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Boron and magnesium foliar application increase grain yield of durum wheat under drought by improving some physiological parameters

Y. Bani Khalaf[1], A. Aldahadha[1,*], O. Migdadi[1] and N. Samarah[2]

[1]Department of Field Crops, National Agricultural Research Center (NARC), PO Box 639, Baqa'a 19381, Jordan
[2]Department of Plant Production, Jordan University of Science and Technology, P.O. Box 3030, 22110, Irbid, Jordan
[*]Correspondence: abdallah.aldahadha@narc.gov.jo

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Abstract. Grain yield of wheat is primarily limited by water stress. Therefore, to increase productivity under drought conditions, a pot experiment was carried out at Maru Agricultural Research Station (MARS), Jordan, during the year 2021 to investigate the effect of foliar fertilizer by boron and magnesium under drought at either tillering or anthesis stages on some physiological parameters and yield components of two varieties of durum wheat. Foliar application by combined boron and magnesium had significantly improved the transpiration rate and relative water content (RWC) of wheat varieties at both tillering (4.39 µg $cm^{-2}s^{-1}$ and 82.55%, respectively) and anthesis (7.43 µg $cm^{-2}s^{-1}$ and 77.28%, respectively) growth stages, when compared with controls at tillering (3.56 µg $cm^{-2}s^{-1}$ and 76.63%, respectively) and anthesis (5.79 µg $cm^{-2}s^{-1}$ and 66.21%, respectively). RWC was significantly the highest by foliar boron (79.4%) at tillering stage under drought. Meanwhile, total chlorophyll content by SPAD was significantly the highest by combined boron and magnesium (46.8) during anthesis stage under drought. In general, the results indicated that var. Maru 1 had significantly higher grain yield (20.1 g/ plant) than var. Hourani (12.1 g/plant) may be due to differences in genetic makeup. Foliar application by combined boron and magnesium significantly increased wheat varieties' grain weight at tillering (18.2 g/plant) and anthesis (8.7 g/ plant) drought when compared with controls at either tillering (13.7 g/plant) or anthesis (5.5 g/plant) drought. However, foliar application did not significantly improve the grain weight under well-watered conditions. Our findings showed that the foliar application is more important at antheis drought than at tillering for increasing grain yield of wheat by improving of some physiological parameters.

Keywords: anthesis, micronutrient, transpiration rate, *Triticum durum*, water stress, yield component.

INTRODUCTION

Wheat (*Triticum durum*) is among the most crucial field crops grown under rainfed conditions in Jordan and considered essential for food security at the national and global level. Extreme climate changes and increased water scarcity challenge global food security, further impaired due to the need to feed a growing global population (Lesk et al., 2016; Munaweera et al., 2022). Drought is a major environmental (abiotic) stress and the most unpredictable constraint, adversely affecting crop production. Drought harms plants by disturbing many plant activities, including the carbon assimilation rate, decreased turgor, and changes in leaf gas exchange, thus causing a reduction in yield (Hussain et al., 2018). Reduced chlorophyll due to water stress causes chlorosis and reduces photosynthesis (Yang et al., 2001; Tyagi & Pandey, 2022). In addition, drought also reduces leaf relative water content (RWC) and stomatal conductance, ultimately leading to reduced growth and biomass production (Bayat et al., 2016; Caser et al., 2018). Moreover, drought stress can occur at any growth stage. However, the drought stress most commonly occurs after anthesis in wheat (Rebetzke et al., 2009; Ru et al., 2022). The yield losses of wheat during the reproductive phase due to drought might be due to its deleterious effects on morphological and physiological traits (Wasaya et al., 2021). Drought leads to tissue dehydration which may cause metabolic injury at later growth stages (Yang et al., 2003; Bandurska, 2022).

Under water stress, plant growth is inhibited due to the disruption of mineral nutrient transportation from the soil solution to the roots (Kohli et al., 2022). Low soil moistures restrict root growth and thus lowers the uptake of nutrients through the roots (Ge et al., 2012). Therefore, foliar fertilizer's efficiency is higher than soil application's under stress conditions (Hu et al., 2008). The supply of nutrients via the roots is restricted under drought because of the negative effect of drought on nutrient availability. The foliar application of different nutrients on different crops and at different growth stages can increase crops' tolerance mechanism and therefore enhance crop yield (Lavon et al., 1999; Tuiwong et al., 2022).

Boron (B) is required by plants in micro quantities and had stimulating resistance responses against drought stress (Awasthi et al., 2022). The nutritional supply of B resulted in improved stomatal conductance and carbon assimilation through full-sized leaf expansion (Waraich et al., 2011). B application improves growth, enhances plant stress tolerance, and improves grain production and water use efficiency (Hussain et al., 2012; Karim et al., 2012). In addition, magnesium (Mg) is a macronutrient required for chlorophyll synthesis and, thus is essential for the photosynthesis process by plants. Also, Mg enhanced drought tolerance and played a vital role in all the biochemical and physiological processes of plants through different pathways, such as the metabolism of carbohydrates and synthesis of proteins (Cakmak & Yazici, 2010).

Several studies have shown that foliar application of boron (Sarkar et al., 2007; Kutman et al., 2010; Naeem et al., 2018) and magnesium (Rodrigues et al., 2021), can increase the yield of crops. Precisely, we hypothesize that the combined application of foliar boron and magnesium could efficiently alleviate drought stress impacts on wheat than applying each solely; thus, the growth and yield of treated wheat increased significantly under such adverse conditions. However, limited or no information is available regarding the effect of the combined foliar application of boron and magnesium on the growth and yield of durum wheat under water stress. Therefore, this study was designed to evaluate the effect of B and Mg application alone and in combination in improving some physiological traits and yield components of two varieties of durum wheat grown under tillering or anthesis drought stress.

MATERIALS AND METHODS

Plant materials

This experiment used two durum wheat (*Triticum durum* L.) varieties (Hourani and Maru1). Maru1 is an improved variety released and registered in 2019–2020, while Hourani is an old variety (released in 1976) known as a drought-tolerant variety (Almeselmani et al., 2013).

Soil preparation and seed sowing

A pot experiment was conducted in a glasshouse at Maru Agricultural Research Station (MARS), Jordan. Seventy two pots (27 cm diameter × 27 cm height) were used for this experiment, and each pot was filled with 4 kg of clay soil mixed with peat (1:1) (v/v). About 2 liters of water were added to each pot until field capacity. Then, diammonium phosphate (18% N and 46% P_2O_5) fertilizer was applied to each pot at 10 g m^{-2}. Three sterilized wheat seeds were placed 2–3 cm below the soil surface. Wheat varieties were sown on 10th January, 2021. Plants were thinned to two seedlings per pot at the two-leaf stage one week after emergence.

Growth conditions and treatments

The temperature in the greenhouse was controlled at 25/15 °C (day/night). The greenhouse's relative humidity (RH) was maintained at approximately 60%. Pots were supplied with NPK fertilizer every week from the beginning of tillering. Foliar spraying was applied twice during the experiment; once at tillering drought and another at anthesis drought and compared with those sprayed at well-watered conditions. In more details, fertilizer treatments (Boron, Magnesium, and Boron+ Magnesium) were sprayed one day before beginning of drought either at tillering or anthesis growth stages, while controls were sprayed with distilled water. Boron was sprayed in the form of boric acid (H_3BO_3) at concentration of 0.3 g L^{-1} (% B in boric acid=17.48%), whereas magnesium in the form of magnesium sulphate ($MgSO_4.7H_2O$) at a concentration of 5 g L^{-1} (% Mg in magnesium sulphate=9.86%, Abou El-Nour & Shaaban, 2012). Each pot was received about 50 mL of foliar solution/ treatment until the leaf surface was wet. Drought was imposed by withholding watering for 7 days at at tillering (GS 22; D1) or anthesis (GS 65; D2) according to the Zadoks scale (Zadoks et al., 1974) on separate sets of plants, and compared with well watered (WW) plants which were regularly watered to field capacity. Pots were watered a twice per week during the vegetative stage, and three times per a week from anthesis stage until maturity. Drought at tillering stage was imposed from 15th February to 22th February, 2021 while those at anthesis stage from 20th March to 27th March, 2021.

Relative water content (RWC)

Relative water content (RWC) was determined according to the method of Slatyer (1967). Samples of about 1 cm^2 from the fully expanded leaves and flag leaves after one week of drought at tillering and anthesis stages, respectively were excised to determine RWC and placed in a cooler containing ice bricks. The samples were placed into small tubes and transferred within three hours after excision to the laboratory to determine the fresh weights (Wf). Leaf samples were placed in deionized water in small tubes kept overnight in a refrigerator at 4 °C. The following morning, leaf samples were carefully blotted with tissue paper, to remove excess water from the leaf surface, and re-weighed to determine turgid weight (Wt). Dry weight (Wd) was determined after oven drying the leaf samples for 24 hours at 80 °C. RWC was calculated as a percentage from the equation:

$$\mathrm{RWC}\ \% = \frac{\mathrm{Wf} - \mathrm{Wd}}{\mathrm{Wt} - \mathrm{Wd}}\ \mathrm{x}100 \qquad (1)$$

Physiological measurements

Transpiration rate (µg cm^{-2} s^{-1}) was measured with a portable steady state porometer (LICOR model LI-1600), while total chlorophyll content (TCC) was determined non-destructively using a portable chlorophyll meter; SPAD 502 Chlorophyll Meter (Spectrum Technologies Inc., Plainfield, IL, USA) on the same leaf as RWC prior to excision at the beginning and one week after plant stresses at either tillering or anthesis stages. Physiological measurements were made on mid-day between 12–2 pm.

Growth and yield components

At full maturity stage, the number of tillers and heads, and proportion of fertile tillers per plant were counted. The plants were harvested on 15^{th} May, 2021 when plants had reached final maturity. The above-ground plant parts were harvested and separated into vegetative and head parts. Threshing separated the grains from heads, and grain weight was determined for each pot. Total dry weight of shoots was determined after drying in an oven at 80 °C for two days. The one thousand-grain weight was determined from the weight of 200- seeds per sample. Harvest index (HI) was calculated by dividing grain weight by total (grain plus shoot) weight.

Statistical analysis

The experiment was performed in a factorial completely randomized design with three factors: two wheat varieties (Hourani and Maru 1), three drought conditions: well-watered (WW), drought at tillering stage (D1) and drought at anthesis stage (D2), and four foliar fertilizer treatments (B, Mg, B+Mg and controls). There were three replicates for each treatment. Pots were placed randomly on the greenhouse bench. Data were analyzed by factorial ANOVA using Statistix 8.1 (Analytical Software 2005). When there were significant interactions, one-way ANOVA was used and means were separated by least significant differences (LSD).

RESULTS AND DISCUSSION

Effect of foliar fertilizer on some physiological measurements under tillering drought

Analysis of variance for variety, foliar fertilizer and drought treatments at tillering stage (D1) and their interaction effects on some physiological parameters is shown in Table 1. All treatments had a significant main effect on transpiration rate. However, only drought treatment significantly affected total chlorophyll content by SPAD, whereas relative water content (RWC) was significantly affected by foliar fertilizer and drought treatments.

Table 1. Analysis of variance (Mean squares values) showing the effect of foliar fertilizer and wheat varieties under tillering (D1) and anthesis (D2) drought conditions on transpiration rate (T), total chlorophyll content by SPAD, and relative water content (RWC)

		Mean Squares at D1			Mean Squares at D2		
Source of variation	DF	T	SPAD	RWC	T	SPAD	RWC
Variety (V)	1	2.25^{*}	0.20^{ns}	2.85^{ns}	0.29^{ns}	5.60^{ns}	34.1^{ns}
Foliar fertilizer (F)	3	1.63^{**}	12.09^{ns}	176.64^{**}	5.91^{**}	33.61^{**}	251.3^{**}
Drought (D)	1	27.99^{**}	406.58^{**}	$4,978.43^{**}$	742.53^{**}	$1,136.85^{**}$	$18,963.5^{**}$
V x F	3	0.084^{ns}	7.62^{ns}	2.02^{ns}	0.77^{ns}	3.87^{ns}	18.8^{ns}
V x D	1	4.01^{**}	0.630^{ns}	0.06^{ns}	0.11^{ns}	3.63^{ns}	42.2^{ns}
F x D	3	2.19^{**}	14.1^{ns}	157.96^{**}	1.465^{ns}	17.18^{**}	278.9^{**}
V x F x D	3	0.075^{ns}	11.66^{ns}	13.69^{ns}	0.89^{ns}	20.08^{**}	17.2^{ns}
Error	30	0.3175	12.23	23.32	0.82	3.56	19.5
CV (%)		13.79	7.11	5.89	13.37	3.88	6.11

*, ** and ^{ns}, denote significant at 5%, 1%, and not significant, respectively.

Effect of foliar fertilizer treatments for wheat varieties on transpiration rate, total chlorophyll content by SPAD and relative water content (RWC) at the beginning (day 0) and end (day 7) of tillering drought (D1) are presented in Table 2. Drought at day 7 significantly reduced transpiration rate, SPAD and RWC compared to day 0. There was no significant effect of wheat varieties on SPAD and RWC. However, transpiration rate was significantly ($P < 0.05$) higher in var. Maru 1 than those in var. Hourani. Moreover, controls had significantly lower transpiration rate and RWC than foliar fertilizer treatments by B, Mg, and B + Mg (Table 2).

Table 2. Mean values of transpiration rate, total chlorophyll content by SPAD, and relative water content (RWC) for two durum wheat varieties (Hourani and Maru 1) and four foliar fertilizer treatments (B, Mg, B+ Mg and controls) under beginning of tillering drought (Day 0) and end of tillering drought (Day 7). Values are the mean of three replications. According to least significant difference (*LSD*) test, different letters within the same columns indicate significant differences ($p < 0.05$). B: Boron; Mg: Magnesium; B+ Mg: combined boron and magnesium

Variety	Drought	Transpiration rate ($\mu g\ cm^{-2}\ s^{-1}$)	SPAD	RWC (%)
Hourani	Day 0	4.92	52.06	91.93
	Day 7	2.82	46.47	71.49
Variety mean		3.87B	49.26A	81.71A
Maru 1	Day 0	4.78	52.16	92.34
	Day 7	3.83	46.11	72.05
Variety mean		4.30A	49.13A	82.19A
Foliar treatment				
B	Day 0	4.82	50.95	92.18
	Day 7	3.39	48.10	79.39
Treatment mean		4.11A	49.53A	85.78A
Mg	Day 0	4.86	52.85	92.79
	Day 7	3.73	45.32	72.89
Treatment mean		4.29A	49.08A	82.84A
B + Mg	Day 0	4.79	53.07	91.84
	Day 7	3.99	47.52	73.26
Treatment mean		4.39A	50.29A	82.55A

Table 2 (continued)

Control	Day 0	4.94	51.57	91.74
	Day 7	2.18	44.22	61.52
Treatment mean		3.56B	47.89A	76.63B
Drought mean				
	Day 0	4.85A	52.11A	92.13A
	Day 7	3.32B	46.29B	71.77B
LSD (0.05)				
Variety		0.33	2.06	2.85
Foliar treatment		0.47	2.92	4.03
Drought		0.33	2.06	2.85

There were significant ($P < 0.01$) foliar fertilizer × drought interaction effect for RWC (Fig. 1, A) and also variety x drought interaction for transpiration rate (Fig. 1, B). Foliar fertilizer treatments had no significant effect on RWC at day 0. However, Plant treated with B had significantly higher RWC than Mg or B+ Mg at day 7 (Fig. 1, A).

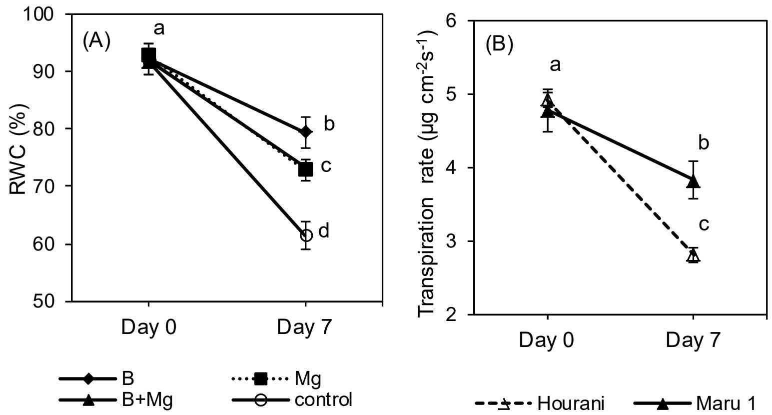

Figure 1. (A) Foliar fertilizer x drought interaction effect on RWC %, and (B) variety x drought interaction effect on transpiration rate during tillering stage. Lines with the same letter are not significantly different at $P < 0.05$ using least significant difference. Error bars show standard errors, $n = 3$.

There was no significant difference between wheat varieties on transpiration rate at day 0. However, transpiration rate was higher by 36% in var. Maru 1 at day 7 of drought (Fig. 1, B). Moreover, there were no significant differences between foliar treatments at day 0 of drought, while controls had significantly less transpiration rate than other foliar treatments at day 7 of drought (data not shown).

Effect of foliar fertilizer on some physiological measurements under anthesis drought

Table analysis of variance showed that foliar fertilizer and drought treatments had a high significant ($P < 0.01$) main effect on all physiological parameters of the study (Table 1). Foliar fertilizer x drought interaction was only high significant ($P < 0.01$) for SPAD and RWC measurements. Also, there was a high significant Variety x Foliar x Drought interaction effect on SPAD parameter.

Table 3 shows the main effect of foliar fertilizer treatments for wheat varieties on transpiration rate, SPAD and RWC at the beginning (day 0) and end (day 7) of anthesis drought (D2). Day 7 drought had significantly reduced transpiration rate, SPAD and RWC by 73%, 18% and 43%, respectively, compared with those at day 0. Additionally, measured physiological parameters revealed a significant reduction in controls compared to other foliar fertilizer treatments. However, B+ Mg treatment had significantly higher RWC than either B or Mg- treatments.

Table 3. Mean values of transpiration rate, total chlorophyll content by SPAD, and relative water content (RWC) for two durum wheat varieties (Hourani and Maru 1) and four foliar fertilizer treatments (B, Mg, B+ Mg and controls) under beginning of anthesis drought (Day 0) and end of anthesis drought (Day 7). Values are the mean of three replications. According to least significant difference (*LSD*) test, different letters within the same columns indicate significant differences ($p < 0.05$). B: Boron; Mg: Magnesium; B+ Mg: combined boron and magnesium

Variety	Drought	Transpiration rate (μg cm^{-2} s^{-1})	SPAD	RWC (%)
Hourani	Day 0	10.84	53.39	92.28
	Day 7	2.88	43.11	50.65
Variety mean		6.8 A	48.25A	71.47A
Maru 1	Day 0	10.59	53.53	92.09
	Day 7	2.82	44.34	54.21
Variety mean		6.70A	48.93A	73.15A
Foliar treatment				
B	Day 0	10.78	54.33	92.55
	Day 7	2.92	43.45	52.48
Treatment mean		6.85A	48.89A	72.52B
Mg	Day 0	10.87	54.03	90.97
	Day 7	3.25	44.42	55.50
Treatment mean		7.06A	49.23A	73.23B
B + Mg	Day 0	11.01	53.28	92.53
	Day 7	3.85	46.83	62.03
Treatment mean		7.43A	50.06A	77.28A
Control	Day 0	10.21	52.18	92.69
	Day 7	1.38	40.20	39.72
Treatment mean		5.79B	46.19B	66.21C
Drought mean				
	Day 0	10.72A	53.46A	92.19A
	Day 7	2.85B	43.73B	52.43B
LSD (0.05)				
Variety		0.53	1.11	2.60
Foliar treatment		0.76	1.57	3.68
Drought		0.53	1.11	2.60

Foliar fertilizer x drought interaction significantly affected total chlorophyll content by SPAD at D2. Foliar fertilizer treatments did not significantly affect SPAD at day 0 of drought. However, B+ Mg treatment had significantly higher SPAD value than either B or Mg treatments at day 7 of drought (Fig. 2). This interaction effect was similar for RWC (data not shown) where B+ Mg treatment had significantly higher RWC (62%) than either B (52.48%) or Mg (55.5%) treatments at day 7 of drought but without significant effect at day 0 of drought.

Fig. 3 shows Variety x Foliar fertilizer x Drought interaction effect on total chlorophyll content by SPAD during anthesis stage. Only B-treatment in var. Hourani had significantly higher SPAD values than controls of var. Maru 1 at day 0 of drought. However, there were no significant differences between controls of var. Maru 1 and B-treatment of var. Hourani at day 7 of drought.

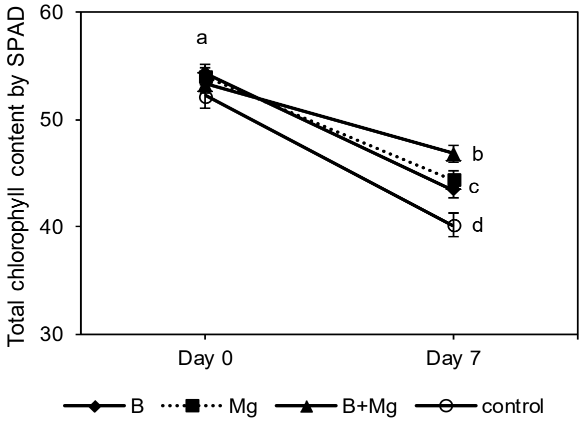

Figure 2. Foliar fertilizer x drought interaction effect on total chlorophyll content by SPAD during anthesis stage. Lines with the same letter are not significantly different at $P < 0.05$ using least significant difference. Error bars show standard errors, $n = 3$.

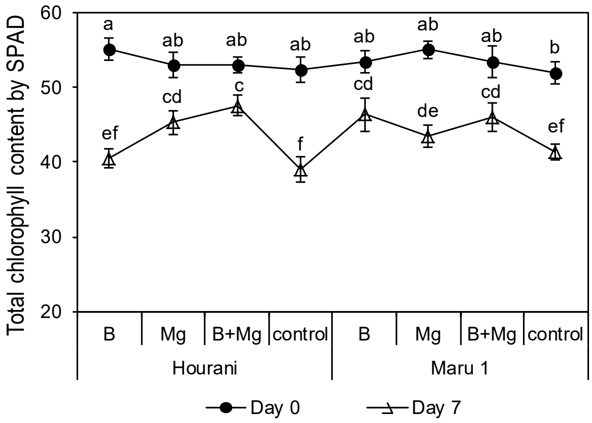

Figure 3. Variety x Foliar fertilizer x Drought interaction effect on total chlorophyll content by SPAD during anthesis stage. Lines with the same letter are not significantly different at $P < 0.05$ using least significant difference. Error bars show standard errors, $n = 3$.

Foliar application effectively improved wheat transpiration rate only under drought conditions. Similarly, Karim et al. (2012) found that the foliar application of boron (B) significantly increased transpiration of winter wheat under drought stress. It has been suggested that plant mineral nutrient status plays a vital role in improving plant resistance to stress conditions (Nadim et al., 2013). The response of micronutrient application to various abiotic stresses depends on the crop, growth stage and concentration of the nutrient solution (Siddiqui et al., 2022). The key mechanisms affecting the ability of micro-and macro-nutrients to alleviate the effects of drought stress include enhancing water uptake and transport, regulating stomatal behavior and transpirational water loss (Waraich et al., 2011; Wang et al., 2021). Our study showed that the efficiency of foliar fertilizers was not significantly different for transpiration rate. Putra et al. (2012) found a similar finding on *Musa* sp. Moreover, transpiration rate of both wheat varieties significantly varied at tillering drought. It is well documented that wheat varieties grown under drought conditions demonstrate natural genetic difference in traits related to drought tolerance (Budak et al., 2013).

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This study showed that drought significantly reduced the transpiration rate of both wheat varieties under different growth stages. Similar results were obtained by Wasaya et al. (2021); Marček et al. (2019) and Karim et al. (2012). Our results showed that wheat transpiration at anthesis drought was lower approximately 14% than at tillering drought. This may due to a higher water uptake of larger root biomass at anthesis time. Similarly, Aldahadha et al. (2019) found that transpiration rates during the anthesis were higher than during the vegetative phase. Therefore, the soil water supply is more rapidly exhausted at anthesis drought (Morgan, 1977).

Foliar application by combined boron and magnesium had increased total chlorophyll content by SPAD at anthesis drought. These results are consistent with other studies (Saad & El-Kholy 2000; Thalooth et al., 2006), indicating that Mg had a main role in chlorophyll formation, activation of enzymes, and it may increase plant resistance to water stress. Similarly, foliar application by B increased total chlorophyll content at late growth stages of winter wheat (Karim et al., 2012). Thus, these findings indicated the prominence of foliar application by combined boron and magnesium to reduce the harmful effects of drought stress that often occur during anthesis. Our results also revealed that total chlorophyll content of wheat was decreased by drought with higher reduction in SPAD values was recorded at anthesis growth stage. Similarly, a decrease in photosynthetic pigments including chlorophyll content in wheat was observed previously with increasing of drought (Kalaji et al., 2016; Chowdhury et al., 2021). Nikolaeva et al. (2010) found that the chlorophyll content decreased by 13–15% only after a 7-day drought period. Abdelkader et al. (2007) documented that the decrease in chlorophyll content as one of the most important limiting factors for plant photosynthetic activity under drought conditions.

It is well known that relative water content (RWC) is an important characteristic that measures water status in plants reflecting the ongoing metabolic activities in tissues and that may be used as a reliable indicator of drought tolerance (Chowdhury et al., 2021). The present study revealed that drought reduced RWC in both wheat varieties. These results were in close agreement with the findings obtained by Chowdhury et al. (2021). A higher reduction in RWC during anthesis drought may be due to higher transpiration rates during anthesis, similar to a wheat study reported by Aldahadha et al. (2019). In the current study, foliar fertilizer significantly increased RWC of wheat under drought conditions. Similar results were obtained by Wasaya et al. (2017) and Ahmad et al. (2019) who found that the foliar application of macro and micro-nutrients improved RWC for some crops. Higher RWC under combined boron and magnesium might be due to higher chlorophyll formation during the drought, whereas the increase in RWC by application of foliar boron might be due to leaf membrane stability (Sayed, 1998) and higher resistance against abiotic stresses (Shehzad et al., 2018; Awasthi et al., 2022).

Effect of foliar fertilizer on growth and yield component of wheat under drought

Analysis of variance for variety, foliar fertilizer and drought treatments and their interaction effects on several wheat growth and yield parameters is presented in Table 4. Wheat variety and drought treatments had a high significant ($P < 0.01$) main effect on all measured wheat growth and yield components. However, foliar fertilizer treatments had a high significant ($P < 0.01$) effect on grain number/plant (GN), grain weight/plant (GW), 1,000-grain weight/plant (1000-GW) and dry matter weight/ plant (DMW) only. There was a high significant variety x drought interaction for all measured growth and yield components except for 1000-GW, DMW, and harvest index (HI). However, foliar fertilizer x drought interaction was only significant ($P < 0.05$) for 1000-GW and GW (Table 4).

Table 4. Analysis of variance (Mean Squares values) showing the effect of foliar fertilizer and wheat varieties under different drought conditions on tiller number/plant (TN), head number/plant (HN), grain number/plant(GN/plt), 1,000-grain weight/ plant (1000-GW), dry matter weight/plant (DMW/plt) and harvest index (HI)

Mean Squares								
Source of variation	DF	TN	HN	GN/plt	1000-GW	GW/plt	DMW/plt	HI
Variety (V)	1	12.50**	10.12**	366,439**	501.92**	1,171.76**	188.82**	0.1303**
Foliar fertilizer (F)	3	0.84^{ns}	1.13^{ns}	14,615**	65.77**	40.75**	53.70**	0.0015^{ns}
Drought (D)	2	40.07**	60.51**	245,353**	2,537.6 **	1,385.97**	768.01**	0.1400**
V x F	3	0.51^{ns}	0.48^{ns}	223^{ns}	4.17^{ns}	1.93^{ns}	12.91^{ns}	0.0011^{ns}
V x D	2	2.69**	3.04**	18,205**	2.26^{ns}	88.80**	13.49^{ns}	0.0012^{ns}
F x D	6	0.08^{ns}	0.21^{ns}	2,723^{ns}	13.38*	6.08*	12.60^{ns}	0.0017^{ns}
V x F x D	6	0.34^{ns}	0.43^{ns}	2,431^{ns}	4.35^{ns}	2.20^{ns}	1.50^{ns}	0.0012^{ns}
Error	46	0.52	0.48	1,930	5.39	2.38	7.34	0.0015
CV (%)		7.78	7.83	11.52	5.81	9.59	13.1	9.55

*, ** and ^{ns}, denote significant at 5%, 1%, and not significant, respectively.

The main means of foliar fertilizer and drought treatments for growth and yield of the two wheat varieties are presented in Table 5. Number of heads (HN) and tillers (TN) per plant were significantly different ($P < 0.01$) between wheat varieties and drought treatments. The HN and TN for var. Maru 1 was significantly higher than those for var. Hourani. Moreover, well-watered (WW) plants had significantly higher HN and TN than those droughted at either D1 or D2. HN was reduced by 13% and 30% for D1 and D2 treatments, respectively, compared to WW treatment. However, foliar treatments did not significantly affect HN and TN (Table 5).

Number of grains (GN) per plant, grain weight (GW) per plant and 1,000-grain weight (TGW) were significantly affected by wheat varieties, drought and foliar treatments (Table 5). Variety Maru1 showed significantly a higher GN, GW and TGW per plant ($P < 0.01$) than var. Hourani. Both D1 and D2 significantly reduced GN, GW and TGW per plant compared with WW treatment, with higher reduction in D2 than in D1. The GW per plant was decreased by 26% and 65% at D1 and D2, respectively when compared with WW conditions. Yet, drought had a smaller effect on grain number than grain weight. In comparison with WW plants, D1 and D2 reduced the GN per plant by 19% and 42%, respectively. On the other hand, plants that were not sprayed by foliar fertilizer (controls) had significantly reduced GW, GN and TGW per plant by 18%, 16% and 6%, respectively when compared with those sprayed by boron and magnesium combination (B + Mg).

Table 5. Main effect of wheat varieties (Hourani and Maru 1), foliar fertilizer treatments and drought treatments on growth and yield components

Main effect	TN	HN	GN	TGW (g)	GW (g)	DMW (g)	HI
Variety							
Hourani	9.0b	8.5b	310.1b	37.3b	12.1b	19.1b	0.37b
Maru 1	9.8a	9.3a	452.8a	42.6a	20.1a	22.3a	0.46a
Foliar treatment							
B	9.5a	9.1a	396.4a	40.3b	16.8a	21.3a	0.42a
Mg	9.5a	9.0a	383.1a	42.0a	16.8a	21.4a	0.42a
B+ Mg	9.3a	9.0a	405.2a	40.0b	16.9a	21.9a	0.42a
Control	9.0a	8.5a	340.9b	37.4c	13.8b	18.1b	0.40a
Drought treatment							
WW	10.6a	10.4a	479.1a	48.0a	23.2a	26.9a	0.46a
D1	9.3b	9.0b	388.0b	44.0b	17.1b	19.3b	0.46a
D2	8.1c	7.3c	277.2c	28.3c	8.1c	15.9c	0.33b
LSD (0.05)							
Variety	0.34	0.33	20.84	1.10	0.73	1.29	0.019
Foliar treatment	0.49	0.47	29.48	1.56	1.04	1.82	0.027
Drought	0.42	0.40	25.53	1.35	0.89	1.58	0.023

B: Boron; Mg: Magnesium; B+ Mg: combined boron and magnesium; WW: well-watered; D1: drought at tillering; D2: drought at anthesis; TN: number of tillers per plant; HN: number of heads per plant; GN: number of grains per plant; TGW: 1000-grain weight; GW: grain weight per plant; DMW: shoot dry weight per plant excluding grain; HI: harvest index; *LSD*: least significant difference at $P < 0.05$. Figures labeled with the same letter in each column are not significantly different.

Dry matter weight (DMW) per plant was similarly affected by treatments as the GW and GN (Table 5). Variety and drought at anthesis (D2) significantly affected harvest index (HI). The overall mean HI of var. Maru1 (0.46) was significantly higher than HI of var. Hourani (0.37). There was no difference between HI of WW and D1 plants; however, HI of D2 was reduced to 0.33. The main effect of foliar fertilizer treatments was not significant for HI.

The interaction effect between variety and drought treatments on HN and GW per plant is presented in Fig. 4. The HN per plant was significantly higher in var. Maru1 than var. Hourani under both WW and D1 conditions, but there was no significant difference between the two varieties at D2 (Fig. 4, A). The reduction of GW per plant in var. Hourani was significantly higher at WW and D1 than D2 compared to var. Maru 1 (Fig. 4, B).

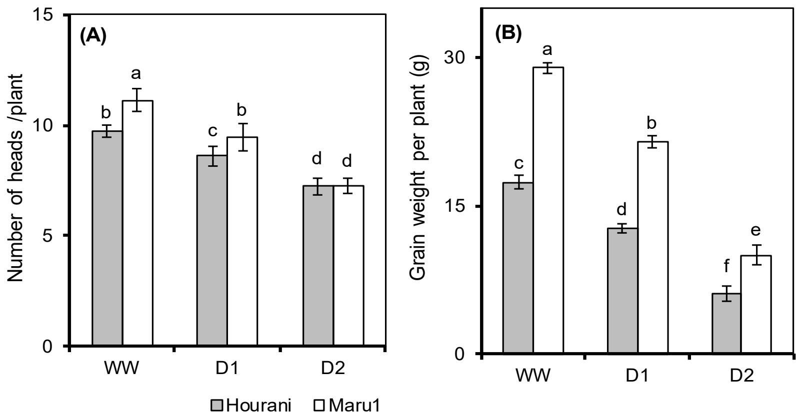

Figure 4. Variety x drought interaction effect on (A) number of heads per plant and (B) grain weight per plant. Columns with the same letter are not significantly different at $P < 0.05$ using least significant difference. Error bars show standard errors, $n = 3$.

There was significant ($P < 0.05$) foliar fertilizer × drought interaction effect for GW per plant (Fig. 5). Combined foliar fertilizer (B+ Mg) treatment did not improve GW under WW conditions compared to controls. However, when compared with controls, B+ Mg treatment had significantly increased the GW per plant by 33% and 57% at D1 and D2, respectively. Similarly, combined foliar boron and magnesium had improved 1000-GW by 6% and 15% at D1 and D2, respectively (data not shown).

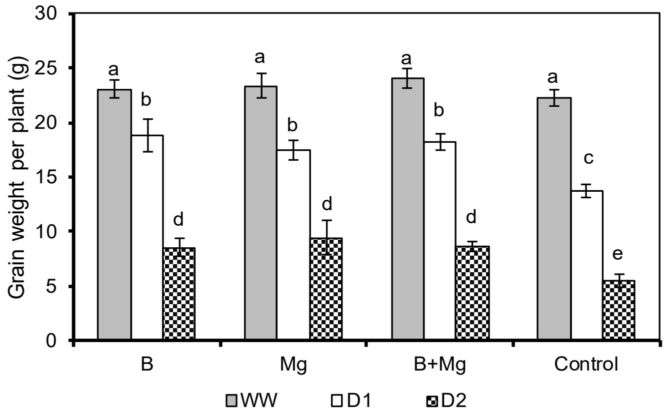

Figure 5. Foliar fertilizer x drought interaction effect on grain weight per plant. Columns with the same letter are not significantly different at $P < 0.05$ using least significant difference. Error bars show standard errors, $n = 3$.

In general, wheat yield and yield components were reduced when the drought was imposed, and its effect was more significant under anthesis drought than tillering drought. A reduction in the growth and metabolic activities leads to a reduction in agronomic and yield attributes under drought conditions (Hussain et al., 2018). Water stress occurring during reproductive phase caused a greater reduction in grain weight and number per plant and in the number of tillers and heads per plant (Aldahadha et al., 2019; Agrawal et al., 2021). A higher reduction in grain yield parameters under anthesis drought might be due to less retention of RWC, reflecting fewer metabolic activities (Clarke & McCaig, 1982). The reduced number of grains may be due to low spikelet per spike and spike length under drought. Thus, the flowering stage proved to be the most sensitive to water deficit. Drought stresses at vegetative or flowering stage considerably decreased total biomass of wheat. Similar findings were obtained by Blum (2005) and Bavita et al. (2015). Decreased 1,000-grain weight was reported by Plaut et al. (2004) under drought at flowering stage due to less efficient and disturbed nutrient uptake and limited photosynthetic translation within the plant which hastened maturity producing shriveled kernels. Reduced yield and yield-related traits under water stress might be due to a reduction in chlorophyll and photosynthetic parameters including stomatal conductance and transpiration rate (Wasaya et al., 2021). Our results also indicated significant differences between both wheat varieties in terms of yield due to a difference in genetic makeup of variety. Yield differences between varieties were greater under well-watered and tillering drought conditions, indicating higher drought tolerance at anthesis stage.

Our study demonstrated that the foliar application increased grain yield of durum wheat under different drought conditions may be due to the crucial role of fertilizers in enhancing photosynthesis, transpiration rate, pollen viability, number of grains per spike and higher concentrations of these nutrients in the grain. Similar results were obtained by Karim et al. (2012) and Abdel-Motagally & El-Zohri (2018). Our findings also agreed with the results of Karim et al. (2012) who found that winter wheat grain yield was not improved by foliar applications in the absence of drought. Furthermore, the foliar application of B and Mg was more effective at anthesis drought for improving the grain yield and 1000-grain weight. These results were similar to findings of Aown et al. (2012) who found that the foliar application of potassium was the most effective at anthesis stage. However, Abdel-Motagally & El-Zohri (2018) found that booting stage was the best time for boron application to get higher grains production.

CONCLUSIONS

Drought stress at either tillering or anthesis growth stage inhibits durum wheat varieties' physiological, growth and yield parameters. Yield reduction was greater during anthesis drought than during tillering. Therefore, exogenous application of B and Mg on wheat under drought alleviated the negative effects of water deficit. Results of this pot experiment revealed that foliar application of B and Mg had enhanced leaf transpiration rate and relative water contents, which improved wheat crop yield. However, the foliar application of B and Mg in combination performed similar as in single nutrient. The results from this study showed the significance of foliar application at anthesis stage for improvement wheat yield under drought conditions. It is a highly recommended to apply a combined foliar boron and magnesium or as a single form by either boron or magnesium especially during the late drought for achieving a higher wheat grain yield. Further study is required to examine the effect of foliar application and drought on wheat yield and growth under field conditions.

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