Research Paper / 47-59

Effect of drought stress on some morphological and physiological traits in *Aegilops tauschii* genotypes

Keyvan Hasanpour[1], Ali Aalami[2*], Ramin Hosseini[3], Shahram Naeimi[4]

[1]Department of Biotechnology, University Campus 2, University of Guilan, Rasht, Iran.
[2]Department of Biotechnology, Faculty of Agricultural Sciences, University of Guilan, P. O. Box: 41996-13776, Rasht, Iran.
[3]Department of Biotechnology, Faculty of Agriculture and Natural Resource, Imam Khomeini International University, Qazvin, Iran.
[4]Department of Biological Control Research, Iranian Research Institute of Plant Protection, Agricultural Research, Eduction and Extension Organization (AREEO), Tehran, Iran.
**Corresponding author, Email: ali_aalami@guilan.ac.ir. Tel: +98-013-33690274.*

Received: 07 Nov 2020; Accepted: 19 Sep 2021.
DOI: 10.30479/IJGPB.2021.14510.1284

Abstract

Aegilops tauschii is one of the ancestors of bread wheat and is the main source of genes for resistance to biotic and abiotic stresses. The present research was performed as a factorial experiment based on a completely randomized design to determine the effect of drought stress on some morphological traits in 23 *A. tauschii* genotypes. Some important morphological and physiological traits were evaluated in the greenhouse conditions. The results showed that root length, the number of leaves and tillers, chlorophyll content, shoot and root fresh weight, shoot and root dry weight, percentage of yellow and rolled leaves at seedling stage and shoot and root dry weight, flag leaf, peduncle and spike length and the number of spikes at maturity stage increased in drought stress. Instead, RWC and shoot length were reduced at the seedling stage in the drought stress condition. In the seedling stage, the highest values obtained for root length, number of leaves, root fresh and dry weight, percentage of yellow and rolled leaves were 44.67 cm, 24.00, 3.35 g/plant, 0.40 g/plant, 50% and 80.79% under drought condition, respectively. In the maturity stage, the highest values obtained for shoot and root dry weights were 26.58 and 41.77 g/plant obtained in genotypes KC-55 and KC-2122 under drought condition. The highest values for flag leaf length, peduncle length, spike length and the number of spike were 12.30 cm, 15.65 cm, 9.08 cm and 30 observed in genotypes KC-2123, KC-2225, KC-2115 and KC-621 at control, respectively. Based on the ward’s cluster analysis, *A. tauschii* genotypes were divided into four different groups. The results of this study showed genotypes KC-621, KC-1772 and KC-2225 were tolerant to drought stress and therefore, they are recommended for use in wheat breeding programs.

***Key words*: *Aegilops tauschii*, Maturity stage, Morphological traits, RWC, Seedling stage.

INTRODUCTION

Hexaploid wheat (*Triticum aestivum*) is derived from the hybridization of tetraploid *Triticum turgidum* with *Aegilops tauschii*. *A. tauschii* Cosson (DD, 2n=2x=14) is the D genome progenitor of bread wheat that has spread from Northern Syria and Turkey to Western China (Wang *et al.,* 2013). This plant is compatible with various environments such as deserts margins, sandy seashore, steppes, rocky hills, roadsides, wastelands and humid temperate forests and has a great genetic diversity (Matsuoka *et al.,* 2008). Based on the genetic background, *A. tauschii* is divided into two phylogenetic lineages called L1 and L2. The first case is related to the *A. tauschii* ssp. *tauschii* and the second case is related to the *A. tauschii* ssp. *strangulataI* (Mizuno *et al.,* 2010; Zhao *et al.,* 2020). Studies have shown that *A. tauschii* (especially L2 lineage) is from the Trans Caucasus and Northern Iran is the origin of the wheat D genome. Due to the long genetic distance between L1 and L2 lineages of *A. tauschii*in Eastern and Southern populations (such as Syria, Afghanistan, Pakistan, Central Asia and China), it seems that this plant has abundant genetic and phenotypic characteristics. Therefore, like many wild ancestors of crops, *A. tauschii*is is considered a very valuable source for resistance to biotic and abiotic stresses (Zhang *et al.,* 2018; Safiyar *et al*., 2021).

Drought is one of the most important stresses that has affected the growth and yield of all crops around the world (Du *et al.,* 2020). Various studies show that drought stress causes a wide range of damage to the plant and inhibits photosynthesis (Ohashi *et al.,* 2006), increases oxidative stress (Porcel and Ruiz-Lozano, 2004) and changes the plant metabolism (Valliyodan and Nguyen, 2006). Under drought stress conditions, many morphological, physiological and biochemical changes occur in the plant (Xu *et al.,* 2015). Therefore, physiological and biochemical factors restricting the plant yield and mechanisms associated with the drought resistance are the main goals of breeding programs (Gálvez *et al.,* 2019; Naderi *et al.,* 2020). Biomass allocation is one of the most important growth factors and is also one of the main strategies for plant drought stress adaptation. Studying the morphological and physiological characteristics of plants in rainfed conditions can increase our understanding of the ability of crops to respond to drought stress and adapt to it (Pour-Aboughadareh *et al.,* 2020).

Various morphological indices such as plant height, number of tillers, peduncle length, spike length and even number of seeds show not only the effect of water restriction in the soil but also show how genotypes adapt to drought stress through morphological changes (Liu *et al.,* 2015). Root is one of the most important organs of the plants in stress conditions, since it causes plant survival through the absorption of water and minerals. Under drought stress conditions, the transfer of assimilates from photosynthetic organs such as leaves to roots and seeds is changed and increases its resistance (Du *et al.,* 2020). With climate change, the adverse effects of drought on the plant are expected to intensify in the coming years (Liu *et al.,* 2020). Accordingly, screening of drought-tolerant cultivars of *Aegilops* is required for drought adaptation and maximum yield. This study aimed to evaluate the morphological responses of 23*A. tauschii* genotypes exposed to drought stress and identify the tolerant genotypes to drought stress.

MATERIALS AND METHODS

Plant materials

A total of 23 *A. tauschii* genotypes were used in the study (Table 1). These genotypes were obtained from the National Plant Gene Bank of Iran in Seed and Plant Improvement Institute, Karaj, Iran.

Growth conditions

All the *A. tauschii* genotypes were grown in the greenhouse of Imam Khomeini International University (IKIU). First, the seeds were soaked in water for 3-4 days. The seeds of *A. tauschii* with similar size were grown in plastic pots (20 cm in diameter and 30 cm in height) with 5-6 seeds per pots. Each pot contained similar volumes of sandy loam soil. Initially, the pots were irrigated and the soil moisture maintained at about 80–100% field capacity for seed germination. Ten days after germination (seedlings had 3-4 leaves) different field capacity levels (control and drought stress) were maintained in the pots. Fourteen days after drought stress three seedlings from each replication were collected and the indices were measured and three seedlings were kept until full maturity and seed production (maturity stage). Soil moisture was measured by using a Delta-T moisture meter device (United Kingdom). The pots were maintained in the greenhouse with a 16/8 photoperiod at 26±2 °C.

Traits evaluation

The following traits were evaluated in the seedling stage: relative water content (RWC), chlorophyll content (sChl; Spad) shoot length (sSL; cm), root length (sRL; cm), shoot fresh weight (sSFW; g/plant), root fresh weight (sRFW; g/plant), shoot dry weight (sSDW; g/plant), root dry weight (sRDW; g/plant), number of leaves (sNL), number of tiller (sNT), percentage of yellow leaves (sPYL; %), percentage of rolled leaves (sPRL; %). Also, the following morphological traits were evaluated in the maturity stage: shoot dry weight (mSDW; g/plant), root dry weight (mRDW; g/plant), flag leaf length (mFLL; cm), peduncle length (mPL; cm), spike length (mSL; cm) and the number of spikes (mNS). All traits were measured based on three randomly selected samples of each genotype during the seedling and maturity stages. Length of flag leaf was measured from leaf sheath to the tip of the leaf. Peduncle length was measured from the last node from the top of the plant to the rachis. The spike length was measured excluding awns.

Statistical analysis

The experiments were performed in factorial experiments based on a completely randomized design in three replications. Data were analyzed using SPSS

Table 1. Genotype code and collection locations of *A. tauschii* genotypes in this study.

No.	Genotype code	Country	Province	Location
1	KC-29	Iran	East Azerbaijan	10 km of Ahar-Tabriz road
2	KC-55	Armenia	-	-
3	KC-58	Iran	East Azerbaijan	10 km of Ahar-Tabriz road
4	KC-65	Iran	East Azerbaijan	10 km of Ahar-Kaleybar road
5	KC-82	Iran	Gilan	Rasht
6	KC-621	Iran	North Khorasan	Bojnurd
7	KC-839	Iran	Mazandaran	Sari
8	KC-1749	Iran	Semnan	Shahroud
9	KC-1772	Iran	Mazandaran	-
10	KC-2009	Iran	Mazandaran	Behshahr
11	KC-2015	Iran	Mazandaran	Nur
12	KC-2115	Iran	Razavi Khorasan	Mashhad
13	KC-2120	Iran	North Khorasan	Bojnurd
14	KC-2121	Iran	North Khorasan	Bojnurd
15	KC-2122	Iran	North Khorasan	Bojnurd
16	KC-2123	Iran	North Khorasan	Bojnurd
17	KC-2189	Iran	Qazvin	Qazvin
18	KC-2225	Iran	Ardabil	Khalkhal
19	KC-2226	Iran	Ardabil	Khalkhal
20	KC-2231	Iran	Ardabil	Khalkhal
21	KC-2241	Iran	Ardabil	Khalkhal
22	KC-2248	Iran	Ardabil	Khalkhal
23	KC-2286	Iran	Chaharmahal and Bakhtiari	Boroujen

26.0 statistical software package and the means were compared by Duncan's multiple range test. Ward's method was used for cluster analysis and classification of different genotypes. The correlation analysis was also conducted based on Pearson correlation coefficients.

RESULTS

Seedling stage

Analysis of variance

The results of the analysis of variance on the traits indicated significant effects for stress (except for sSL, sRL, and sSFW) and genotypes (except for sChl). The interaction of stress and genotype effects was significant for all traits except for sChl. The coefficient of variation (CV) ranged from 10.98 to 18.86%; the highest value was observed for sSFW (18.86%), followed by sChl (17.88%) and sRL (17.81%) (Table 2).

Range of data and mean comparison

Drought stress significantly decreased RWC around 8.13% compared with the control conditions and increased sNL, sNT, sChl, sRFW, sSDW, sRDW, sPYL and sPRL compared with the control condition. The highest value for RWC was 71.72% obtained at control condition and the highest values for sNL, sNT, sChl, sRFW, sSDW, sRDW, sPYL and sPRL were obtained as 14.22, 3.22, 9.30, 1.29 g/plant, 0.27 g/plant, 0.16 g/plant, 25.04% and 21.83% observed in the drought stress condition (Table 3). The response of each genotype for the traits is shown in Tables 2 and 3. The highest values obtained for RWC, sSL, sRL, sNL, sNT, sSFW, sRFW, sSDW, sRDW, sPYL and sPRL were 77.91%, 8 cm, 39.33 cm, 19.17, 3.67, 2.79 g/plant, 2.34 g/plant, 0.51 g/plant, 0.24 g/plant 37.45% and 40.39% observed in genotypes KC-2009, KC-621, KC-65, KC-2009, KC-55, KC-1749, KC-1749, KC-1749, KC-2286, KC-58 and KC-2231 (Tables 2 and 3).

Under the control condition, RWC ranged from 61.74% to 79.56% (mean ~71.72%), and genotypes KC-2123, KC-2009, and KC-2015 showed a high value of RWC. Under the drought condition, RWC varied between 46.14% and 77.61% (mean ~65.89%), and genotypes KC-82, KC-621, and KC-2009 had the highest values. There was variability in sSL under both conditions; this trait varied between 4.25 cm and 8.00 cm (average ~6.47) under the control condition, and between 4.17 cm and 8.00 cm (average ~6.35) under the drought conditions. Under the control condition, genotypes KC-621, KC-1749, KC-65 and KC-2286 were identified as the genotypes with high sSL; under drought conditions, the genotypes with the highest sSL were KC-621, KC-1749, and KC-65.

Table 2. Analysis of variance for measured traits in *A. tauschii* genotypes at the seedling stage under control and drought stress conditions.

Source of variation	df	Mean of square											
		RWC	sSL	sRL	sNL	sNT	sChl	sSFW	sRFW	sSDW	sRDW	sPYL	sPRL
Stress	1	1174.094**	0.505^{ns}	1.244^{ns}	57.399**	25.225**	274.696*	0.005^{ns}	2.131**	0.024**	0.065**	4051.269**	15538.415**
Genotype	22	140.050*	4.943**	138.303**	84.906**	2.049**	75.149^{ns}	1.480**	1.326**	0.066**	0.016**	453.524**	415.020**
Stress×Genotype	22	140.489*	1.254*	148.162**	39.262**	4.179**	59.259^{ns}	0.726**	1.139**	0.031**	0.012**	341.084**	454.431**
Error	92	81.334	0.748	25.833	4.312	0.246	49.117	0.067	0.032	0.002	0.0003	11.671	1.512
Coefficient of variation (%)		13.11	13.50	17.81	15.30	17.78	17.88	18.86	15.39	17.23	12.22	17.41	10.98

^{ns}, * and **: indicate non-significant and significant at 5% and 1% probability levels, respectively.
S: Seedling stage, RWC: Relative water content, SL: Shoot length, RL: Root length, NL: Number of leaves, NT: Number of tillers, Chl: Chlorophyll content, SFW: Shoot fresh weight, RFW: Root fresh weight, SDW: Shoot dry weight, RDW: Root dry weight, PYL: Percentage of yellow leaves, PRL: Percentage of rolled leaves.

Table 3. Mean values for traits under control and drought conditions in 23 *A. tauschii* genotypes at the seedling stage.

Stress	Genotype	sRWC (%)	sSL (cm)	sRL (cm)	sNL	sNT	sSFW (g/plant)	sRFW (g/plant)	sSDW (g/plant)	sRDW (g/plant)	sPYL (%)	sPRL (%)
	KC-29	74.48±3.53^{a-d}	5.67±0.73^{d-j}	22.33±0.88^{i-n}	9.67±0.88^{o-v}	3.00±0.00^{efg}	0.89±0.14^{m-s}	1.06±0.01^{k-q}	0.14±0.02^{mno}	0.08±0.00^{lm}	24.39±0.61^{gh}	7.20±0.96^{kl}
	KC-55	77.62±2.53^{a}	6.50±0.58^{a-e}	24.25±1.59^{f-n}	11.00±0.58^{m-t}	3.67±0.33^{cde}	1.20±0.26^{j-p}	0.81±0.07^{n-s}	0.23±0.02^{h-l}	0.08±0.01^{lm}	14.17±1.27^{k-o}	6.39±0.20^{l}
	KC-58	61.74±6.70^{a-f}	6.33±0.93^{a-f}	21.33±1.88^{k-n}	16.67±0.67^{e-j}	3.67±0.67^{cde}	2.63±0.27^{b}	0.73±0.10^{q-t}	0.45±0.05^{bc}	0.08±0.00^{lm}	17.61±1.31^{i-m}	0.00±0.00^{m}
	KC-65	68.25±4.67^{a-e}	7.50±0.76^{abc}	32.00±0.58^{d-j}	13.33±1.20^{i-p}	5.00±0.00^{a}	1.87±0.23^{c-g}	2.31±0.09^{b}	0.30±0.05^{e-h}	0.24±0.00^{b}	12.54±1.05^{m-p}	0.00±0.00^{m}
	KC-82	64.50±3.80^{a-e}	5.50±0.58^{e-j}	27.17±1.59^{e-m}	16.00±2.08^{f-k}	2.67±0.33^{fgh}	1.22±0.14^{j-o}	0.44±0.05^{tuv}	0.33±0.05^{efg}	0.15±0.00^{e-i}	6.45±0.78^{pqr}	0.00±0.00^{m}
	KC-621	74.48±0.86^{a-d}	8.00±0.58^{a}	39.00±3.51^{a-d}	19.33±0.67^{b-g}	2.67±0.33^{fgh}	2.10±0.46^{cd}	1.78±0.15^{def}	0.43±0.02^{bc}	0.07±0.00^{m}	5.73±1.35^{qrs}	0.00±0.00^{m}
	KC-839	71.96±4.06^{a-e}	7.00±0.50^{a-d}	23.33±0.88^{g-n}	13.67±1.76^{i-o}	2.33±0.33^{ghi}	1.40±0.18^{g-l}	0.44±0.05^{tuv}	0.27±0.04^{g-j}	0.18±0.00^{cd}	14.00±0.93^{k-o}	0.00±0.00^{m}
	KC-1749	71.18±2.86^{a-e}	7.83±0.17^{ab}	31.67±0.88^{d-k}	21.33±0.88^{abc}	2.00±0.00^{hi}	3.56±0.29^{a}	2.32±0.05^{b}	0.64±0.06^{a}	0.20±0.00^{c}	10.94±1.06^{n-q}	0.00±0.00^{m}
	KC-1772	71.54±1.97^{a-e}	6.17±0.17^{b-h}	32.67±1.45^{d-i}	20.00±2.31^{b-e}	2.00±0.00^{hi}	1.46±0.08^{f-l}	0.49±0.06^{s-v}	0.29±0.02^{e-i}	0.16±0.00^{c-g}	1.39±0.39^{rs}	0.00±0.00^{m}
	KC-2009	78.85±2.26^{a}	6.50±0.29^{a-e}	22.67±4.26^{i-n}	17.33±1.76^{d-i}	1.00±0.00^{j}	1.34±0.14^{h-m}	0.79±0.10^{p-s}	0.32±0.09^{efg}	0.09±0.01^{klm}	7.72±0.34^{opq}	0.00±0.00^{m}
	KC-2015	77.67±3.89^{a}	5.00±0.58^{f-j}	28.17±5.18^{e-m}	9.00±0.58^{q-v}	1.00±0.00^{j}	0.58±0.05^{rst}	0.69±0.01^{r-v}	0.14±0.01^{mno}	0.06±0.00^{m}	12.04±0.47^{m-q}	0.00±0.00^{m}
Control	KC-2115	69.86±4.99^{a-e}	6.77±0.37^{a-d}	33.33±3.33^{c-h}	11.33±1.33^{l-s}	2.67±0.33^{fgh}	1.57±0.23^{e-l}	0.73±0.02^{q-t}	0.09±0.01^{no}	0.07±0.00^{m}	9.58±0.68^{n-q}	0.00±0.00^{m}
	KC-2120	74.06±2.55^{a-d}	6.75±0.14^{a-d}	42.50±1.44^{abc}	9.33±0.88^{p-v}	2.33±0.33^{ghi}	1.67±0.06^{d-j}	0.80±0.04^{o-s}	0.25±0.01^{g-k}	0.11±0.00^{jkl}	15.07±2.05^{k-n}	0.00±0.00^{m}
	KC-2121	76.06±1.16^{abc}	6.00±0.29^{c-h}	23.33±3.33^{g-n}	8.67±0.88^{r-v}	2.33±0.33^{ghi}	0.66±0.06^{q-t}	0.38±0.07^{uv}	0.13±0.01^{mno}	0.06±0.01^{m}	12.88±1.11^{l-p}	0.00±0.00^{m}
	KC-2122	73.29±1.72^{a-d}	6.17±0.60^{b-h}	34.00±5.03^{c-f}	11.00±1.15^{m-t}	0.00±0.00^{k}	0.82±0.09^{n-s}	1.63±0.19^{efg}	0.15±0.01^{l-o}	0.13±0.01^{hij}	24.19±1.56^{gh}	0.00±0.00^{m}
	KC-2123	79.56±3.49^{a}	6.00±1.32^{c-h}	21.67±0.88^{j-n}	6.33±0.33^{uv}	1.67±0.33^{ij}	0.78±0.13^{p-t}	1.14±0.03^{j-o}	0.09±0.00^{no}	0.13±0.00^{g-j}	20.00±1.92^{h-k}	0.00±0.00^{m}
	KC-2189	64.92±3.94^{a-e}	7.00±0.00^{a-d}	32.00±1.73^{d-j}	15.67±0.67^{f-k}	4.00±0.00^{bcd}	1.68±0.10^{d-j}	1.44±0.27^{g-j}	0.30±0.01^{e-k}	0.14±0.00^{f-j}	13.00±1.01^{l-p}	0.00±0.00^{m}
	KC-2225	65.83±6.20^{a-e}	7.25±0.14^{a-d}	22.50±0.87^{i-n}	14.00±0.58^{h-n}	1.67±0.33^{ij}	1.67±0.01^{d-j}	1.34±0.00^{g-k}	0.28±0.00^{f-i}	0.14±0.00^{f-i}	9.39±1.98^{n-q}	0.00±0.00^{m}
	KC-2226	74.19±4.60^{a-d}	4.25±0.14^{ij}	36.50±0.87^{b-e}	7.00±0.58^{tuv}	2.00±0.00^{hi}	0.48±0.00st	1.45±0.00^{g-j}	0.10±0.00^{no}	0.15±0.00^{d-i}	34.52±2.49^{def}	0.00±0.00^{m}
	KC-2231	68.57±0.55^{a-e}	6.25±0.14^{a-f}	26.50±0.87^{e-m}	8.67±0.33^{r-v}	2.00±0.00^{hi}	0.71±0.08^{p-t}	0.89±0.02^{l-r}	0.20±0.00^{i-m}	0.15±0.00^{d-h}	31.02±4.56^{ef}	0.00±0.00^{m}
	KC-2241	70.41±16.7^{a-e}	5.60±1.07^{d-j}	29.00±3.06^{e-m}	17.00±1.15^{e-j}	2.00±0.00^{hi}	1.37±0.04^{g-m}	0.83±0.06^{n-s}	0.27±0.02^{g-j}	0.13±0.00^{hij}	10.07±0.58^{n-q}	0.00±0.00^{m}
	KC-2248	72.17±0.74^{a-d}	7.25±0.14^{a-d}	24.50±1.44^{f-n}	10.67±0.33^{m-t}	2.33±0.33^{ghi}	0.72±0.10^{p-t}	0.72±0.06^{q-t}	0.10±0.00^{no}	0.08±0.01^{lm}	10.17±0.60^{n-q}	0.00±0.00^{m}
	KC-2286	68.44±6.73^{a-e}	7.50±0.58^{abc}	23.67±1.45^{g-n}	10.33±0.88^{m-u}	2.33±0.33^{ghi}	1.05±0.05^{l-r}	0.65±0.04^{r-v}	0.17±0.01^{k-n}	0.08±0.00^{lm}	9.81±0.81^{n-q}	0.00±0.00^{m}

S: Seedling stage, RWC: Relative water content, SL: Shoot length, RL: Root length, NL: Number of leaves, NT: Number of tillers, SFW: Shoot fresh weight, RFW: Root fresh weight, SDW: Shoot dry weight, RDW: root dry weight, PYL: Percentage of yellow leaves, PRL: Percentage of rolled leaves.
Values in each column followed by the same letter in superscript are not significantly different according to the Duncan's multiple range test.

Table 3 (continued). Mean values for traits under control and drought conditions in 23 *A. tauschii* genotypes at the seedling stage.

Stress	Genotype	sRWC (%)	sSL (cm)	sRL (cm)	sNL	sNT	sSFW (g/plant)	sRFW (g/plant)	sSDW (g/plant)	sRDW (g/plant)	sPYL (%)	sPRL (%)
	KC-29	68.41±1.37^{a-e}	4.17±0.44^{j}	24.60±3.70^{f-n}	8.00±0.58^{s-v}	2.00±0.00^{hi}	0.73±0.13^{p-t}	0.85±0.10^{m-r}	0.13±0.01^{mno}	0.06±0.00^{m}	0.00±0.00^{s}	21.10±0.56^{gh}
	KC-55	68.79±0.96^{a-e}	6.00±0.29^{c-h}	44.00±2.31^{ab}	12.00±1.15^{k-s}	3.67±0.33^{cde}	0.69±0.00^{q-t}	1.83±0.00^{de}	0.10±0.00^{no}	0.18±0.00^{cd}	0.00±0.00^{s}	0.00±0.00
	KC-58	66.36±3.66^{a-e}	7.17±0.60^{a-d}	27.50±2.75^{e-m}	13.67±0.88^{i-o}	2.67±0.33^{fgh}	1.11±0.07^{k-q}	0.87±0.08^{l-r}	0.32±0.02^{efg}	0.18±0.01^{cde}	12.54±1.05^{m-p}	80.79±1.44^{a}
	KC-65	75.93±3.08^{abc}	7.83±0.44^{ab}	46.67±1.20^{a}	13.33±0.88^{i-p}	2.00±0.00^{hi}	1.28±0.18^{i-n}	1.18±0.10^{i-l}	0.25±0.01^{g-k}	0.12±0.00^{ijk}	12.77±1.96^{m-p}	12.77±0.83^{i}
	KC-82	77.61±0.42^{a}	4.50±0.29^{hij}	31.00±2.89^{d-l}	24.00±1.15^{a}	3.33±0.33^{def}	1.80±0.05^{d-h}	1.50±0.15^{f-i}	0.38±0.02^{c-f}	0.16±0.01^{d-h}	18.15±0.84^{h-m}	22.32±0.21^{fg}
	KC-621	77.25±2.10^{ab}	8.00±0.29^{a}	33.60±2.35^{c-g}	17.33±0.33^{d-i}	2.67±0.33^{fgh}	2.31±0.06^{bc}	1.13±0.08^{j-p}	0.42±0.01^{bcd}	0.13±0.00^{g-j}	7.56±0.93^{opq}	22.65±0.94^{fg}
	KC-839	53.64±5.99^{ef}	6.17±0.33^{b-h}	28.83±3.17^{e-m}	13.00±1.53^{j-q}	2.00±0.00^{hi}	1.59±0.06^{e-k}	0.81±0.06^{n-s}	0.47±0.06^{b}	0.09±0.00^{klm}	23.33±1.69^{hi}	40.14±1.54^{b}
	KC-1749	67.73±4.68^{a-e}	8.00±0.50^{a}	32.67±2.96^{d-i}	16.67±2.33^{e-j}	4.00±0.00^{bcd}	2.02±0.01^{cde}	2.37±0.23^{b}	0.38±0.01^{cde}	0.27±0.01^{b}	16.08±0.29^{j-n}	10.82±0.23^{ij}
	KC-1772	65.45±4.28^{a-e}	4.67±0.17^{g-j}	23.07±1.57^{h-n}	15.33±2.03^{g-l}	3.33±0.33^{def}	1.52±0.15^{e-l}	1.98±0.22^{cd}	0.27±0.01^{g-j}	0.27±0.00^{b}	24.24±1.66^{gh}	0.00±0.00^{m}
	KC-2009	76.97±2.84^{ab}	6.10±0.06^{b-h}	44.00±3.46^{ab}	21.00±1.73^{a-d}	4.00±0.00^{bcd}	1.94±0.03^{c-f}	1.51±0.19^{e-i}	0.37±0.01^{c-f}	0.14±0.02^{f-j}	13.10±1.21^{l-p}	12.63±0.92^{i}
	KC-2015	56.26±16.5^{def}	4.80±0.21^{f-j}	15.33±3.53^{n}	5.67±0.88^{v}	1.00±0.00^{j}	0.30±0.06^{t}	1.27±0.09^{h-k}	0.06±0.01^{o}	0.14±0.00^{g-j}	21.43±3.57^{hij}	0.00±0.00^{m}
Drought	KC-2115	73.14±2.64^{a-d}	6.23±0.43^{b-f}	28.00±2.57^{e-m}	12.33±0.88^{k-r}	3.33±0.33^{def}	1.76±0.20^{d-i}	0.56±0.08^{r-v}	0.30±0.00^{e-h}	0.08±0.01^{lm}	19.41±1.40^{h-l}	8.19±0.57^{kl}
	KC-2120	70.88±4.64^{a-e}	7.33±0.44^{a-d}	20.67±2.96^{lmn}	10.67±0.67^{m-t}	3.00±0.58^{efg}	1.41±0.19^{g-l}	0.36±0.03^{v}	0.19±0.01^{j-m}	0.06±0.00^{m}	21.94±1.00^{hij}	30.83±0.83^{d}
	KC-2121	71.91±5.17^{a-e}	6.33±0.44^{a-f}	24.33±4.26^{f-n}	8.67±0.33^{r-v}	2.33±0.33^{ghi}	1.51±0.22^{f-l}	1.15±0.04^{j-n}	0.27±0.02^{g-j}	0.13±0.01^{hij}	34.72±1.39^{def}	19.44±0.67^{h}
	KC-2122	70.68±8.96^{a-e}	7.07±0.70^{a-d}	28.33±5.21^{e-m}	10.00±1.15^{n-u}	3.67±0.33^{cde}	1.30±0.14^{h-n}	0.40±0.02^{tuv}	0.09±0.01^{no}	0.14±0.02^{f-i}	36.94±1.94^{de}	20.56±0.56^{gh}
	KC-2123	63.93±3.57^{a-e}	7.17±0.33^{a-d}	21.10±0.49^{lmn}	11.33±1.20^{l-s}	3.67±0.33^{cde}	1.24±0.11^{j-o}	0.41±0.01^{tuv}	0.25±0.01^{g-k}	0.07±0.00^{m}	38.96±4.17^{cd}	24.36±1.16^{f}
	KC-2189	61.80±4.14^{a-f}	5.87±0.35^{c-i}	29.00±8.28^{e-m}	8.33±0.33^{r-v}	2.00±0.00^{hi}	0.69±0.05^{q-t}	1.58±0.09^{e-h}	0.14±0.01^{l-o}	0.25±0.03^{b}	48.15±1.85^{ab}	28.24±1.66^{e}
	KC-2225	59.00±2.97^{b-f}	6.77±0.15^{a-d}	26.67±3.56^{e-m}	14.33±1.67^{h-m}	4.33±0.33^{abc}	1.57±0.09^{e-l}	1.21±0.09^{i-l}	0.31±0.02^{e-h}	0.18±0.00^{c-f}	33.90±1.33^{def}	9.28±0.66^{jk}
	KC-2226	46.14±5.00^{f}	6.50±0.29^{a-e}	26.50±3.75^{e-m}	22.67±1.45^{ab}	4.67±0.33^{ab}	1.53±0.10^{e-l}	2.23±0.09^{bc}	0.45±0.04^{bc}	0.26±0.01^{b}	29.63±5.46^{fg}	24.26±2.28^{f}
	KC-2231	66.85±5.08^{a-e}	6.83±0.17^{a-d}	19.83±1.59^{mn}	15.67±2.33^{f-k}	4.00±0.58^{bcd}	1.63±0.16^{d-j}	1.14±0.01^{j-o}	0.37±0.00^{c-f}	0.18±0.01^{cde}	43.89±4.55^{bc}	24.44±1.44^{f}
	KC-2241	53.68±1.85^{ef}	5.00±0.29^{f-j}	28.00±0.58^{e-m}	19.67±1.45^{b-f}	4.00±0.00^{bcd}	1.27±0.08^{i-o}	1.19±0.01^{i-l}	0.27±0.01^{g-j}	0.14±0.01^{g-j}	36.44±0.72^{de}	24.20±1.02^{f}
	KC-2248	58.25±4.26^{c-f}	7.00±0.76^{a-d}	26.00±3.00^{f-m}	15.33±0.67^{g-l}	3.67±0.33^{cde}	1.10±0.14^{k-q}	0.73±0.10^{q-t}	0.17±0.01^{k-n}	0.13±0.00^{g-j}	32.74±3.90^{def}	36.90±0.60^{c}
	KC-2286	64.76±3.63^{a-e}	6.50±0.58^{a-e}	28.75±0.72^{e-m}	18.00±0.00^{c-h}	4.67±0.33^{ab}	1.41±0.07^{g-l}	3.35±0.20^{a}	0.34±0.01^{d-g}	0.40±0.04^{a}	50.00±0.00^{a}	27.78±0.00^{e}

S: Seedling stage, RWC: Relative water content, SL: Shoot length, RL: Root length, NL: Number of leaves, NT: Number of tillers, SFW: Shoot fresh weight, RFW: Root fresh weight, SDW: Shoot dry weight, RDW: root dry weight, PYL: Percentage of yellow leaves, PRL: Percentage of rolled leaves.
Values in each column followed by the same letter in superscript are not significantly different according to the Duncan's multiple range test.

The sRL indicated a high variability in both conditions. In the control, sRL ranged from 21.33 to 42.50 cm (average ~28.44), and the best genotypes were identified as KC-2120, KC-621, and KC-2226. In the drought condition, this trait varied between 15.33 and 46.67 cm (average ~28.63), and genotypes KC-65, KC-55, and KC-2009 had the highest root length. The sNL ranged from 6.33 to 21.33 (average 12.93) under the control condition, whereas in the drought condition it ranged from 5.67 to 24.00 (average 14.22). Under control conditions, genotypes KC-1749, KC-1772, and KC-621 showed the highest values for the number of leaves; under drought conditions, the highest number of leaves were observed in genotypes KC-82, KC-2226, and KC-2009. The range of variability across all 23 tested genotypes for sNT was high in both growth conditions; it ranged from 0 to 5.00 (average 2.36) and from 1.00 to 4.67 (average 3.22) under control and drought conditions, respectively. The highest values for sNT under the control condition were recorded for genotypes KC-65, KC-2189, KC-55 and KC-58; under drought conditions, the highest values were observed in genotypes KC-2226, KC-2286, and KC-2225 compared to other genotypes (Table 3).

The range of variability for sSFW was limited, and it varied between 0.48 and 3.56 g/plant (average 1.37 g/plant) and between 0.30 and 2.31 g/plant (average 1.38 g/plant) under control and drought conditions, respectively. The highest shoot fresh weight in control and drought conditions were observed in genotypes KC-1749 and KC-621, respectively. The sRFW indicated a low variability, ranging from 0.38 to 2.32 g/plant (average 1.04 g/plant) under control conditions, and from 0.36 to 3.35 g/plant (average 1.29 g/plant) under the drought condition. Genotypes KC-1749, KC-65, and KC-621 in the control and KC-2286, KC-1749, and KC-2226 in the drought condition had the highest root fresh weight. The range of variability for sSDW was also low. It spanned from 0.085 to 0.643 g/plant (average 0.246 g/plant) and from 0.061 to 0.472 g/plant (average 0.273 g/plant) under control and drought conditions, respectively. Genotypes KC-1749, KC-58, and KC-628 in the control condition, and KC-839, KC-2226, and KC-621 in the drought condition indicated the highest shoot dry weight. In the control condition, sRDW varied between 0.055 and 0.243 g/plant (average 0.12 g/plant), and the highest values were obtained in 65, 1749, and 839. Under the drought condition, sRDW varied between 0.056 and 0.401 g/plant (average 0.163 g/plant), and the highest values were recorded in KC-2286, KC-1749, and KC-1772. The *A. tauschii* genotypes in the present study revealed a high variability for sPYL at both conditions. In the control condition, sPYL ranged from 1.39 to 34.52% (average 14.20%); genotypes KC-621 and KC-1772 indicated the lowest percentage of yellow leaves. Under the drought condition, sPYL ranged from 0.00 to 50.00% (average 25.04%); genotypes KC-621, KC-29, and KC-55 showed the lowest percentage of yellow leaves. There was a high rate of variation in sPRL among the 23 *A. tauschii* genotypes in the control and drought conditions. The sPRL ranged from 0.00 to 7.20% (average 0.59%), in the control condition. However, sPRL ranged from 0.00 to 80.79% (average 21.81%) and genotypes KC-55, KC-2225, and KC-1772 had low percentages of rolled leaves under drought conditions (Table 3).

Maturity stage

Analysis of variance

The results of the analysis of variance on the traits indicated significant effects for stress and genotypes. The interaction of stress and genotype effects was significant for all measured traits. The coefficient of variation (CV) ranged from 11.01 to 17.63%; the highest value was observed for SDW (17.63%), followed by mFLL (15.66%) and mPL (13.60%) (Table 4).

Range of data and means comparison

Drought stress significantly increased mSDW, mRDW, mFLL, mPL, mSL and mNS by 9.27%, 27.18%, 29.21%, 12.22%, 16.82% and 18.67% compared with the control condition, respectively. The highest value for mSDW, mRDW, mFLL, mPL, mSL and mNS were obtained as 12.61 g/plant, 14.13 g/plant, 5.21 cm, 4.50 cm, 5.24 cm and 9.30 observed in the drought stress condition. Among different genotypes the highest values obtained for mSDW, mRDW, mFLL, mPL, mSL and mNS were 21.31g/plant, 28.53 g/plant, 9.83 cm, 12.49 cm, 8.99 cm, and 20.33 obtained for genotypes KC-2122, KC-2122, KC-2121, KC-2225, KC-2115 and KC-2225 (Table 5).

The mSDW indicated a high variability, ranging from 6.08 to 20.16 g/plant (average 11.54 g/plant) under control conditions, and from 3.82 to 26.57 g/plant (average 12.61 g/plant) under drought condition. Genotypes KC-2015, KC-2123, and KC-2121 in the control and KC-55, KC-2122, and KC-2225 had the highest shoot dry weight in the drought condition. The range of variability for mRDW was also high. It varied from 2.45 to 21.27 g/plant (average 11.11 g/plant) and from 1.71 to 41.77 g/plant (average 14.13 g/plant) under control and drought conditions, respectively. Genotypes KC-2123, KC-2009, and KC-2189 in the control condition, and genotypes KC-2122, KC-2231,

Table 4. Analysis of variance for measured traits in *A. tauschii* genotypes at the maturity stage under control and drought stress conditions.

Source of variation	df	Mean of square					
		mSDW	mRDW	mFLL	mPL	mSL	mNS
Stress	1	39.536**	313.985**	47.796**	8.155**	19.626**	73.920**
Genotype	22	82.779**	222.088**	50.839**	56.302**	47.147**	314.240**
Stress×Genotype	22	72.633**	231.957**	14.027**	20.551**	11.111**	144.420**
Error	92	1.770	4.950	0.523	0.335	0.426	0.971
Coefficient of variation (%)		11.01	17.63	15.66	13.60	13.43	11.49

^{ns}, * and **: indicate non-significant and significant at 5% and 1% probability levels, respectively.
M: Maturity stage, SDW: Shoot dry weight, RDW: Root dry weight, FLL: Flag leaf length, PL: Peduncle length, SL: Spike length, NS: Number of spike.

Table 5. Mean values for traits under control and drought conditions in 23 *A. tauschii* genotypes at maturity stage.

Stress	Genotypes	Shoot dry weight	Root dry weight	Flag leaf length	Peduncle length	Spike length	No. of spike
	KC-29	8.39±1.24^{p-s}	5.99±0.18^{r-v}	3.90±0.06^{ij}	8.12±1.55^{ef}	4.30±0.58^{i-l}	15.67±0.33^{fg}
	KC-55	6.78±0.02^{rst}	5.46±0.02^{r-v}	6.09±0.05^{fg}	4.59±0.05^{klm}	6.59±0.05^{c-f}	2.67±0.33^{opq}
	KC-58	6.73±0.36^{rst}	4.59±0.60^{q-v}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-65	6.08±0.04^{stu}	7.83±0.04^{n-r}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-82	9.71±0.15^{m-q}	7.61±0.18^{o-t}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-621	8.84±0.18^{o-r}	2.45±0.17^{v}	3.70±0.29^{ijk}	4.50±0.77^{lmn}	6.45±0.01^{c-g}	30.00±0.58^{a}
	KC-839	11.33±0.48^{k-o}	12.56±0.27^{j-m}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-1749	8.32±0.12^{p-s}	3.59±0.66^{r-v}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-1772	7.87±0.07^{qrs}	16.49±0.01^{g-j}	2.80±0.06^{jkl}	7.69±0.11^{fg}	4.30±0.06^{i-l}	17.33±0.33^{ef}
	KC-2009	15.90±1.01^{d-g}	21.22±0.46^{ef}	3.12±0.07^{jkl}	4.05±0.03^{m-q}	4.40±0.23^{i-l}	18.67±0.88^{e}
	KC-2015	20.16±0.36^{c}	18.36±1.15^{fgh}	3.25±0.03^{i-l}	5.47±0.08^{jkl}	6.18±0.38^{d-h}	16.00±0.58^{f}
Control	KC-2115	15.44±0.40^{d-h}	13.64±1.72^{i-l}	6.50±0.87^{d-g}	4.43±0.25^{lmn}	9.08±1.05^{a}	12.00±0.58^{i}
	KC-2120	7.00±0.60^{rst}	3.17±0.38^{uv}	3.33±1.67^{i-l}	6.59±0.24^{hi}	5.12±0.07^{h-k}	2.33±0.33^{opq}
	KC-2121	17.19±0.20^{de}	17.06±0.22^{ghi}	8.12±0.07^{c}	8.87±0.12^{de}	6.87±0.94^{cde}	4.67±0.33^{lmn}
	KC-2122	17.16±0.09^{de}	15.30±0.17^{h-k}	7.19±0.11^{c-f}	4.17±0.10^{m-p}	8.22±0.12^{ab}	11.00±0.58^{ij}
	KC-2123	17.75±0.25^{d}	21.27±0.18^{ef}	12.30±0.17^{a}	3.13±0.07^{pqr}	8.13±0.07^{ab}	6.00±0.00^{l}
	KC-2189	13.23±0.53^{h-l}	19.64±0.33^{efg}	4.53±0.17^{hi}	3.00±0.00^{qrs}	4.00±0.00^{klm}	2.33±0.33^{opq}
	KC-2225	15.18±0.10^{e-h}	17.33±0.19^{f-i}	5.30±0.17^{gh}	15.65±0.26^{a}	6.02±0.01^{e-h}	14.00±0.58^{gh}
	KC-2226	10.92±0.47^{l-p}	7.75±1.39^{n-s}	7.09±0.05^{c-f}	3.00±0.00^{qrs}	8.25±0.14^{ab}	5.67±0.88^{lm}
	KC-2231	8.70±0.11^{pqr}	12.03±0.01^{k-n}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-2241	7.88±0.56^{qrs}	5.83±0.52^{r-v}	7.75±0.53^{cd}	3.09±0.05^{pqr}	6.79±0.07^{cde}	4.00±0.58^{mno}
	KC-2248	8.41±1.33^{p-s}	8.73±1.45^{m-q}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-2286	16.57±0.68^{def}	7.75±1.07^{n-s}	7.72±0.05^{cd}	6.00±0.29^{ij}	8.45±0.55^{ab}	18.00±1.15^{e}

M: Maturity stage, SDW: Shoot dry weight, RDW: Root dry weight, FLL: Flag leaf length, PL: Peduncle length, SL: Spike length, NS: Number of spikes.
Values in each column followed by the same letter in superscript are not significantly different according to the Duncan's multiple range test.

Table 5 (Continued). Mean values for traits under control and drought conditions in 23 *A. tauschii* genotypes at maturity stage.

Stress	Genotypes	Shoot dry weight	Root dry weight	Flag leaf length	Peduncle length	Spike length	No. of spike
	KC-29	15.54±1.18^{d-h}	25.79±2.03^{cd}	5.88±0.55^{fg}	10.85±0.18^{b}	6.00±0.39^{e-h}	23.67±0.67^{c}
	KC-55	26.58±0.31^{a}	28.83±1.90^{c}	9.53±0.90^{b}	6.33±0.17^{hij}	6.55±0.22^{c-f}	6.00±1.00^{l}
	KC-58	6.81±0.65^{rst}	8.39±0.47^{m-q}	7.09±0.05^{c-f}	4.00±0.00^{m-r}	5.25±0.14^{g-j}	2.00±0.00^{pq}
	KC-65	9.59±0.79^{m-q}	8.48±0.53^{m-q}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-82	11.72±1.90^{j-n}	23.50±1.46^{de}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-621	9.18±1.06^{n-r}	8.60±2.32^{m-q}	7.70±0.08^{cd}	8.65±0.36^{def}	8.09±0.24^{ab}	9.00±0.58^{k}
	KC-839	8.32±0.99^{p-s}	13.78±1.04^{i-l}	5.82±0.51^{fgh}	10.10±0.45^{bc}	5.75±0.59^{e-h}	3.67±0.33^{nop}
	KC-1749	9.61±0.30^{m-q}	15.15±2.05^{h-k}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-1772	9.58±0.91^{m-q}	3.36±0.95^{tuv}	2.25±0.24^{l}	5.59±0.05^{ijk}	5.42±0.14^{f-i}	21.00±1.73^{d}
	KC-2009	14.34±0.19^{f-i}	17.27±0.13^{f-i}	0.00±0.00^{m}	0.00±0.00^{u}	0.00±0.00^{n}	0.00±0.00^{s}
	KC-2015	13.64±0.78^{g-k}	10.75±2.06^{l-o}	2.39±0.07^{kl}	4.79±0.22^{klm}	3.87±0.37^{lm}	18.00±1.00^{e}
Drought	KC-2115	3.82±0.48^{u}	3.48±0.25^{s-v}	7.13±1.10^{c-f}	4.00±0.33^{m-r}	8.92±0.05^{a}	2.33±0.33^{opq}
	KC-2120	11.41±0.34^{k-n}	11.45±1.72^{k-o}	7.13±0.07^{c-f}	7.09±0.05^{gh}	5.25±0.14^{g-j}	2.00±0.00^{pq}
	KC-2121	10.09±1.62^{m-q}	9.59±2.48^{l-p}	11.55±0.12^{a}	3.25±0.14^{o-r}	9.00±0.14^{a}	1.67±0.33^{rs}
	KC-2122	25.46±0.97^{a}	41.77±4.31^{a}	6.50±0.29^{d-g}	8.34±0.19^{def}	6.25±0.14^{d-h}	15.67±0.33^{fg}
	KC-2123	11.84±0.65^{i-m}	9.73±1.86^{l-p}	7.58±0.38^{cde}	2.03±0.12st	7.57±0.33^{bc}	13.67±0.88^{h}
	KC-2189	13.52±1.03^{g-k}	8.33±0.10^{m-q}	5.25±0.14^{gh}	4.25±0.14^{mno}	3.00±1.50^{klm}	1.67±0.33^{rs}
	KC-2225	22.44±1.36^{b}	12.01±1.12^{k-n}	5.58±0.47^{gh}	9.34±0.48^{cd}	6.12±0.05^{e-h}	26.67±0.88^{c}
	KC-2226	13.17±0.41^{h-l}	5.09±0.33^{q-v}	5.92±0.43^{fg}	1.87±0.40^{t}	6.89±0.36^{cde}	20.67±0.33^{d}
	KC-2231	14.12±1.20^{f-j}	38.08±1.46^{b}	6.25±0.14^{efg}	4.67±0.10^{klm}	4.14±0.08^{j-m}	6.33±0.33^{l}
	KC-2241	13.76±0.53^{g-k}	12.57±1.86^{j-m}	6.30±0.17^{efg}	3.48±0.03^{n-r}	6.50±0.29^{c-g}	5.67±0.33^{lm}
	KC-2248	10.76±1.13^{l-p}	7.31±0.32^{o-u}	3.94±0.61^{ij}	2.90±0.83^{rs}	7.42±0.43^{bcd}	24.33±0.88^{c}
	KC-2286	4.85±0.36^{tu}	1.71±0.40^{v}	5.97±0.50^{fg}	1.99±0.30st	8.50±0.19^{ab}	10.00±0.58^{jk}

M: Maturity stage, SDW: Shoot dry weight, RDW: Root dry weight, FLL: Flag leaf length, PL: Peduncle length, SL: Spike length, NS: Number of spikes.

Values in each column followed by the same letter in superscript are not significantly different according to the Duncan's multiple range test.

and KC-55 in the drought condition indicated the highest root dry weights. In the control condition, mFLL varied between 0.00 and 12.30 cm (average 4.03 cm), and the highest values were obtained in genotypes KC-2123, KC-2121, and KC-2241. Under the drought condition, mFLL varied between 0.00 and 11.55 cm (average 5.21cm) and the highest values were recorded in genotypes KC-2121, KC-55, and KC-621. The *A. tauschii* genotypes revealed a high variability for mPL at both conditions. In the control condition, mPL ranged from 0.00 to 15.65 cm (average 4.01 cm); genotypes KC-2225, KC-2121, and KC-29 indicated the highest peduncle length. Under the drought condition, mPL ranged from 0.00 to 10.85 cm (average 4.50 cm); genotypes KC-29, KC-839, and KC-2225 were identified as having the highest peduncle length. There was a high rate of variation in mSL among the 23 *A. tauschii* genotypes in the control and drought conditions. The mSL ranged from 0.00 to 9.07 cm (average 4.48 cm) and KC-2115, KC-2286 and KC-2226 were identified as the genotypes with high spike length in control condition. Under the drought condition, mSL ranged from 0.00 to 9.00 cm (average 5.24 cm) and genotypes KC-2121, KC-2115, and KC-2286 had high spike length under drought conditions. There was variability in mNS under both conditions; this trait varied between 0.00 and 30.00 (average 7.84) under control condition, and between 0.00 and 26.67 (average 9.30) under drought conditions. Under control condition, genotypes KC-621, KC-2009 and KC-2286 were identified as the genotypes with high mNS; under drought condition, the genotypes with the highest mNS were KC-2225, KC-2248, and KC-29 (Table 5).

Cluster analysis

Cluster analysis was performed based on the Ward's coefficient on the data obtained in seedling and maturity stages for grouping of different *A. tauschii* genotypes.

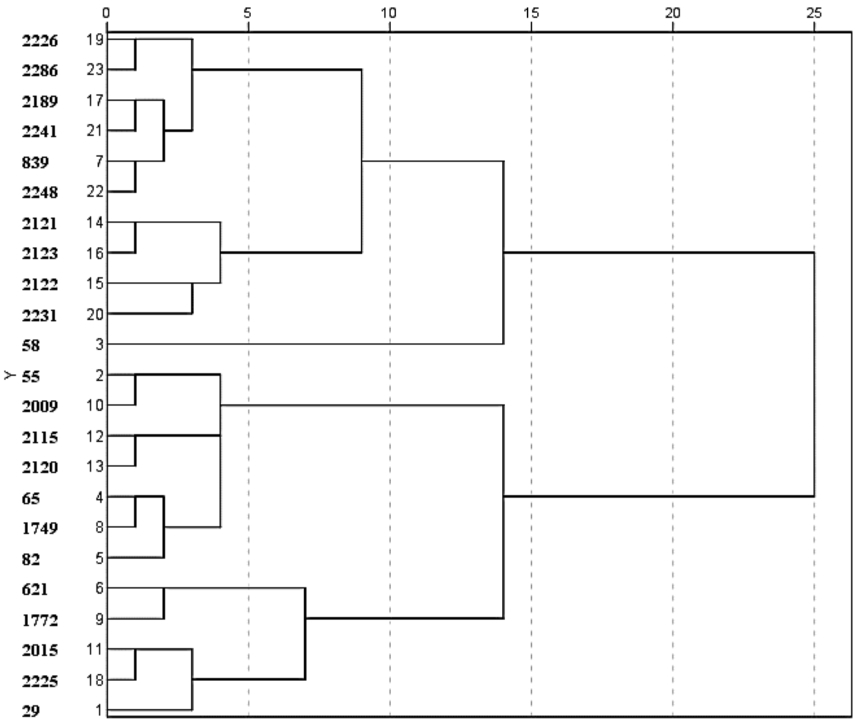

Figure 1. Ward's linkage cluster analysis of *A. tauschii* genotypes.

The dendrogram showed that 23 *A. tauschii* genotypes were classified into four different groups (Figure 1). In the first cluster, there were ten genotypes including KC-2226, KC-2286, KC-2189, KC-2241, KC-839, KC-2248, KC-2121, KC-2123, KC-2122 and KC-2231, while cluster two comprised of one genotype KC-85, the third cluster composed of seven genotypes KC-55, KC-2009, KC-2115, KC-2120, KC-65, KC-1749 and KC-82 and the fourth cluster composed of five genotypes including KC-621, KC-1772, KC-2015, KC-2225, and KC-29. Also, the results showed that the clustering of different genotypes did not correspond with the collected regions. The genotypes in cluster 1 showed higher sRDW, sPYL, mRDW, mFFL and mSL, the genotypes in cluster 2 showed higher sSL, sNL, sNT, sChl, sSFW, sSDW and sPRL, the genotypes in cluster 3 showed higher sRWC, sRL and sRFW and the genotypes in cluster 4 showed higher mSDW, mPL and mNS (Table 6).

Table 6. Cluster analysis of the traits in *A. tauschii* genotypes.

Traits	Clusters			
	1	2	3	4
sRWC (%)	66.56	64.05	72.53	69.04
sSL (cm)	6.37	6.75	6.67	6.05
sRL (cm)	26.76	24.42	32.90	26.79
sNL	12.58	15.17	14.97	13.27
sNT	2.78	3.17	3.04	2.37
sChl (spad)	38.10	42.43	39.80	39.94
sSFW (g/plant)	1.15	1.87	1.66	1.31
sRFW(g/plant)	1.13	0.80	1.25	1.18
sSDW(g/plant)	0.23	0.38	0.29	0.25
sRDW(g/plant)	0.15	0.13	0.14	0.13
sPYL (%)	27.72	15.08	12.71	14.01
sPRL (%)	13.52	40.40	7.42	6.02
mSDW(g/plant)	12.75	6.77	11.16	13.08
mRDW(g/plant)	13.79	6.49	12.19	12.11
mFFL (cm)	5.99	3.54	3.06	4.28
mPL (cm)	3.71	2.00	2.65	8.06
mSL (cm)	5.78	2.63	3.28	5.67
mNS	7.75	1.00	3.28	19.13

S: Seedling stage, M: Maturity stage, RWC: Relative water content, SL: Shoot length, RL: Root length, NL: Number of leaves, NT: Number of tillers, Chl: Chlorophyll content, SFW: Shoot fresh weight, RFW: Root fresh weight, SDW: Shoot dry weight, RDW: Root dry weight, PYL: Percentage of yellow leaves, PRL: Percentage of rolled leaves, FLL: Flag leaf length, PL: Peduncle length, SL: Spike length, NS: Number of spike.

Correlation among measured traits

To determine the effects of drought stress on the relationships among the measured traits, we used Pearson's correlation coefficients among the traits in both control and drought stress conditions. The sRWC showed a negative and significant correlation with sNT, sRDW, sPYL, and sPRL. The association pattern between sSLwith sRL, sNT, sChl, sSFW and sSDW was positive and significant. The sRL showed a positive and significant correlation with sNL and sRFW and a negative and significant correlation with sPYL. The sNL showed a positive and significant correlation with sNT, sChl, sSFW, sRFW, sSDW and sRDW and negative and significant correlation with mSDW, mFFL, mPL and mSL. The sNT showed a positive and significant correlation with sSFW, sRFW, sSDW, sRDW, sPYL and sPRL and a negative and significant correlation with mPL. The sChl indicated a positive and significant correlation with sSFW and sSDW and negative and significant correlation with sPRL and mRDW. A positive and significant correlation was also observed among sSFW with sRDW and sSDW and a negative correlation obtained between sSFW with mSDW, mRDW, mFFL, mPL and mSL. The sRFW showed a positive and significant correlation with sSDW, sRDW and sPYL and negative and significant correlation with mRDW and mPL. The sSDW indicated a positive and significant correlation with sRDW and sPYL and a negative and significant correlation with mSDW, mSRW, mFFL, mPL and mSL. The sRDW showed a positive and significant correlation with sPYL and negative and significant correlation with mPL and mSL. The sPYL showed a positive and significant correlation with sPRL, mFFL and mSL. The sPRL indicated a positive and significant correlation with mFFL. The mSDW showed a positive and significant correlation with mEDW, mFFL, mPL, mSL and mNS. The mRDW indicated a positive and significant correlation with mFFL and mPL. The mFFL showed a positive and significant correlation with mPL, mSL and mNS. The mPL indicated a positive and significant correlation with mSL and mNS. The mSL showed a positive and significant correlation with mNS (Table 7).

DISCUSSION

After several decades of breeding activities for tolerance against environmental stresses, drought stress is still recognized as one of the most important and effective factors in reducing the yield of crops, especially wheat. Due to limited gene resources in wheat, it seems that the use of secondary gene pool is necessary to increase tolerance in common cultivars. Wild relatives of wheat, especially wild species of the genus *Aegilops*, have been identified as one of the key gene sources for use in wheat breeding programs. In many studies on these species, a significant potential against unfavorable growth conditions has been reported (Arabbeigi *et al.,* 2014; Hairat and Khurana, 2015; Ahmadi *et al.,* 2018). Drought stress has a negative effect on the growth and yield of crops and its severity depends on the genotype of the plant and the duration of stress (Qaseem *et al.,* 2019). Among the various agronomic traits, yield and yield components are very important and affect the production of crops, especially in wheat. In a wheat breeding program, improving traits such as the spike length and the number of spikes can increase yield under drought stress conditions (Gaju *et al.,* 2009).

In this study, the diversity of 23 *A. tauschii* genotypes based on morphological and physiological traits was investigated under normal conditions and drought stress in the greenhouse. The results indicated that different genotypes showed different responses to drought stress. RWC and shoot length decreased in drought stress at the seedling stage, but root length, number of leaves, number of tillers, chlorophyll content, shoot fresh and dry weight, root fresh and dry weight, percentage of yellow and rolled leaves increased in the seedling and maturity stages. However, some studies state that the drought stress had a negative effect on grain filling period, plant height, peduncle length, number of spikes per plot, number of grains per spike, thousand grains weight, grain yield, biomass and harvest index of wheat genotypes (Liu *et al.,* 2015; Etminan *et al.,* 2019; Qaseem *et al.,* 2019; Pour-Aboughadareh *et al.,* 2020).

Therefore, it seems that Aegilops has a higher ability against drought stress than wheat and probably benefits from an efficient drought tolerance mechanism. Actually *A. tauschii* is an opportunist in nature and in competition with other plants, it uptakes water and nutrients from the soil faster and grows rapidly and reaches the reproductive stage (Abbas *et al.,* 2019). Du *et al.* (2020) reported that drought stress reduces the shoot biomass of soybean cultivars, increases the contents of soluble sugar and sucrose in the leaves and decreases starch content in the roots. Khakwani *et al.* (2012) reported a significant loss in yield attributes by evaluation of the response of six wheat genotypes to different levels of drought stress and normal conditions regarding yield and yield components parameters. Johari-Pireivatlou (2010) considered the impact of drought stress on the biological yield of four wheat genotypes and depicted that resistant genotypes showed greater biological and grain yield. Khakwani *et al.* (2011) reported a significant loss in yield attributes of harvest index, biological yield and 1000-grains weight with the same pattern by evaluating the response of six wheat genotypes to different levels of drought stress and normal conditions.

Table 7. Correlation among different traits under control and drought stress conditions.

Traits	sRWC	sSL	sRL	sNL	sNT	sChl	sSFW	sRFW	sSDW	sRDW	sPYL	sPRL	mSDW	mRDW	mFFL	mPL	mSL	mNS
sRWC																		
sSL	0.01																	
sRL	0.11	0.17*																
sNL	-0.10	0.16	0.19*															
sNT	-0.21*	0.18*	0.06	0.41**														
sChl	0.00	0.21*	0.04	0.19*	0.07													
sSFW	0.01	0.43**	0.14	0.62**	0.31**	0.27**												
sRFW	-0.15	0.03	0.27**	0.35**	0.30**	0.10	0.28**											
sSDW	-0.14	0.29**	0.13	0.73**	0.28**	0.24**	0.81**	0.34**										
sRDW	-0.27**	0.04	0.10	0.31**	0.37**	0.07	0.16	0.74**	0.27**									
sPYL	-0.30**	-0.10	-0.22**	-0.13	0.26**	-0.11	-0.15	0.20*	-0.06	0.39**								
sPRL	-0.24**	0.08	-0.09	0.11	0.23**	-0.20*	-0.01	-0.01	0.17*	0.16	0.36**							
mSDW	0.01	-0.12	-0.01	-0.21*	-0.10	-0.16	-0.32**	-0.12	-0.41**	-0.13	0.01	-0.14						
mRDW	0.13	-0.11	-0.04	-0.08	-0.02	-0.26**	-0.18*	-0.18*	-0.24**	-0.10	-0.01	0.04	0.67**					
mFFL	0.01	-0.07	-0.13	-0.33**	-0.05	-0.08	-0.28**	-0.13	-0.32**	-0.17	0.21*	0.24**	0.33**	0.17*				
mPL	-0.04	-0.08	-0.15	-0.27**	-0.20*	-0.11	-0.18*	-0.24**	-0.21*	-0.27**	-0.11	0.08	0.35**	0.27**	0.46**			
mSL	-0.05	-0.09	-0.08	-0.25**	-0.07	-0.05	-0.25**	-0.08	-0.29**	-0.17*	0.19*	0.15	0.23**	-0.01	0.86**	0.52**		
mNS	-0.15	-0.07	-0.15	0.01	-0.05	-0.01	-0.16	0.01	-0.15	-0.08	0.02	-0.04	0.35**	0.06	0.20*	0.48**	0.48**	

S: Seedling stage, M: Maturity stage, RWC: Relative water content, SL: Shoot length, RL: Root length, NL: Number of leaves, NT: Number of tillers, Chl: Chlorophyll content, SFW: Shoot fresh weight, RFW: Root fresh weight, SDW: Shoot dry weight, RDW: Root dry weight, PYL: Percentage of yellow leaves, PRL: Percentage of rolled leaves, FLL: Flag leaf length, PL: Peduncle length, SL: Spike length, NS: Number of spike.

CONCLUSIONS

Employing drought-tolerant and high-yielding genotypes is an effective way to diminish the drought effects. Assessment of genotypes using morphological and physiological characters under normal and drought conditions is a suitable method for achieving this goal. In the present study, two irrigation regimes (normal and drought stress conditions) were used for the genotypes evaluation. Statistical analysis showed that KC-621, KC-1772 and KC-2225 genotypes were able to better tolerate drought conditions. Thus, they can be exploited to transmit tolerance genes to commercial wheat cultivars in breeding programs.

ACKNOWLEDGMENTS

The authors thanks from the National Plant Gene Bank of Iran in Seed and Plant Improvement Institute for seed providing.

REFERENCES

Abbas A., Yu H., Cui H., and Li X. (2019). Effect of drought stress on chlorophyll fluorescence, and biomass portioning of *Aegilops tauschii* l. *Applied Ecology and Environmental Research*, 17(1): 1071–1082.

Ahmadi J., Pour-Aboughadareh A., Ourang S. F., Mehrabi A. A., and Siddique K. H. M. (2018). Wild relatives of wheat: *Aegilops–Triticum* accessions disclose differential antioxidative and physiological responses to water stress. *Acta Physiologiae Plantarum*,40(5): 90.

Arabbeigi M., Arzani A., Majidi M. M., Kiani R., Sayed Tabatabaei B. E., and Habibi F. (2014). Salinity tolerance of *Aegilops cylindrica* genotypes collected from hyper-saline shores of Uremia Salt Lake using physiological traits and SSR markers. *Acta Physiologiae Plantarum*, 36(8): 2243–2251.

Du Y., Zhao Q., Chen L., Yao X., Zhang W., Zhang B., and Xie F. (2020). Effect of drought stress on sugar metabolism in leaves and roots of soybean seedlings. *Plant Physiology and Biochemistry*, 146: 1–12.

Etminan A., Pour-Aboughadareh A., Mohammadi R., Shooshtari L., Yousefiazarkhanian M., and Moradkhani H. (2019). Determining the best drought tolerance indices using artificial neural network (ANN): Insight into application of intelligent agriculture in agronomy and plant breeding. *Cereal Research Communications*, 47(1): 170–181.

Gaju O., Reynolds M. P., Sparkes D. L., and Foulkes M. J. (2009). Relationships between large-spike phenotype, grain number, and yield potential in spring wheat. *Crop Science*, 49(3): 961–973.

Gálvez S., Mérida-García R., Camino C., Borrill P., Abrouk M., Ramírez-González R. H., Biyiklioglu S., Amil-Ruiz F., Dorado G., Budak H., Gonzalez-Dugo V., Zarco-Tejada P. J., Appels R., Uauy C., Hernandez P., and The I. (2019). Hotspots in the genomic architecture of field drought responses in wheat as breeding targets. *Functional & Integrative Genomics*, 19(2): 295–309.

Hairat S., and Khurana P. (2015). Evaluation of *Aegilops tauschii* and *Aegilops speltoides* for acquired thermotolerance: Implications in wheat breeding programmes. *Plant Physiology and Biochemistry*, 95: 65–74.

Johari-Pireivatlou M. (2010). Effect of soil water stress on yield and proline content of four wheat lines. *African Journal of Biotechnology*, 9(1): 036–040.

Khakwani A. A., Dennett M., and Munir M. (2011). Drought tolerance screening of wheat varieties by inducing water stress conditions. *Songklanakarin Journal of Science & Technology*, 33(2): 135–142.

Khakwani A. A., Dennett M., Munir M., and Abid M. (2012). Growth and yield response of wheat varieties to water stress at booting and anthesis stages of development. *Pakistan Journal of Botany*, 44(3): 879–886.

Liu H., Searle I. R., Mather D. E., Able A. J., and Able J. A. (2015). Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent. *Crop and Pasture Science*, 66(10): 1024–1038.

Liu Y., Zhang P., Li M., Chang L., Cheng H., Chai S., and Yang D. (2020). Dynamic responses of accumulation and remobilization of water soluble carbohydrates in wheat stem to drought stress. *Plant Physiology and Biochemistry*, 155: 262–270.

Matsuoka Y., Takumi S., and Kawahara T. (2008). Flowering time diversification and dispersal in central Eurasian wild wheat *Aegilops tauschii* Coss.: genealogical and ecological framework. *PLoS One*, 3(9): e3138

Mizuno N., Yamasaki M., Matsuoka Y., Kawahara T., and Takumi S. (2010). Population structure of wild wheat D-genome progenitor *Aegilops tauschii* Coss.: implications for intraspecific lineage diversification and evolution of common wheat. *Molecular Ecology*, 19(5): 999–1013.

Naderi S., Fakheri B.-A., Maali-Amiri R., and Mahdinezhad N. (2020). Tolerance responses in wheat landrace Bolani are related to enhanced metabolic adjustments under drought stress. *Plant Physiology and Biochemistry*, 150: 244–253.

Ohashi Y., Nakayama N., Saneoka H., and Fujita K. (2006). Effects of drought stress on photosynthetic gas exchange, chlorophyll fluorescence and stem diameter of soybean plants. *Biologia Plantarum*, 50(1): 138–141.

Porcel R., and Ruiz-Lozano J. M. (2004). Arbuscular mycorrhizal influence on leaf water potential, solute accumulation, and oxidative stress in soybean plants subjected to drought stress. *Journal of Experimental Botany*, 55(403): 1743–1750.

Pour-Aboughadareh A., Mohammadi R., Etminan A., Shooshtari L., Maleki-Tabrizi N., and Poczai P. (2020). Effects of drought stress on some agronomic and morpho-physiological traits in durum wheat genotypes.

Sustainability, 12(14): 5610.

Qaseem M. F., Qureshi R., and Shaheen H. (2019). Effects of pre-anthesis drought, heat and their combination on the growth, yield and physiology of diverse wheat (*Triticum aestivum* l.) genotypes varying in sensitivity to heat and drought stress. *Scientific Reports*, 9(1): 6955.

Valliyodan B., and Nguyen H. T. (2006). Understanding regulatory networks and engineering for enhanced drought tolerance in plants. *Current Opinion in Plant Biology*, 9(2): 189–195.

Wang J., Luo M.-C., Chen Z., You F. M., Wei Y., Zheng Y., and Dvorak J. (2013). *Aegilops tauschii* single nucleotide polymorphisms shed light on the origins of wheat D-genome genetic diversity and pinpoint the geographic origin of hexaploid wheat. *New Phytologist*, 198(3): 925–937.

Wang J. Y., Turner N. C., Liu Y. X., Siddique K. H. M., and Xiong Y. C. (2017). Effects of drought stress on morphological, physiological and biochemical characteristics of wheat species differing in ploidy level. *Functional Plant Biology*, 44(2): 219–234.

Xu W., Cui K., Xu A., Nie L., Huang J., and Peng S. (2015). Drought stress condition increases root to shoot ratio via alteration of carbohydrate partitioning and enzymatic activity in rice seedlings. *Acta Physiologiae Plantarum*, 37(2): 9.

Zhang D., Zhou Y., Zhao X., Lv L., Zhang C., Li J., Sun G., Li S., and Song C. (2018). Development and utilization of introgression lines using synthetic octaploid wheat (*Aegilops tauschii*×hexaploid wheat) as donor. *Frontiers in Plant Science*, 9: 1113.

Zhao X., Bai S., Li L., Han X., Li J., Zhu Y., Fang Y., Zhang D., and Li S. (2020). Comparative transcriptome analysis of two *Aegilops tauschii* with contrasting drought tolerance by RNA-seq. *International Journal of Molecular Sciences*, 21(10): 3595