgg	9,47 b-e	3,54 b-f	5,00 c-f
V23	6,32 bcd	11,87 a	3,53 b-f	4,72 d-g
V24	5,07 efg	9,16 c-f	3,10 def	4,51 efg
V25	5,66 c-f	10,49 a-d	3,52 b-f	6,39 abc
V26	6,89 ab	10,8 ab	3,03 ef	3,60 g
V29	7,94 a	10,69 abc	4,05 a-d	5,92 a-d
V30	6,41 bc	8,87 def	4,14 abc	5,09 b-e

Legend: T0 = Control; T10 = 10% PEG-6000 solution
V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131

Under favorable conditions, the ANOVA and the Newman-Keuls classification showed 12 significantly different statistical groups. V10, V29 and V26 gave the highest root length of 7.9 cm while V4, V8, V17, V19 and V9 were the least root length varying between 3.92 and 6.16 cm. This result, which related to the genetic variability of barley genotypes, is in agreement with those observed by Soltani et al. (2006) on wheat.

Under stress, induced by PEG-6000, root length (RL) is greatly affected, but the response intensity and harmful effects of such stress depend on the genotypes tested. In this case we observed significant differences among genotypes. The highest average (RL) varied between 4.05 and 5.012 cm and was observed for V4, V7, V8, V18, V29 and V30. The Tunisian genotype (V7) was the most interesting one, with (RL) of 5.12 cm. On the other hand, the lowest (RL) varied between 3.03 and 3.64cm, was observed for V9, V10, V15, V19, V20, V23, V24, V25 and V26. The ability of V4, V7, V8, V18, V29 and V30of barley genotypes to develop their roots under water deficit conditions suggests the induction of certain genes involved in root elongation by stress or the structure modification allowing roots to sustain their development, in accordance with what was reported by Badiow et al. (2004).

Moreover, the root length in stressful conditions can inform us on the plant's tolerance to stress. Indeed, the ability of any plant to extend its roots under stressful conditions is a reliable indicator of the tolerance to water deficit. This phenomenon allows it to easily absorb water and nutrients in the deep layers even if these depths are reached by only one main root.

The stress tolerance index (STI), based on root length, illustrated in Figure 2, shows that the V7, V30 and V29 genotypes are the most tolerant against V9 which is the most sensitive.

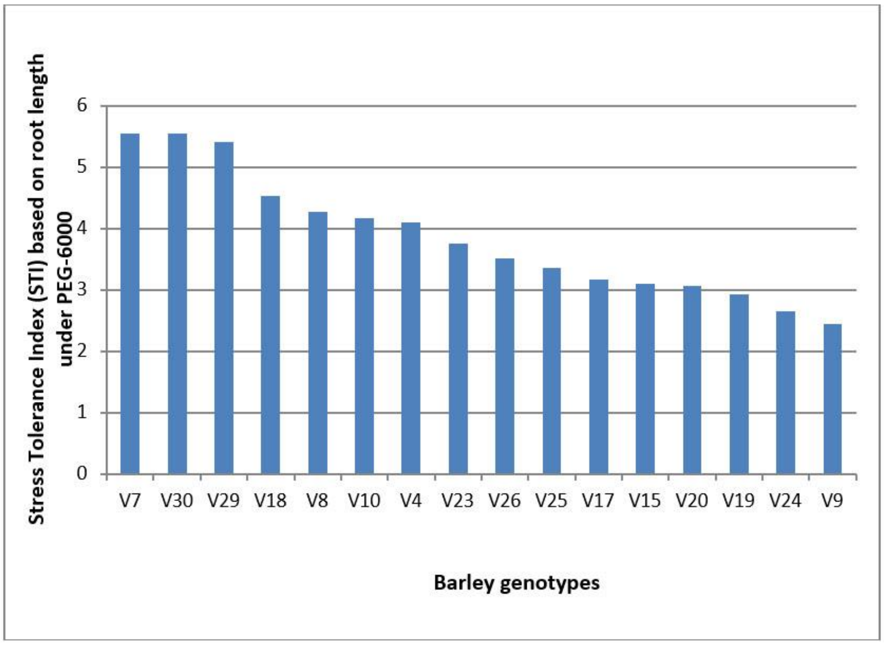

Figure 2: Barley stress tolerance index, based on root length under physiological stress

Legend: V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131

In the other hand, based on shoot length (SL) or Coleoptiles, there were significant differences among genotypes and between drought stress and favorable water regime (Table 2). With the exception of V8 and V18 genotypes, all the remainders decreased their shoot length under physiologic stress induced by PEG-6000. In the control, overall, the genotypes V23, V25, V26 and V29 showed the highest average shoot length (10.49-11.87cm) while the genotypes V8, V9, V15 and V18 showed the lowest ones (4.93-6.17cm). The other genotypes were intermediate. In the stressed trial, the highest average shoot length (7.02cm), was observed at V8, while the drastic reduction was recorded at V26 (3.6 cm).

For all genotypes, physiological stress, induced by PEG-6000, affected the early seedling growth of barley (SL). This is due may be to the low amount of water absorbed or the metabolic disorders induced by stress generating Reactive Oxygen Species. The growth decrease is more important when the shoot is higher in the control. Moreover, a positive correlation (Y=0.0826X+5.7402, R^2=0.72) was observed between the shoot length (SL) under favorable conditions and the reduction percentage when the genotypes are subjected to physiological stress. Under these conditions, shorter shoot length in favorable conditions would be less reduced under stress conditions and could be considered as another criterion for selecting the most tolerant genotype to stress at an early stage. This result is in agreement with that previously shown by Channaoui et al. (2017) in rapeseed and other crops.

Assessment of Barley Tolerance to Drought in the Field

Leaf Relative Water Content

Leaf relative water content is the main indicator of plant water status in water deficit conditions. In the control, this indicator presented values ranged between 85.87 (V4) and 89.97% (V29) while it presented values ranged between 58.96% (V10) and 79.72% (V30) under stressed (Table 3). In the stressed conditions, high relative water content was presented by V30, V7, V26, V29, V24 and V20 genotypes. While low RWC was found at V19 and V10 genotypes.

Table 3: Leaf relative water content and duration to heading date in barley genotypes subjected to water deficit

Genotypes	RWC (%) (Control)	RWC (%) (Stressed)l	Days from Sowing to Heading
V30	89.00 ±4.0	79.72 ±3.57	118
V7	87.85 ±5.5	77.28 ±4.61	120
V26	88.95 ± 2.3	76.95 ± 4.01	121
V29	89.97 ± 4.5	76.47 ± 3.49	122
V24	88.65 ± 4.5	72.15 ± 3.18	122
V20	88.47 ±2.65	70.82 ±3.36	126
V18	89.80 ± 3.9	69.20 ± 1.41	143
V25	86.89 ±5.75	68.19 ±2.75	118
V8	88.55 ±4.0	66.87 ±1.82	148
V15	86.90 ±4.0	66.80 ±4.41	143
V9	88.80± 1.75	66.80± 5.87	135
V17	88.40 ± 1.20	64.82 ± 1.43	143
V4	85.87 ± 4.00	62.45 ± 3.99	136
V23	87.84 ± 5.5	64.45 ± 4.61	121
V19	88.84 ±4.5	60.44 ±3.92	129
V10	85.96 ± 5.30	58.96 ± 2.67	145

Legend: V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131

After covering the trial by plastic sheet to avoid rains, the depletion of the water stock in the soil will depend on the ability of the genotypes to extend their root in depth, their efficiency in limiting water loss through transpiration and their earliness. Therefore, the earlier genotypes will finish its vegetative cycle before the soil drying comparatively to the later ones.

The number of days from sowing to heading date and the RWC of each genotype suggested that the genotypes having kept their leaf relatively hydrated are those which are early, except for V23 and V25. These two genotypes despite their precocity showed a low RWC comparatively to the other ones, probably because their intense foliar transpiration and inefficient closing stomata. Therefore, the earliness provides an important clue to varietal adaptation to drought since it permits a long grain-filling period and generating well filled grain and high yield which remains the final criterion by which to judge varieties under stress conditions as it was suggested by Vaezi et al. (2010).

Grain Yield

The final grain yield is estimated after harvesting plots and expressed in Qha^{-1}. The data, illustrated in Table 4, showed that the mean yield of genotypes in the control ranged from 19.43 Qha^{-1} (V10) to 48.05 Qha^{-1} (V30) and from 15.88 to 46 Qha^{-1} under water deficit. Higher grain yield is recorded with the majority of Egyptian genotypes especially V30 and with one Tunisian genotype (V7) which produced the best grain yield under both conditions. Yield of these two genotypes were 48.05 and 46.11 Qha^{-1} under favorable conditions against 46.00 and 42.87 Qha^{-1} under water deficit conditions. These are also the earliest and are those who have kept their leaves more hydrated compared to other genotypes tested (Table 3). It should be noted that V30 has greater adaptability than the others according to data acquired in other geographically diverse sites (Chalak et al. 2015).

Overall, Egyptian genotypes proved to be the most productive in both favorable and water deficit conditions (except for V23). The statistical analysis showed significant difference ($P<0.05$) among barley genotypes under control and water limitation treatment (Table 4). Newman-Keuls test ranked genotypes on eight (08) homogeneous groups for the control and five (05) groups for the water deficit treatment. Whatever the treatment tested, V30 and V7 were in the first class and V10 in the last class. The high yield of these two genotypes (V30 and V7) in both water regimes is similar to what Abdel-Raouf et al. (2012) and Chalak et al. (2015) found in other geographic sites. These authors showed the superiority of V30 yield under both stress and favorable water conditions. The yield stability of this genotype during the two years of experimentation under various water regimes indicates its adaptability to the different environmental conditions unlike the other genotypes whose position changes according to the water regime.

Table 4: Classification of yield genotypes in homogeneous groups (Means with the same letter are not significantly different)

Control			Stress		
Grain yield (Qha^{-1})			Grain yield (Qha^{-1})		
Genotypes	**Means**	**t Grouping**	**Genotypes**	**Means**	**t Grouping**
V30	48.05	a	V7	46.00	a
V7	46.11	ab	V30	42.87	a
V24	45.74	ab	V25	34.27	b
V26	42.59	abc	V24	34.07	b
V29	41.50	a-d	V26	33.83	b
V25	40.92	a-e	V18	33.00	b
V20	38.73	a-e	V29	32.90	b
V18	37.41	b-f	V20	32.00	bc
V15	35.84	b-f	V15	31.05	bc
V8	32.50	c-g	V4	25.13	cd
V4	31.66	d-g	V8	21.54	de
V17	30.77	efg	V17	21.33	de
V23	27.29	fgh	V9	20.27	de
V9	27.00	fgh	V19	20.15	de
V19	23.10	gh	V23	19.77	de
V10	19.43	h	V10	15.88	e

Legend: V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131

Therefore, the superiority yielding of the two genotypes under variable environmental conditions and their stability across years is also a valuable selection index that can be used in any plant breeding program as it was suggested by Karimizadeh et al. (2016).

Under both conditions, the ranking of genotypes according to grain yield was different indicating different responses to drought (Table 4). This finding justified the use of stress indices to describe the behavior of genotypes under stress and non-stress conditions.

Comparing Genotypes Based on the Tolerance Indices

To investigate suitable stress tolerance indicators for screening genotypes under drought, grain yield of different genotypes under both, stress and non-stress conditions were measured using different sensitivity and tolerance indicators (Table 5).

The Stress Tolerance Index (STI) was defined by Fernandez (1992) in order to identify genotypes that produce high yields under both stress and favorable conditions. However, several authors (Golabadi et al., 2006; Ayranci et al., 2014; EL-Shawy et al., 2017) have used numerous other indicators of tolerance to drought in order to classify their plant materials.

Based on the (STI) parameter, the genotypes V30 and V7 are the most tolerant to water stress whereas V10 is the most sensitive (Figure 3). Nevertheless, genotypes ranked according to the (TOL) or (SSI) indices, showed a slightly different patterns compared to that generated by (STI) (Table 5).

The yield stability index of V30 and V7 (YSI) is also another criterion confirming the tolerance of these two genotypes to drought (Table 5). However, the remaining high-yielding genotypes (V24, V25, V26, and V29) might differ in yield stability and suggest that this stability and high average yield are not mutually exclusive. Therefore, V30 and V7 could be used as bloodstock in the improvement programs for drought tolerance.

The yields (Yp), (Ys) and the tolerance indices (Table 5) as well as the correlation curves (Figure 4) showed positive correlations between Ys and (STI) and between Ys and (YSI). However, (TOL) and (SSI) which were negatively correlated with (Ys) have shown their limit in selecting the most tolerant barley genotype. In fact, selection based on (TOL= Yp-Ys) favors genotypes with low yield potential under non-stress conditions and high yield under stress conditions. However, it is not always the case in this study, the majority of the genotypes was high yielding under favorable conditions, which explain the negative correlation and the low coefficient between (TOL) and Ys. Similar to the (TOL) index, (SSI) does not differentiate between potentially drought-tolerant genotypes and those having low overall yield potential. Nevertheless, the high coefficient obtained is due to its formula which includes the mean yield of all tested genotypes ($SSI = [1- (Ys) / (Yp)] / [1- (\bar{Y}s) / (\bar{Y}p)]$). Similar results reported by Mohammadi et al. (2011) and Ilker (2011b) indicated that the (STI) index is more suited for selecting the most productive RILs (Recombinant Inbred Lines) under stress conditions. Therefore, (STI) and (YSI) constitute the best predictors of Ys, and are more suitable for enhancing yield productivity in any species genotypes under drought stress than (TOL) or (SSI). These outcomes (yield stability index: YSI) are also supported by the finding of Ayranci et al. (2014).

Table 5: Indices calculated under stress conditions

Genotypes	Yp		Ys		TOL	SSI	STI	YSI
V30	48.05	a	43.27	a	4.79	0.429	1.646	0,900
V7	46.11	ab	42.45	a	3.66	0.342	1.550	0,921
V24	45.74	ab	31.93	b	13.80	1.300	1.156	0,698
V26	42.59	abc	34.27	b	5.74	0.841	1.155	0,805
V25	41.50	a-e	35.27	b	5.66	0.595	1.143	0,862
V29	40.92	a-d	33.83	b	7.66	0.795	1.111	0,815
V20	38.73	a-e	28.33	bc	10.40	1.1561	0.869	0,731
V18	37.41	b-f	31.67	b	5.74	0.661	0.938	0,974
V15	35.84	b-f	26.43	bc	9.417	1.130	0.750	0,737
V8	32.50	c-g	21.63	de	10.87	1.440	0.557	0,675
V4	31.66	d-g	23.97	cd	7.69	1.046	0.601	0,757
V17	30.77	efg	16.16	de	14.61	2.043	0.394	0,525
V23	27.29	fgh	17.16	de	10.13	1.598	0.371	0,629
V9	27.00	fgh	19.39	de	7.62	1.215	0.414	0,718
V19	23.10	gh	18	de	5.10	0.951	0.329	0,779
V10	19.43	h	12.8	e	6.63	2.044	0.197	0,659

Legend: V4=Kairouan; V7=Rihane; V8=Sidi-Bouzid; V9=Sabra; V10=Tombari
V15=Techedrette; V17=Saïda; V18=Sidi-Mehdi; V19=Ras-El-mouche; V20=Naïlia
V23=Giza123; V24=El Arich; V25=Ksar; V26=Giza2000; V29=Giza125; V30=Giza 131
Yp: Yield (Qha^{-1}) under favorable conditions
Ys: Yield (Qha^{-1}) under stressed conditions
TOL: Tolerance
SSI: Stress Susceptibility Index
STI: Stress Tolerance Index
YSI: Yield Stability Index

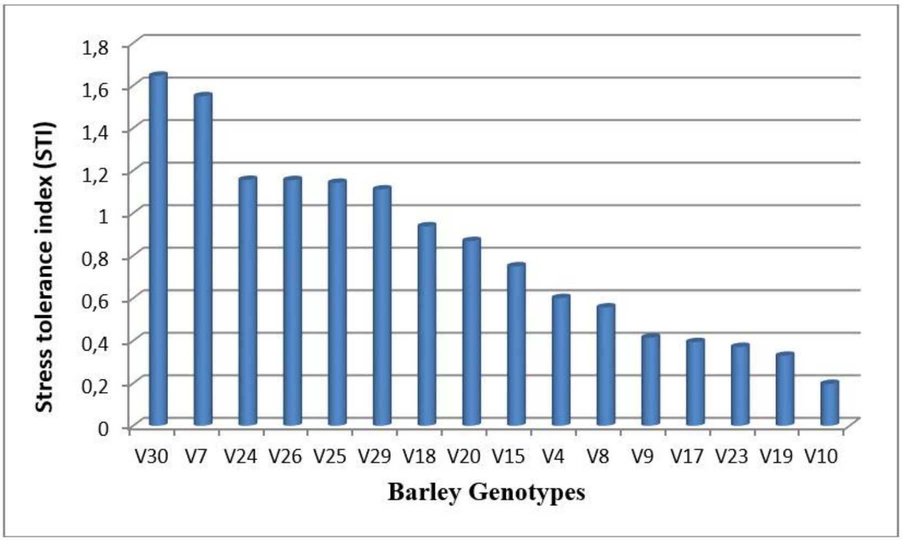

Figure 3: Stress tolerance index, based on field yield, according to barley genotypes

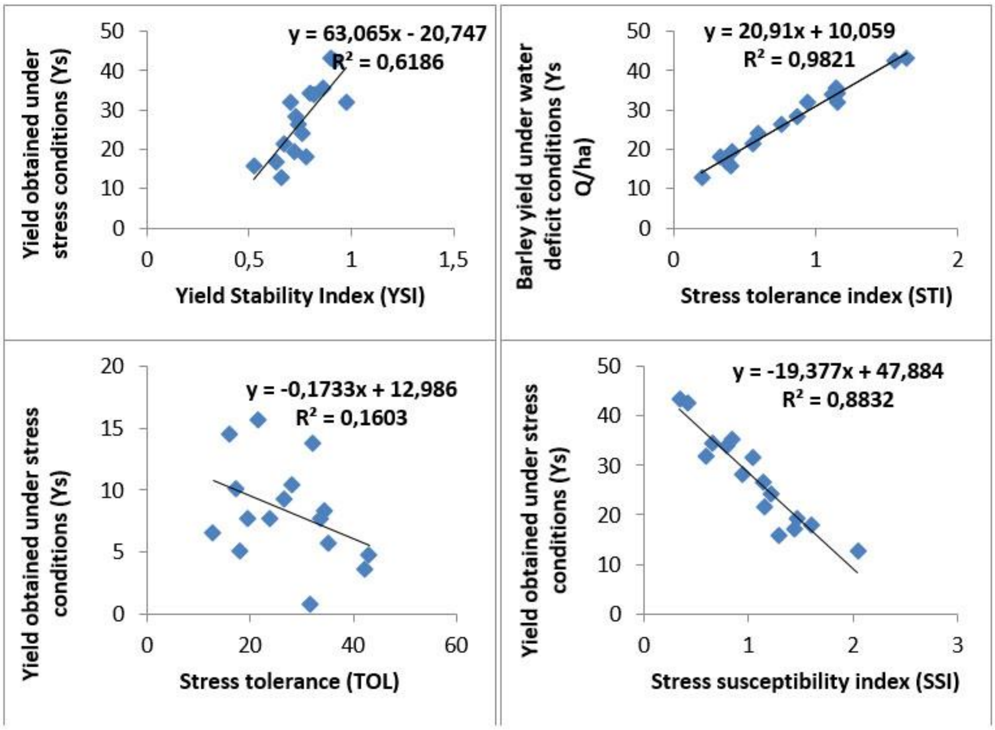

Figure 4: Correlations between grain yield, under water deficit conditions, and tolerance indices (YSI, STI, TOL and SSI).

In this work, the higher (STI) or (YSI) signify that the genotype is high yielding under stress conditions. On the other hand, the higher (SSI) or (TOL) indicate that the genotype is susceptible to drought. This result falls in line with that reported by Ramirez-Vallejo and Kelly (1998) on beans, by Farshadfar and Sutka (2002) on maize and by Anwar et al. (2011) on wheat.

Based on all drought tolerance indices used, V30 and V7 drought tolerance were found, with highest (STI) and (YSI), while V10 and V19 genotypes displayed the lowest (STI) and grain yield under stress condition (Ys).

Correlation between grain yield under water deficit conditions and root length, at the germination stage

Bassu et al. (2011) explained that root system is able to grow under water-deficit conditions would be able to extract water, even from the deepest soil layers. This characteristic is particularly important for crops that are regularly subjected to water deficit. The study conducted, at the germination stage, under physiological stress induced by PEG-6000, showed positive correlation between field yield under water deficit conditions and the ability of genotypes to maintain their growing root system under PEG-induced stress, at the germination stage (Figure 5).

The result obtained showed significant correlation ($R^2 = 0.4075$) between the root length, at germination stage, under physiological stress and the yield obtained, in the field, under water deficit conditions.

Our results are in agreement with those of Bassu et al. (2011) who found that the development of numerous and long roots under water deficit conditions is a reliable criterion for assessing the drought tolerance level of durum wheat.

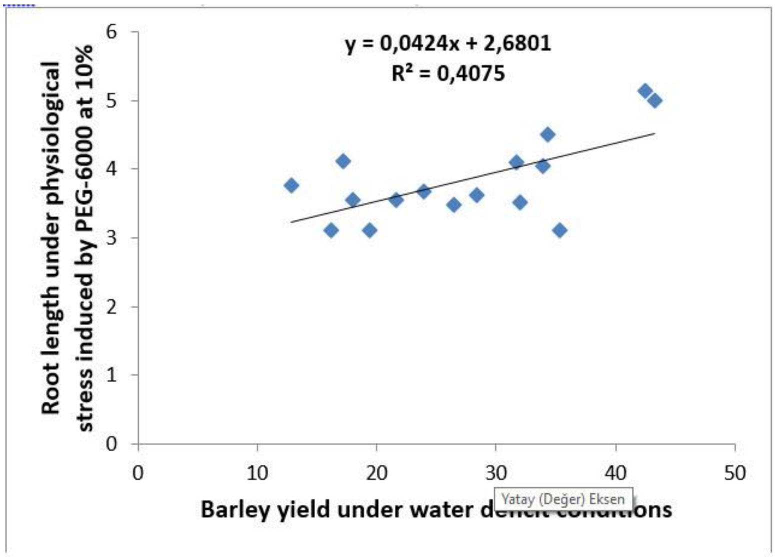

Figure 5: Relationship between yield, under water deficit, and root length, at germination stage, under physiological stress (PEG-6000)

CONCLUSION

This study has identified V30 (from Egypt) and V7 (from Tunisia) genotypes as the most productive in both favorable and drought conditions. Although they are statistically in the same group, V30 still produces slightly more than V7 and has the highest drought tolerance index. These two genotypes are among the earliest ones that terminate their cycle rapidly compared to the others. On the other hand, V10 constantly indicates the lowest yield regardless of the water regime. Significant and positive correlations between Ys and (STI) and between Ys and (YSI) were established. As well as significant negative correlations between this parameter (Ys) and (SSI) and (TOL) were pointed out. These correlations identify (STI and YSI) as the most suitable indicators for screening drought tolerant genotypes.

In addition, a positive correlation between drought tolerance in the field and the ability of the roots to grow in a stressful environment, at the germination stage, is also well demonstrated. Thus, the selection of drought tolerant genotypes could be carried out, based on this correlation, at the early stage in the laboratory, to evaluate a huge population for their tolerance to drought. It would be more cost-effective and less time consuming, to evaluate a large number of genotypes at an early-stage.

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