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EVALUATION OF PHYSIOLOGICAL TRAITS, YIELD AND YIELD COMPONENTS AT TWO GROWTH STAGES IN 10 DURUM WHEAT LINES GROWN UNDER RAINFED CONDITIONS IN SOUTHERN SYRIA

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ABSTRACT. Water stress, which limits the distribution and productivity of durum wheat (*Triticum durum* Desf.) in the Mediterranean region, is also considered to be a major factor reducing yield in semiarid regions. Improving drought resistance is thus an important objective in plant breeding programs for rainfed agriculture. The current study was carried out to identify drought-tolerant durum wheat lines among 10 lines and one variety (Douma1, the control) in the first and second settlement zones in the Southern part of Syria and to recognize the most important physiological parameters associated with drought tolerance. Membrane stability index, chlorophyll (chl) content, relative water content and chl fluorescence were recorded at the vegetative and anthesis stages, as were yield and yield components. Data recorded at vegetative and anthesis stages in both zones showed that there were significant differences between all lines growing in the first and second settlement zones and that all characters in the second zone were significantly lower than those in the first zone. Line 1 was superior to Douma1 in terms of membrane stability index, relative water content, chl content and chl florescence, also showing better yield and higher total plant biomass, tiller number/m^2, 1000 grain weight and grain number/ear than the control. The ability of wheat cultivars to perform reasonably well

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in variable rainfall and water-stressed environments is an important trait since it allows for stable production under drought stress. Moreover, prior to genetic manipulation, it is important to characterize the physiological parameters of known drought-tolerant or drought-sensitive wheat cultivars with the objective of better understanding their physiological responses under drought.

Abbreviations: F_v/F_m (Maximum quantum yield of PS II derived form chlorophyll fluorescence measurements); MSI (membrane stability index); RWC (relative water content); TGW (1000 grain weight).

Key words: Chlorophyll; F_v/F_m; Membrane stability; Rainfed; Relative water content; Wheat; Water deficit

INTRODUCTION

Wheat (*Triticum* spp.), which is one of the first domesticated food crops, represents the first source of calories (after rice) and an important source of proteins in developing countries (Hossain and Teixeira da Silva, 2013a, 2013b). Wheat is a widely adapted crop around the world, providing one third of the world's population with more than half of their calories and nearly half of their protein (Farshadfar *et al.*, 2013).

Wheat's importance is fortified by its global production, occupying 15% of 1500 million ha of arable land (Datta *et al.*, 2011) and represents about 30% of the world's cereal area, with over 220 million ha cultivated worldwide (Cossani and Reynolds, 2012). Wheat production (i.e., yield) varies from year to year and from location to location and under changing global climate, it is becoming increasingly important to adapt the crop to new environmental conditions (Almeselmani *et al.*, 2011b) in order to maximize nutritional qualities (Noorka and Teixeira da Silva, 2012). Drought, an environmental stress, is the most significant factor restricting plant growth and crop productivity in agricultural plantations around the world (Tas and Tas, 2007). Drought affects about 32% of 99 million ha under wheat cultivation in developing countries and at least 60 million ha under wheat cultivation in developed countries (Shamsi *et al.*, 2011). Wheat is mainly grown on rainfed lands and about 35% of the area of developing countries consists of semiarid environments in which the available moisture constitutes a primary constraint on wheat production (Farshadfar *et al.*, 2013). Water is necessary for plant growth and development as it is involved in various physiological functions and is essential for different metabolic activities. Thus, inadequate environmental conditions like drought cause disorders at morphological, physiological, biochemical and molecular levels (Saeedipour, 2012).

Drought stress tolerance has been observed in almost all plants but its extent varies from species to species and even within a species (Taheri *et al.*, 2011). It is possible to select or create new varieties of crops to obtain a better productivity under water stress if the morpho-anatomical and physio-biochemical characteristics of changes related to drought resistance are understood (Martínez *et al.*, 2007).

Improving the genetic potential of wheat to drought stress and identification of tolerant genotypes are the main objectives of regional breeding programmes (Hossain *et al.*, 2013a, 2013b). Thus, selection and development of new drought-tolerant wheat genotypes that can adapt to climate change is essential to ensure sustainable and productive wheat production (Hagyo *et al.*, 2007). Consequently, understanding the physiological mechanisms that enable plants to adapt to water deficit and maintain growth and productivity during a period of stress could help to screen and select heat or drought-tolerant genotypes while traits related to this tolerance can be used in wheat breeding programmes (Zaharieva *et al.*, 2001). Studying physiological and biochemical responses to water deficit may help in breeding plant cultivars of high yield and stability under drought conditions. Membrane stability index (MSI), relative water content (RWC), chlorophyll (chl) content and chl fluorescence (F_v/F_m) are major physiological traits associated with drought tolerance and yield stability of wheat under drought stress (Almeselmani *et al.*, 2011a, 2012). The primary objective of this experiment was to identify drought-tolerant durum wheat (*Triticum durum* Desf.) lines in Syria and important physiological traits associated with yield stability under rainfed conditions.

MATERIALS AND METHODS

Plant materials and growth conditions

Ten parental durum wheat lines were used (*Table 1*) while Douma1 served as the control since this variety is adapted to both agro-ecological zones used in this study. Seeds were obtained from the Crop Research Administration, General Commission for Scientific Agricultural Research, Syria (through a collaboration programme with the International Maize and Wheat Improvement Center (CIMMYT), Mexico), and sown under rainfed conditions in the field on the 20th of November, 2010 in the first settlement zone (Jellen Agricultural Research Center, annual rainfall = 400 mm) and in the second settlement zone (Izra Research Station, annual rainfall = 299 mm), hereafter referred to as the 1^{st} and 2^{nd} zone, respectively. Crops were sown at an adjusted rate of 300 viable seeds/m^2 in three replications.

Table 1 - Durum wheat lines obtained from CIMMYT, Mexico used in this study

	Parental
1	SORA/2*PLATA
2	CMH85.797//DUKE
3	SNITAN/BUSCA
4	CMH 79.1159/POC/
5	VRKS-3/7/ENTE/M
6	CNDO/VEE//CELTA
7	ENTE/MEXI-2//
8	PLATA-6/GRE
9	RASCON-37/2*T
10	SOOTY-9/RA

Standard agronomic practices were performed, relevant meteorological parameters were obtained from the observatory at each research station and rainfall was recorded. Chl content, MSI, RWC and F_v/F_m were estimated on the first fully expanded leaf (third from top) at the vegetative stage and from the flag leaf at the anthesis stage. At each stage three measurements from each replication were made. After excluding abnormal readings, the mean of the three measurements of each replication was calculated.

Chlorophyll content

A chl meter (SPAD meter; SPAD 502 Plus Chlorophyll Meter, Spectrum Technologies Inc., Aurora, IL, USA) was used to indirectly measure the relative chl concentration of leaves by non-invasive measurements.

Membrane stability index

MSI was determined by recording the electrical conductivity of leaf leachates in double distilled water (DDW) at 40 and 100°C (Deshmukh *et al.*, 1991). Leaf samples (0.1 g) were cut into discs of uniform size and placed in test tubes containing 10 ml of DDW in two sets. One set was kept at 40°C for 30 min while the other set was placed in a boiling water bath for 15 min. Their respective electric conductivities, C1 and C2, were measured by a conductivity meter as follows: $MSI = [1 - (C1/C2)] \times 100$

Relative water content

RWC was determined by the method of Barrs and Weatherley (1962) in which 100 mg (fresh weight, FW) of leaf material was placed in DDW in a Petri dish for 2 h to make the leaf tissue turgid. The turgid weight (TW) of leaf material was measured after carefully soaking the tissues between two sheets of filter paper. This leaf material was then placed in a paper bag and dried in oven at 65°C for 24 h and the dry weight (DW) was recorded. The RWC was calculated by using the formula:

$$RWC(\%) = \frac{(FW - DW)}{(TW - DW)} \times 100$$

Chlorophyll fluorescence

To estimate the polyphasic rise of fluorescence transients, intact leaves of non-stressed and water-stressed plants were measured by a Plant Efficiency Analyzer (PEA, Handsatech Instruments Ltd., King's Lynn, UK), according to Strasser *et al.* (1995). To measure chl fluorescence, all samples were covered and kept in the dark for 30 min before fluorescence measurements. Transients, induced by red light of 3000 μmol m^{-2} s^{-1} provided by an array of six light emitting diodes (peak at 650 nm), focused on the sample surface to give homogenous illumination over the exposed area of the sample surface, and maximum quantum yield of photosystem (PS) II (F_v/F_m) was measured. Readings were taken from nine plants.

Yield and yield components

In mid-June, plants were harvested from 1 m^2 and used to record the number of tillers, grain number/ear, 1000 grain weight (TGW), grain yield and total biomass.

Experimental design and statistical analyses

The experiment was laid out in a completely randomized block design with three replications. The data were analyzed statistically by analysis of variance (ANOVA) and least significant differences (LSD) values were determined at $P < 0.05$.

RESULTS AND DISCUSSION

A recent increase in world wheat production is not sufficient to meet the demands of a growing population since its production in many regions of the world is below average because of adverse environmental conditions and because wheat cultivation is mainly restricted to such zones with scarcity of water (Moaveni, 2011). Therefore achieving a genetic increase in yield under these environments is a recognized difficult challenge for plant breeders while progress in yield grain has been much higher in favorable environments. The search for varieties with improved resistance to abiotic stresses is a major goal of plant breeders and researchers all over the world.

In the 2nd zone, 42.7 mm of rainfall was received by plants from the anthesis stage onwards, which indicates the exposure of plants to terminal drought stress during the experiment. However, 293 mm was the total amount of rainfall received during the growing season in the 2nd zone, while in the 1st zone only 99 mm was received at anthesis and grain filling stages and 358.8 mm was the total amount of rainfall during the whole season (*Fig. 1*). During the growing season, there was 22% less rain in the 2nd zone than in the 1st zone. In general this amount is insufficient for drought-susceptible varieties and lines, which, under such conditions, may suffer negative impacts to plant growth and production.

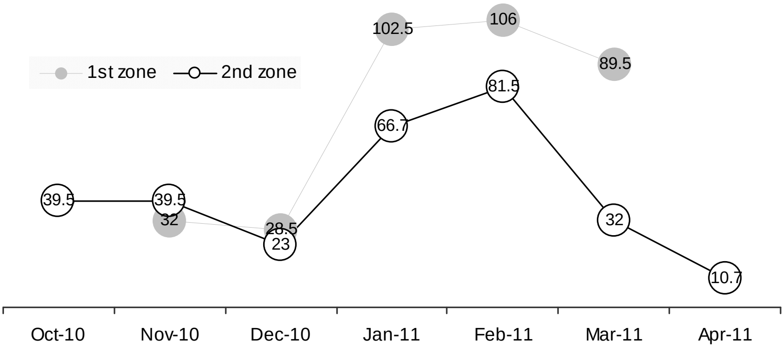

Figure 1 - Total amount of rainfall (mm) during the growing season in the 1st and 2nd settlement zones in southern Syria

Chlorophyll content

According to Manivannan *et al.* (2007), chl is one of the major components of chloroplasts for photosynthesis and relative chl content has a positive relationship with photosynthetic rate. In addition, flag leaf chl content is an indicator of photosynthetic activity and its stability indicates the conjugation of assimilate biosynthesis (Bijanzadeh and Emam, 2010). Chl content is positively linked to photosynthetic rate, which increases biomass production and grain yield; significant relationships between chl content and yield components facilitate the selection of high-yielding grain amaranth genotypes (Pandy and Singh, 2010). According to Nikolaeva *et al*. (2010), drought decreases chl content in wheat.

The results of this experiment showed significant differences in SPAD values between all lines in both zones and higher values was recorded in the lines grown in the 1st than in the 2nd zone (*Fig. 2*). The values at the anthesis stage were higher than at the vegetative stage. Higher SPAD values were recorded in lines 10 and 7 i.e., 62.9 and 62.3, respectively, at the vegetative stage in the 1st zone, higher than the control (60.5). Line 8 showed the highest value (48.2) in the 2nd zone (*Fig. 2*). At the anthesis stage, highest chl content was recorded in line 1, followed by line 2 and it was higher than the control in the 1st zone, while in the highest value of the 2nd zone was recorded in lines 1 and 3 (53.3 and 50.8 units, respectively). Line 1 showed an 18% reduction in chl content in the 2nd zone, compared with the 1st zone, while the control was 25% lower (*Fig. 3*).

Chl maintenance is essential for photosynthesis under drought stress in drought-tolerant wheat genotypes (Sairam *et al.*, 1998). This trait has been used successfully for screening and selecting drought-tolerant wheat cultivars (Almeselmani *et al*., 2011a, 2011b, 2012). According to Izanloo *et al*. (2008), water deficit leads to an increased depletion of chl and a decreased chl concentration. Zaharieva *et al*. (2001) reported that leaf color and chl content were correlated, as expected, since chl loss is the main factor responsible for change in leaf color.

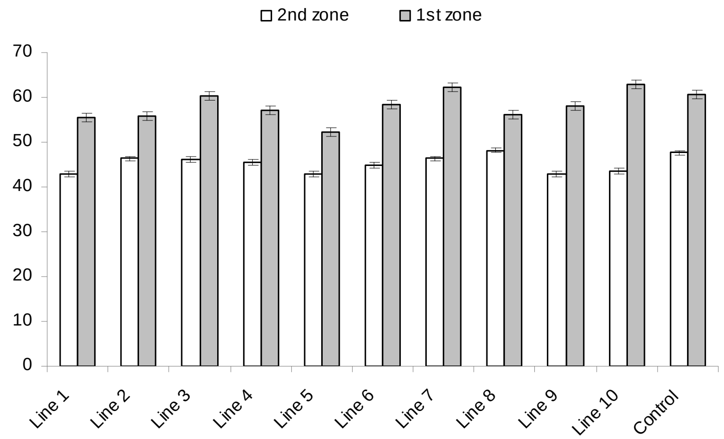

Figure 2 - Chlorophyll content (SPAD reading) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 1.5; between varieties in the 2nd zone = 1.8; between zones = 2.8

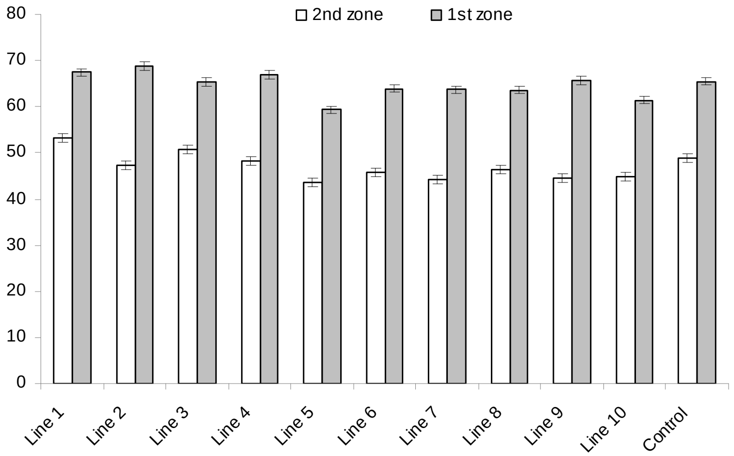

Figure 3 - Chlorophyll content (SPAD reading) of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 1.3; between varieties in the 2nd zone = 1.6; between zones = 2.6

Shamsi (2010) reported that the chl content of drought-resistant and sensitive wheat cultivars decreased under drought stress, but resistant cultivars had higher chl content. Avenson *et al.* (2005) demonstrated that chl content is positively correlated with photosynthetic rate. Crops may increase chl content as an effective way to increase biomass production and grain yield (Habibi *et al.* 2011).

Our findings indicate that chl content differed significantly among lines and between the two zones although the highest amount of total chl was recorded at the anthesis stage, and greater chl content was recorded in the 1st than in the 2nd zone. Araus *et al.* (1998) also reported that drought treatment caused a 20% reduction in leaf chl content in durum wheat. Nikolaeva *et al.* (2010) noted a decline in chl content from 13% to 15% in three varieties of water-stressed wheat compared with well-watered plants. Harb and Lahham (2013) also noted that chl synthesis was inhibited under water deficit conditions.

Membrane stability index

The cell membrane is one of the first targets of plant stress and the ability of plants to maintain membrane integrity under drought determines a plant's tolerance towards drought (Ahmadizadeh, 2013).

A significant reduction in MSI in the 2nd zone relative to the 1st zone in all lines was observed while MSI values increased in the 1st and 2nd zones as the plant aged (i.e., transition from vegetative stage to anthesis stage) (*Figs. 4, 5*). Highest MSI values at the vegetative stage were recorded in lines 8 and 1 in the 1st and 2nd zones, respectively (*Fig. 4*). At the anthesis stage, line 1 showed the highest MSI value in the 1st and 2nd zone i.e., 89.4 and 79.4%, respectively (*Fig. 5*). MSI is a widely used criterion to assess crop drought tolerance. Electrolyte leakage is correlated with drought tolerance (Ahmadizadeh *et al.*, 2011).

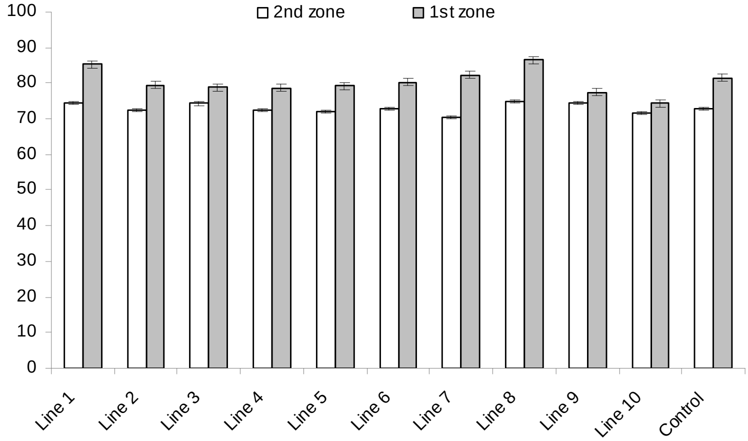

Figure 4 - Membrane stability index (%) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 1.4; between varieties in the 2nd zone = 1.7; between zones = 3.3

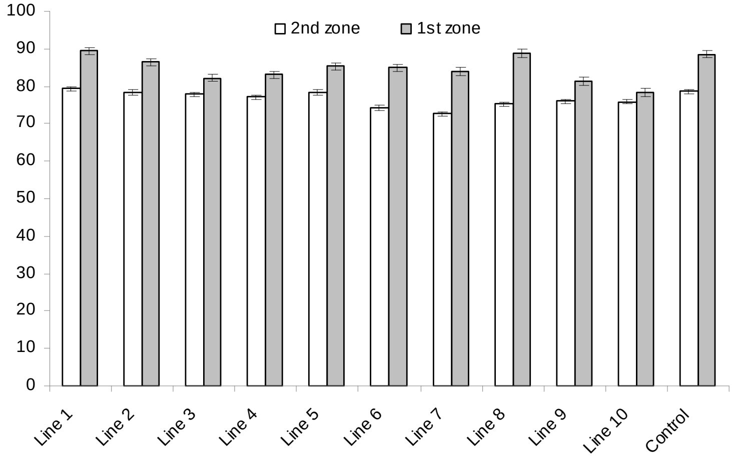

Figure 5 - Membrane stability index (%) of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 1.1; between varieties in the 2nd zone = 1.3; between zones = 2.4

Leakage is due to increasing damage to cell membranes (Almeselmani *et al.*, 2013), which emphasizes the importance of MSI in discriminating drought-tolerant from drought-susceptible lines. Increased electrolyte leakage indicates mechanical strain on membranes under severe drought (Chaves and Oliveira, 2004). A plant's drought tolerance strategy may be associated with the integrity of the cell membrane preservation and its rapid reparation while cell and organelle membranes are primary sites for desiccation injury (Gechev *et al.* 2012).

Relative water content

Leaf RWC is a more important indicator of water status than other water potential parameters under drought stress. During plant development, drought stress significantly reduced RWC values (Siddique *et al.*, 2000). RWC values were higher in the 1st, compared with the 2nd zone at all growth stages, although highest RWC values at the vegetative stage were recorded in lines 7, 1 and 8 i.e., 91.8, 90.4 and 90.3%, respectively, in the 1st zone (*Fig. 6*). Line 1 showed the highest RWC (85.4%) at the anthesis stage, higher than the control (*Fig. 7*). In the 2nd zone, highest RWC values were recorded in lines 7 and 2 i.e., 88.3 and 84.9%, respectively, which were higher than the control while at the anthesis stage, lines 1, 10 and 3 showed highest values i.e., 79.4, 78.9 and 78.6%, respectively.

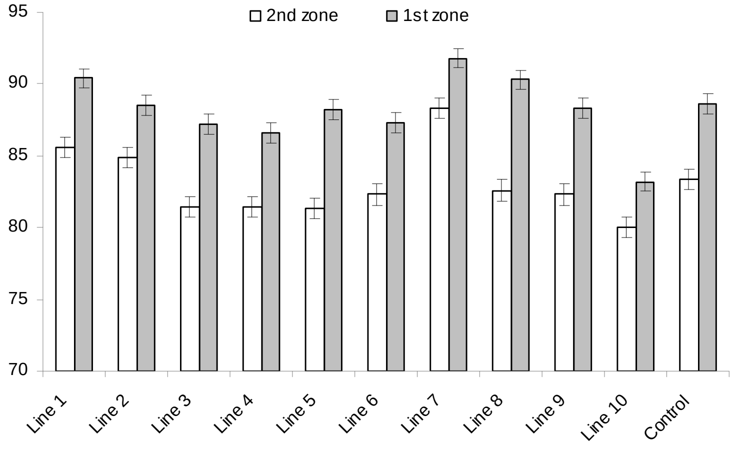

Figure 6 - Relative water content (%) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 1.2; between varieties in the 2nd zone = 1.5; between zones = 4.2

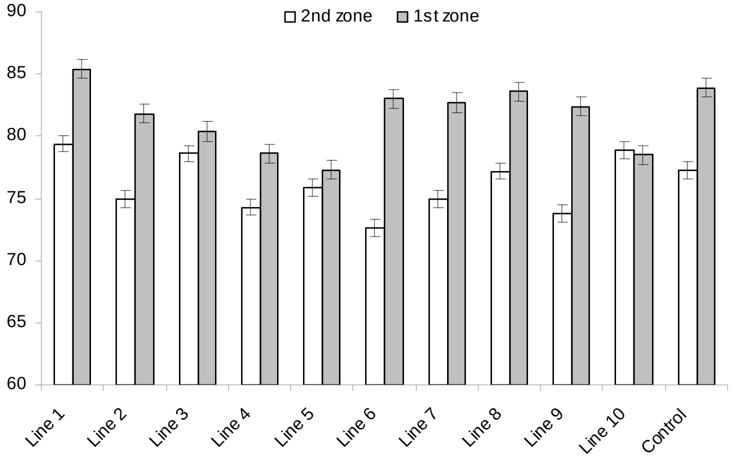

Figure 7 - Relative water content (%) of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 2.3; between varieties in the 2nd zone = 3.2; between zones = 3.2

RWC indicates that the water status of cells has a significant association with yield and stress tolerance (Almeselmani *et al.*, 2011a, 2011b, 2012). Leaf RWC, which is very responsive to drought stress and is correlated with drought tolerance (Colom and Vazzana, 2003), has been proposed as a better indicator of water stress than other growth or biochemical parameters (Sinclair and Ludlow, 1985). Leaves, when subjected to drought, tend to exhibit large reductions in RWC and water potential, as observed by Bijanzadeh and Emam (2010), who noted that RWC decreased sharply from 92.1% in well-watered conditions to 66.7% (27.5% reduction) under drought stress.

Chlorophyll fluorescence

Chl fluorescence is a way to study the effects of different stresses including drought, salinity and temperature on photosynthetic efficiency (or yield) of leaves (Zobayed *et al.*, 2005). In the present work, fluorescence and spectrofluorescence were used to screen plants under drought stress.

Drought stress inhibits photosynthesis in plants and causes changes in chl contents and damages the photosynthetic apparatus (Ahmadizadeh, 2013). According to Paknejad *et al.* (2007), drought stress reduces the variable (F_v) an initial fluorescence (F_0) parameters and quantum yield (F_v/F_m).

The ability to maintain the functionality of the photosynthetic machinery under water stress, therefore, is of major importance in drought tolerance (Mohammadi *et al.*, 2009). The drastic changes in chl fluorescence measurements most probably indicate the physical dissociation of PSII reaction centers from the light harvesting complex, a substantial accumulation of inactivated PSII centers as well as photoinhibition (Ahmadizadeh, 2013). Ma *et al.* (1995) reported that higher photochemical efficiency plays an important role in drought tolerance. This phenomenon is a criterion for thylakoid membrane integrity and electron transfer efficiency from PSII to PSI (Mamnouie *et al.*, 2006).

A significant reduction in chl fluorescence (F_v/F_m) values were observed in all lines grown in the 2nd compared to the 1st zone, and F_v/F_m values decreased as plant age advanced (*Figs. 8, 9*). According to Mamnouie *et al.* (2006), the photochemical efficiency of PSII is determined by the F_v/F_m ratio which decreases significantly during drought stress in barley.

The use of chl fluorescence from intact, attached leaves is a reliable, non-intrusive method for monitoring photosynthetic events and for judging the physiological status of oat plants (Rizza *et al.*, 2001). The variable to maximum fluorescence ratio (F_v/F_m) is indicative of potential or maximum quantum yield of PSII (Behra *et al.*, 2002). For this reason, chl fluorescence has often been proposed as a useful tool for screening durum and bread wheat for drought (Flagella *et al.*, 1995).

The data presented in *Fig. 8* shows significant differences in F_v/F_m values between different lines grown in each zone. The highest value was recorded at the vegetative stage in line 3 i.e., 0.86 in the 1st zone and in line 6 i.e., 0.73 in the 2nd zone. At the anthesis stage, highest values were recorded in lines 1, 7 and 8 i.e., 0.82, 0.81 and 0.81, respectively, in the 1st zone, while in the 2nd zone lines 1 and 2 showed highest F_v/F_m values i.e., 0.78 and 0.76, respectively (*Fig. 9*).

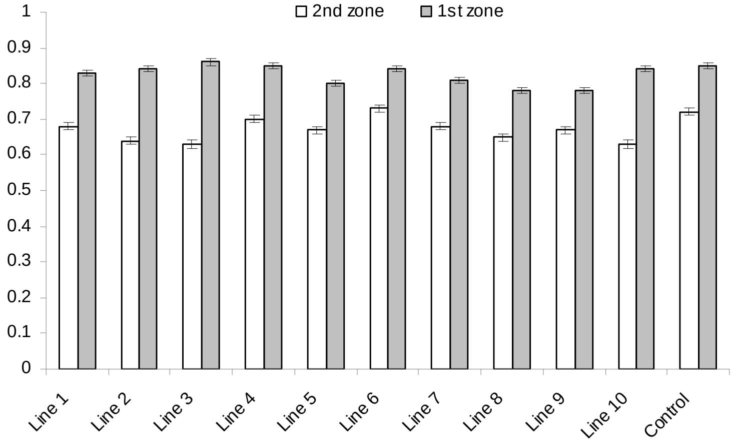

Figure 8 - Chlorophyll fluorescence (*F_v/F_m*) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at *$P \leq 0.05$*: between varieties in the 1st zone = 0.08; between varieties in the 2nd zone = 0.09; between zones = 0.06

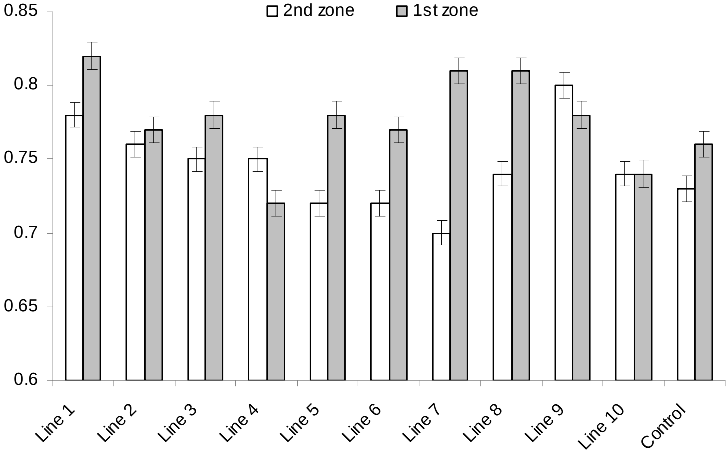

Figure 9 - Chlorophyll fluorescence (F_v/F_m) of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 0.06; between varieties in the 2nd zone = 0.07; between zones = 0.07

A similar effect of water stress on the PS II efficiency and a significant decline in F_v/F_m values were reported in intact rice leaves (Xu *et al.*, 1999). Chl fluorescence quick variation can be used as a valuable index for the evaluation of plants' tolerance to environmental stresses (Paknejad *et al.*, 2007). Flagella *et al.* (1995) also reported that drought tolerant cultivars showed a smaller decrease in photosynthetic efficiency (F_v/F_m ratios) and higher osmotic adjustment and leaf water potential under water stress.

Yield components

The negative effect of drought stress on yield and yield components in wheat is well documented (Guo *et al.*, 2004). Significant differences in total biomass between all lines grown in the 1st and 2nd settlement zones, however in the 1st zone lines 9 and 10 i.e., 1538 and 1462 g/m^2 were more superior and total biomass exceed that of control Douma1 i.e., 1403 g/m^2. In contrast, in the 2nd zone, line 1 showed highest yield i.e., 845 g/m^2, superior to Douma1 in the same zone i.e., 782 g/m^2. However, line 1 showed a 29% reduction in total biomass in the 2nd zone compared to the 1st one, while Douma1 showed a 44% reduction (*Fig. 10*). Plants produce maximum biomass under an adequate water supply, whereas moisture stress causes a marked decrease in plant biomass production (Ashraf, 1998). Moisture stress is known to reduce biomass, tillering ability, grains/spike and grain size at any stage when it occurs, but the extent of damage depends on the intensity and length of that stress.

With regard to grain yield, significant differences were recorded between different lines grown in the 1st and 2nd zones; however, a significant reduction in all lines was recorded in the 2nd, compared with the 1st zone (*Fig. 11*). Highest values for grain yield in the 1st zone were recorded in lines 1, 3 and 2 i.e., 657, 649 and 647 g/m^2, respectively; these values significantly exceeded the value of the control. In the 2nd zone, highest grain yield was recorded in lines 1, 2 and 9 i.e., 275, 246 and 236 g/m^2, while Douma 1 showed 198 g/m^2. According to Ali (2011), growth of wheat grain is reduced depending upon the degree of water deficit and the rate of stress development, thereby limiting final wheat grain yield. Drought stress at the grain-filling period dramatically reduces grain yield (Talebi *et al.*, 2009).

Akram (2011) claimed that the sensitivity of grain yield depends upon the severity of stress and the stage when it is applied. Water deficit imposed at different stages of grain growth separately showed a significant reduction in grain yield, possibly as a result of reducing the production of photoassimilates (source limitation) for grain filling, reducing the sink power to absorb photoassimilates and reducing the duration of grain filling (Martiniello and Teixeira da Silva, 2011). Akram (2011) also reported that most likely the early processes of grain growth (cell division and formation of sink size) are less affected by water deficiency. Therefore, a reduction in grain weight and grain yield under post-anthesis water deficiency might reflect the lack of supply of photoassimilates for grain filling (Ahmadi *et al.*, 2009; Abdoli and Saeidi, 2012). Water stress at anthesis reduces pollination and thus fewer grains are formed per spike which results in the reduction of grain yield (Akram, 2011).

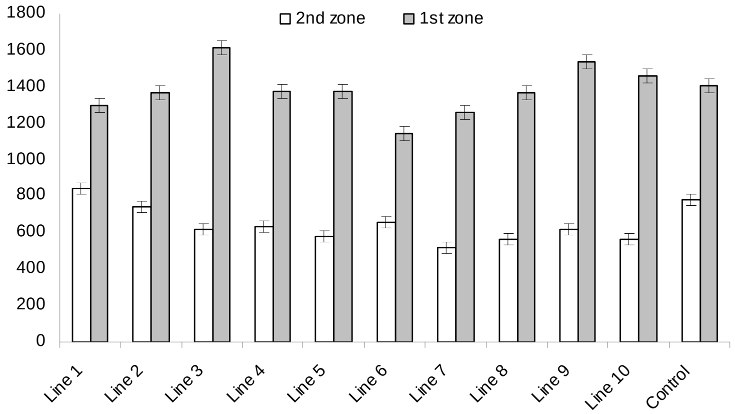

Figure 10 - Total biomass (g/m^2) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 33; between varieties in the 2nd zone = 48; between zones = 112

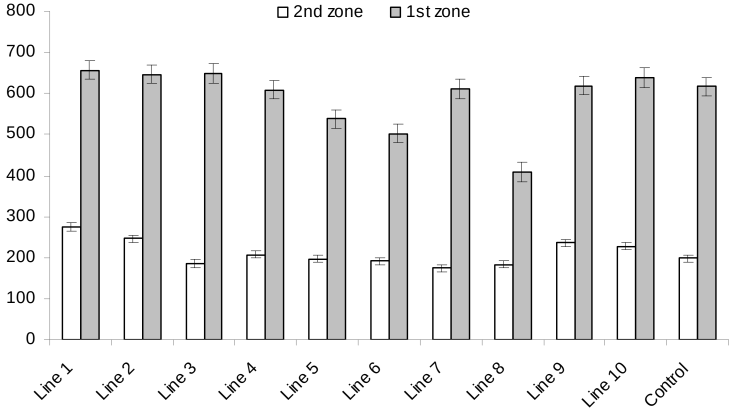

Figure 11 - Grain yield (g/m^2) of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at *P* ≤ 0.05: between varieties in the 1st zone = 18; between varieties in the 2nd zone = 21; between zones = 23

Tiller number/m^2 differed significantly between all lines in each growing zone, and the lines in the 1st zone showed higher values than those in the 2nd zone. In the 1st zone, lines 1 and 10 i.e., 389 and 388 were superior to the control i.e., 370, while in the 2nd zone, lines 1 and 2 showed highest values i.e., 298 and 287, respectively, compared with the control i.e., 265 (*Fig. 12*). Line 1 showed a 23% reduction in tiller number/m^2 in the 2nd zone, compared with the 1st zone while the control showed a 28% reduction. Drought stress may reduce all yield components, but particularly the number of fertile spikes per unit area and the number of grains/spike. Karim *et al*. (2000) investigated the effect of water stress at the reproductive stage on grain growth pattern and yield responses of wheat and found that 94% of tillers of irrigated plants produced ears, compared to 79% of stressed plants.

Grain number/ear also differed significantly between lines grown in the 1st and 2nd zones. In the 1st zone, lines 8 and 1 showed highest grain number/ear i.e., 56.8 and 53.4, compared to the control i.e., 47.5, while in the 2nd zone, line 6 showed the highest value i.e., 44.4, compared to the control (39.5), as shown in *Fig. 13*. However, all lines showed a significant reduction in this trait in the 2nd zone, compared with the 1st zone. Ngwako and Mashiqa (2013) found that the number of grains/spike is sensitive to drought stress, which, during maturity, resulted in about a 10% decrease in yield. The number of grains, grain yield, biological yield and harvest index decreased when water stress was imposed at the anthesis stage (Jatoi *et al*., 2011). Drought stress reduced all yield components, decreasing the number of fertile spikes as well as the number of grains per spike by 60% and 48%, respectively (Shamsi and Kobraee, 2011).

According to Saleem (2003), drought stress reduced the number of grains/spike and grain yield, and genotypes with a higher number of grains/ear produce greater yield (Iqbal *et al.*, 1999). According to Elhafid *et al.* (1998), drought leads to reduced flower pollination which affects the number of grains produced. Tompkins *et al.* (1991) reported a significant suppressive effect of water stress on the number of grains/spike.

Compared with the 2nd zone, the values of TGW were higher in the 1st zone. Data in *Fig. 14* shows highest TGW in lines 6, 2 and 1 i.e., 55.3, 53.8 and 53.5 g, respectively, higher than control in the 1st zone, while in the 2nd zone, highest values were recorded in lines 9 and 1 i.e., 47.9 and 46.8 g, respectively, higher than the control. Saeidi *et al.* (2010) found that post-anthesis water deficiency stress reduced grain yield and TGW. Zafarnaderi *et al.* (2013) showed that grain yield is strongly affected by water stress because of the reduction in number of spikes/m^2, number of grains/spike and TGW under stress conditions. Highest TGW was observed in drought-tolerant varieties i.e., 51.6 g, but no significant differences between susceptible and moderately tolerant varieties (Almeselmani *et al.*, 2012). Drought stress during the flowering stage disrupts flowing, photosynthesis and the transfer of stored substances into grains, which reduces the number and weight of grains (Shamsi and Kobraee, 2011).

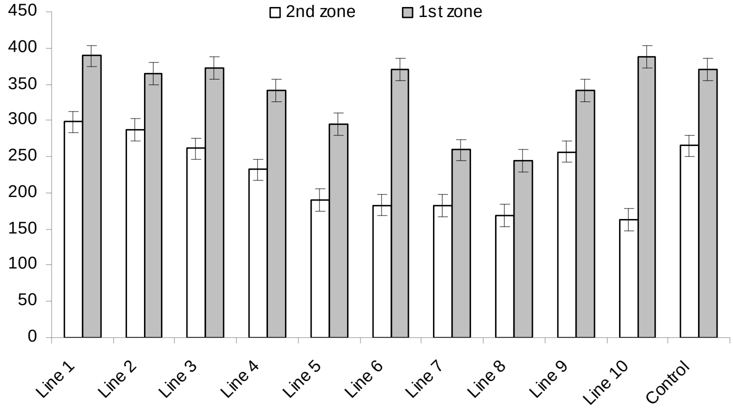

Figure 12 - Tiller number/m^2 of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 1.4; between varieties in the 2nd zone = 1.7; between zones = 31

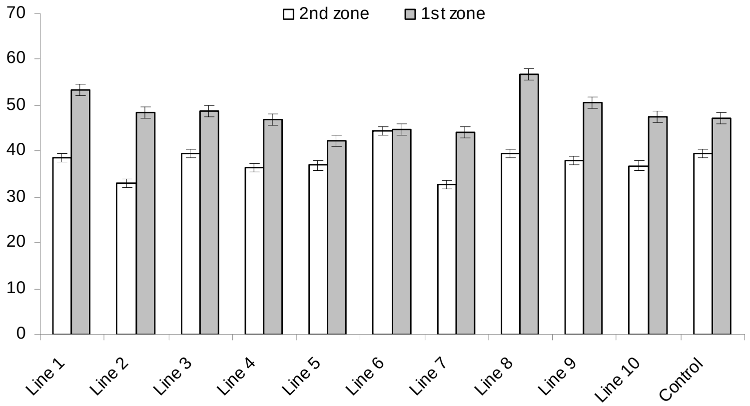

Figure 13 - Grain number/ear of 10 lines of durum wheat and in var. Douma1 as the control at anthesis in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 0.9; between varieties in the 2nd zone = 1.2; between zones = 4.6

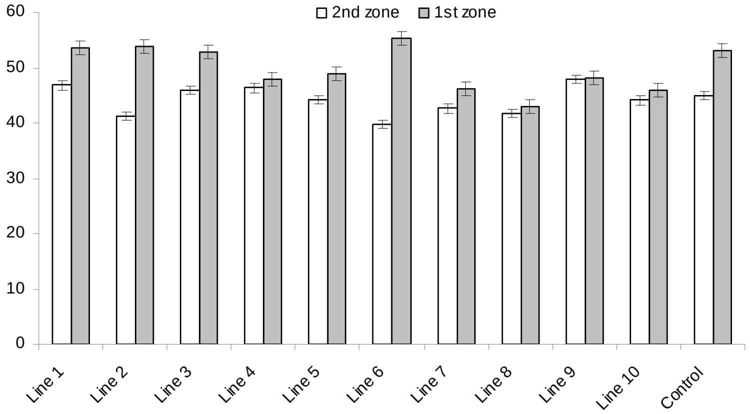

Figure 14 – 1000 grain weight (g) of 10 lines of durum wheat and in var. Douma1 as the control at the vegetative stage in the 1st and 2nd settlement zones. LSD values at $P \leq 0.05$: between varieties in the 1st zone = 0.7; between varieties in the 2nd zone = 1.3; between zones = 1.3

Water stress imposed during later stages might additionally cause a reduction in the number of kernels/ear and kernel weight (Dencic *et al.*, 2000). According to Atefeh *et al.* (2011) kernel weight is negatively influenced by high temperatures and drought during ripening. A significant reduction in TGW of wheat has been reported by Ahmad and Arian (1999) and Abdoli *et al.* (2013). Khan *et al.* (2005) also observed that TGW of wheat was reduced mainly due to increasing water stress.

CONCLUSIONS

Drought, being the most influential environmental stress, severely impairs plant growth and development, limits plant production and the performance of crop plants, in particular wheat (Hossain *et al.,* 2013), more than any other environmental factor (Shao *et al*., 2009). Our data shows that the effect of drought on all traits was transferred to yield, particularly at the anthesis stage. Tolerant lines showed better physiological performance and maintained a stable and efficient physiology, thus resulting in better yield. Line 1 performed best and should be included in wheat breeding programmes for developing drought-tolerant varieties.

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