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Research article

Physiological and anatomical studies of two wheat cultivars irrigated with magnetic water under drought stress conditions

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ABSTRACT

The aim of this study was to assess some physiological parameters and anatomical changes in two wheat plant cultivars (*Triticum aestivum L. cvs.* Sakha 93 and Sids 9) in response to irrigation with magnetized water under two levels of drought stress (field capacity (FC) of 75% and 50%) and the control (FC 100%) in two consecutive winter growing seasons (November 20 to May 5 2014/2015 and 2015/2016). Pot experiments were carried out in a greenhouse in the experimental farm of the Faculty of Agriculture, Menoufia University, Shibin El-Kom, Egypt. A water deficit, particularly at 50% FC, significantly decreased growth and parameter values, above all in Sakha 93, and disrupted most physiological aspects, biochemical constituents and internal structural features of both wheat cultivars. Irrigation with magnetized water alleviated the negative consequences of drought stress on most physiological and biochemical parameters to a variable extent: the whole plant dry weight, total water content, total soluble sugar concentration in leaves, total free amino acids and proline increased by about 32, 12, 17, 27 and 73%, respectively, under 50% FC drought stress in Sids 9 compared to the control. As the levels of drought increased, the grain yield (g/plant) decreased considerably, from about 81% in Sakha 93 at 50% FC to 26% in Sids 9 at 75% FC. The use of magnetic water increased grain yield from 61% in Sakha 93 at 75% FC to about 268% in Sids 9 at 50% FC. Magnetic water also increased the thickness of the flag leaf midvein and lamina, as well as the metaxylem vessel diameter of Sakha 93 by 28.8, 11.7 and 20.0%, respectively, compared to the control. The application of magnetic water increased the growth and the other parameter values studied in both cultivars but above all in Sakha 93, whereas Sids 9 produced more grain yield under all levels of drought stress. As the growth and grain production increased in both cultivars when using magnetic water, this study recommends this type of irrigation for these wheat plants, which are widespread in Egypt.

1. Introduction

Wheat (*Triticum aestivum)* is one of the most widely cultivated cereal crops in Egypt. In the 2016 growing season, the cultivated area of wheat plants in Egypt reached about 3.34 million feddan, with a total production of 9 million tons (FAOSTAT, 2016). Due to its high nutritional content of proteins and carbohydrates, wheat is a staple food in the diet of the Egyptian population. In addition, wheat straw is an important feedstuff for livestock animals. Egypt has developed plans to ration the use of irrigation water due to drought and over-consumption. The main challenges for the production and quality of any crop is water availability throughout the growing season.

Drought has negative effects on plants since it decreases photosynthesis (McKay et al., 2003), impairs cell division and elongation (Hussain et al., 2008), and loss of cell turgor (Taiz and Zeiger, 2006) which limits plant growth and reduces productivity. Under conditions of drought stress, plants tend to perform an osmotic adjustment, conserving the cell turgor by the accumulation of solutes in their cells (Patakas et al., 2002). In addition, plant leaves show some morphological reactions, such as leaf wrapping (Monneveux, 1991), closing stomata and reducing the absorption of light radiation (Araus et al., 1997). Most wheat breeding programs worldwide have focused on improving drought tolerance, as wheat plants often suffer water deficiency during the major part of their growing period. Recent genetic

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improvement programs in Egypt have focused on genetic diversity among wheat cultivars in search of drought-tolerant high-yielding varieties.

On the other hand, among new technologies, magnetized irrigation water is a useful tool to reduce the negative effects of drought and maximize crop plant productivity. The advantages of magnetized water include a high level of purity, and being environmentally friendly, and safe and easy to use. The magnetic field changes physico-chemical characteristics of natural water, including solubility, pH, melting temperature, viscosity, conductivity, the refractive index and reduction of surface tension (Takatshinko, 1997; Grewal and Maheshwari, 2011). Additionally, magnetic fields weaken the intra-cluster hydrogen bonds, breaking the larger clusters, and forming smaller clusters with stronger inter-cluster hydrogen bonds. These tiny, uniform clusters have a hexagonal structure, which allows them to easily enter the passage ways in plant cell membranes (Wang et al., 2013). These alterations produce some positive effects in plants, such as a need for less irrigation, improved nutrient absorption, higher production of endophyto-hormones and greater osmotic pressure (Mousa et al., 2013). To date, studies on the use of magnetized water in the irrigation of crop plants, especially wheat, are still scarce. So, the aim of the present study was to ascertain the effect of magnetized irrigation water on drought resistance and grain yield in two wheat varieties widely cultivated in Egypt. In this context, various plant physiological and anatomical parameters were studied under different levels of drought stress, comparing magnetized and non-treated water.

2. Materials and methods

2.1. Experimental conditions

A pot experiment was carried out under greenhouse conditions at the Experimental Farm of the Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt. The experiment was conducted in two consecutive winter growing seasons (November 5 to May 5, 2014/2015 and 2015/2016). Grains of the wheat (*Triticum aestivum* L.) cultivars Sakha 93 and Sids 9 were obtained from the Wheat Research Institute, Agricultural Research Center, Giza, Ministry of Agriculture and Land Reclamation, Egypt. Sakha 93 is an Egyptian high-yielding cultivar released in 1990 and characterized by its resistance to high salinity and stripe rust. Sids 9 is another Egyptian cultivar, released in 1994 and characterized by its resistance to soil salinity, although it is more sensitive to rust diseases (Shehab El-Din et al., 1999). Clay loam soil was used in this experiment; its physical and chemical properties are shown in Table 1.

2.2. Treatments

The procedure and steps of the experimental work can be summarized as follows:

1) Irrigation with tap water (control group).
2) Irrigation with magnetic water. The water was passed through a magnetron, which is a magnetic tube (model U.T.I, 1-inch diameter, output 4–6 m^3/h) produced by Magnetic Technologies L.C.C., Russia, branch United Arab of Emirates.
3) Drought stress treatments of three water regimes: field capacities of 100%, 75% and 50%. Field capacities were maintained by weighing the pot every day. The irrigation was performed depending on the field capacity by adding the required volume of water manually.
4) The experimental design involved 12 treatments: two wheat plant cultivars were irrigated with tap and magnetic water at three water deficit levels, with 4 replicates of each treatment. Polyethylene pots with an inner diameter of 30 cm and depth of 30 cm were used and each pot was filled with 8 kg of prepared soil. Fifteen seeds without visible defects, insect damage and malformation were sown in each pot on November 20 in both seasons. From each replicate one plant sample was taken 90 days after the sowing date at 7 am for the different physiological and chemical analyses. The soil was fertilized by N, P and K according to the recommendations of the Ministry of Agriculture.

2.3. Studied traits

2.3.1. Physiological and production characteristics

2.3.1.1. Growth measurements. The following measurements were taken: plant height (cm), fresh and dry weights of roots, shoots and the whole plant (g), shoot/root ratio, leaf area (cm^2/plant) using the disk method of Bremner and Taha (1966), and leaf area index calculated with the formula of Simane et al. (1993).

2.3.1.2. Water relations. The total, free and bound water in leaves was determined using the method described by Gosev (1960).

Relative water content (RWC) was estimated following the formula of Kalapos (1994): RWC% = [(Turgid weight- Fresh weight)/(Turgid weight- Dry weight)] x 100.

Values of total soluble solids (TSS) of the cell sap were obtained for the pressed sap of the fourth upper leaf of tested plants using the Abbe Refrectometer, and the osmotic pressure values (Atm) were calculated using special tables according to the method described by Gosev (1960).

The succulence degree (SD) was estimated according to the equation of Kreeb (1990): SD = Fresh weight/Dry weight.

The transpiration rate (TR) (mg/cm2.h) was determined according to the equation of Kreeb (1990): TR = [(Fresh weight – Plant weight after 1 h)/Plant area in cm^2] * 1000.

Membrane permeability (integrity): the absorption of the leakage of solutes across the cell membrane of tissues was determined at the ultraviolet wavelength 273 nm following the method of Leopold et al. (1981).

2.3.1.3. Chemical measurements. Photosynthetic pigments, chlorophyll *a*, *b* and carotenoids, were assessed using a spectrophotometer (Fadeel, 1962).

Mineral elements: 0.2 g of dried ground leaves of the tested plants was digested in H_2SO_4 (concentrated) and H_2O_2 (5:1) for chemical analysis of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), iron (Fe), manganese (Mn) and zinc (Zn) according to A.O.A.C. (1995).

Total soluble sugars (mg/g dry weight of sample) in the fine dry leaf powder were estimated in 80% ethanolic extract using colorimetric methods (Dubios et al., 1956). Total free amino acids were determined in the same ethanolic extract of leaves according to the method

Table 1
Physical and chemical properties of the clay loam soil used.

Particle size distribution > 2 mm %					pH	EC_e dS/m at 25 °C	Soil paste extract analysis (meq/L)							
Coarse sand	Fine sand	Silt	Clay	Texture grade			Anions				Cations			
							$CO_3^=$	HCO_3^-	CL^-	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	K^+
2.35	41.00	29.00	27.70	Clay loam	7.80	2.50	–	4.50	8.30	19.20	14.50	6.39	10.52	0.32

described by Sadasivam and Monikom (1992).

Free proline (μmole/g fresh weight) was extracted from fresh wheat leaves by 3% sulphosalicylic acid according to Bates et al. (1973).

2.3.1.4. Yield components at harvest time. Spike weight (g/plant), grain number/spike, grain weight (g)/spike, weight of 100 grains (g), grain yield (g/plant) and straw yield (g/plant) were determined.

2.3.2. Anatomical characters and changes

A comparative microscopical analysis of plant material was carried out to ascertain the most prominent changes in plant growth in response to the different treatments. Some specimens of the flag leaf developed on the main stem of wheat cv. Sakha 93 were taken. Plant samples were taken during the 2nd growing season of 2015/2016 at 90 days from the sowing date (representing the heading stage). Specimens were fixed for at least 48 h in FAA (10 ml formalin, 5 ml glacial acetic acid and 85 ml ethyl alcohol 70%). The materials were washed in 50% ethyl alcohol, dehydrated in a normal butyl alcohol series, embedded in paraffin wax of melting point 56 °C, sectioned to a thickness of 20 μm (20 μm), double stained with safranin-light green, cleared in xylene and mounted in Canada balsam (Nassar and El-Sahhar, 1998). Sections were microscopically analyzed and photomicrographed.

2.4. Statistical analysis

The obtained data were statistically analysed using SAS software, version 9.2 (SAS Institute, 2008) to conduct analysis of variance tests (ANOVA). From differences between the means of interaction between the three main factors (drought stress level, water type and cultivars), orthogonal comparisons were performed using Duncan's New Multiple Range Test at a 5% significance level.

3. Results and discussion

As the differences between the results of the two growing seasons (2014/2015 and 2015/2016) were insignificant, only the results of the second season are presented.

3.1. Growth characteristics

Table 2 shows growth traits in Sakha 93 and Sids 9 wheat genotypes after irrigation by magnetic water under different levels of drought stress. The results show that growth decreased significantly ($P < 0.05$) as drought stress intensified. The deficit in the leaf area was 12% under 50% FC in Sids 9 compared to the control. These results are in accordance with those of Farooq et al. (2009), who reported that drought stress reduces leaf size, stem extension and root proliferation. Wheat plants irrigated with magnetic water exhibited highly significant increases in all growth traits: the leaf area increased by about 8 and 7% and the whole plant dry weight also increased by about 32 and 51%, respectively, under 50% FC drought stress in Sids 9 and Sakha 93 compared to the control. The improvement in most growth parameters after using magnetic water was more pronounced in Sakha 93. Similar results were obtained with cowpea plants by Sadeghipour (2016), who reported that irrigation with magnetic water increased plant height and biomass production. Also, Ferrari et al. (2015) indicated that lettuce plants supplied with a half or a quarter of the evaporated water lost increased fresh and dry weight and root length when the water was treated with a magnetic device, counteracting the deleterious effect of a limited water supply.

The improvement of growth parameters may be attributed to the stimulatory effect of magnetic water on photosynthetic pigments and protein biosynthesis (Tables 4 and 5). The mode of action of magnetic water is through its partially broken hydrogen bonds. Moreover, some water molecules become like free monomer molecules that can easily penetrate the biological cell walls, thus promoting plant growth (Toledo et al., 2008), as well as protein biosynthesis and mineral accumulation (Table 5). Selim et al. (2009) stated that the increased cell division and enlargement may be attributed to the increment in enzyme activities, gibberellic acid (GA_3), indole acetic acid (IAA) and cytokinin synthesis and reduced abscisic acid (ABA).

3.2. Water relations

An increase in drought stress also resulted in a reduction in values of water relations (Table 3). However, with magnetic water irrigation, the total water content increased, most noticeably in Sids 9 under a drought stress of 50% FC. Also in Sids 9, a significant increase of around 2 and 9% was observed in osmotic pressure and the transpiration rate, respectively, at 50% FC. At 75% FC, the results for these parameters were similar for Sakha 93 and Sids 9, each increasing by about 1% compared to the control. In both cultivars, the free water percentage and succulence degree increased significantly, while membrane permeability decreased significantly when the magnetic water was applied. These results are in agreement with those obtained with lettuce seeds by Garcia-Reina and Arza-Pascual, 2001, who found that the magnetic field caused alternations in the osmotic pressure and capacity of the cellular tissues to absorb water. In addition, Sadeghipour (2016) found that irrigation of cowpea plants with magnetic water increased their relative water content.

Table 2
Effect of drought stress and magnetized water treatments on some growth parameters of wheat cultivars Sakha 93 and Sids 9 in the 2nd growing season.

Treatments			Characters									
			Plant height (cm)	Leaf area (cm^2/plant)	Fresh weight (g/plant)			Dry weight (g/plant)			Shoot/root ratio	Leaf area index
FC%	*Magnetic Treatments*	cultivar			Root	shoot	whole	Root	shoot	whole		
100	**Control**	**Sakha 93**	39.00^{de}	141.19^{de}	0.12^{b}	1.91^{cd}	2.02^{cd}	0.030^{b}	0.487^{def}	0.517^{de}	16.538^{abc}	1.124^{de}
	Magnetic Water		56.33^{a}	191.96^{a}	0.50^{a}	3.68^{a}	4.18^{a}	0.145^{a}	1.153a	1.298^{a}	9.686^{c}	1.528^{a}
	Control	**Sids 9**	49.33^{abc}	158.05^{cbd}	0.17^{b}	2.12^{bcd}	2.29^{bcd}	0.055^{b}	0.682^{cd}	0.737^{bcd}	18.657^{abc}	1.258^{bcd}
	Magnetic Water		50.67^{ab}	169.80^{b}	0.21^{b}	2.52^{bc}	2.72^{bc}	0.083^{ab}	0.832^{bc}	0.915^{bc}	15.967^{c}	1.352^{b}
75	**Control**	**Sakha 93**	41.00^{de}	145.55^{de}	0.15^{b}	1.96^{cd}	2.10^{bcd}	0.038^{b}	0.623^{cde}	0.662^{cde}	16.440^{abc}	1.159^{de}
	Magnetic Water		53.00^{a}	168.66^{b}	0.19^{b}	2.76^{b}	2.95^{b}	0.052^{b}	0.920^{b}	0.972^{b}	19.512^{abc}	1.343^{b}
	Control	**Sids 9**	39.33^{de}	144.98^{de}	0.15^{b}	2.00^{bcd}	2.14^{bcd}	0.050^{b}	0.498^{def}	0.548^{de}	17.621^{abc}	1.154^{de}
	Magnetic Water		43.33^{bcd}	163.74^{cb}	0.18^{b}	2.54^{bc}	2.72^{bc}	0.032^{b}	0.813^{bc}	0.845^{bc}	26.127^{ab}	1.304^{bc}
50	**Control**	**Sakha 93**	34.67^{e}	139.11^{e}	0.13^{b}	1.41^{d}	1.54^{d}	0.060^{b}	0.418^{ef}	0.478^{de}	11.431^{bc}	1.108^{e}
	Magnetic Water		38.67^{de}	148.96^{cde}	0.17^{b}	2.03^{bcd}	2.20^{bcd}	0.043^{b}	0.678^{cd}	0.722^{bcd}	16.337^{abc}	1.186^{cde}
	Control	**Sids 9**	40.33^{de}	139.68^{de}	0.06^{b}	1.43^{d}	1.50^{d}	0.013^{b}	0.395^{f}	0.408^{e}	30.833^{a}	1.112^{de}
	Magnetic Water		42.33^{cde}	150.48^{cde}	0.12^{b}	2.02^{bcd}	2.15^{bcd}	0.028^{b}	0.508^{def}	0.537^{de}	18.448^{abc}	1.198^{cde}

FC = Field Capacity; Control = Tap water; Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 3
Effect of drought stress and magnetized water treatments on some water relations of wheat cultivars Sakha 93 and Sids 9 in the 2nd growing season.

Treatments			Characters						
FC%	Magnetic Treatments	Cultivar	Total water content(%)	Free water (%)	Bound water (%)	Osmotic Pressure C.S.(bar)	Succulence degree	Transpiration rate (mg/cm^2.h)	Membrane Permeability (%)
100	**Control**	**Sakha 93**	71.850^{de}	38.649^{e}	33.201^{e}	7.185^{f}	3.427^{ab}	0.462^{c}	18.482^{bc}
	Magnetic Water		73.382^{a}	32.947^{bcd}	40.434^{a}	9.160^{e}	6.000^{bcd}	1.079^{a}	17.559^{bc}
	Control	**Sids 9**	69.222^{bc}	30.565^{abc}	38.658^{abc}	11.650^{d}	3.300^{cd}	0.631^{abc}	17.931^{a}
	Magnetic Water		74.445^{d}	36.753^{ab}	37.692^{cd}	11.777^{d}	4.300^{cd}	0.752^{abc}	16.087^{a}
75	**Control**	**Sakha 93**	71.026^{ab}	30.313^{bcd}	40.712^{cde}	11.735^{d}	3.808^{cd}	0.999^{ab}	18.662^{bc}
	Magnetic Water		65.925^{cd}	40.051^{abc}	25.874^{ab}	11.861^{d}	3.132^{bcd}	1.012^{ab}	16.436^{bc}
	Control	**Sids 9**	70.882^{cde}	37.420^{cd}	33.461^{abc}	11.988^{d}	3.560^{cd}	0.725^{abc}	16.398^{bc}
	Magnetic Water		72.288^{de}	39.934^{bcd}	32.354^{cde}	14.732^{a}	2.948^{bc}	0.823^{abc}	11.092^{bc}
50	**Control**	**Sakha 93**	58.081^{bc}	37.234^{bc}	20.847^{abc}	13.212^{b}	2.357^{d}	0.598^{bc}	16.372^{b}
	Magnetic Water		64.847^{abc}	37.274^{bc}	27.573^{cd}	13.465^{b}	2.089^{a}	0.649^{abc}	12.190^{bc}
	Control	**Sids 9**	69.722^{de}	30.938^{de}	38.785^{bc}	11.650^{d}	2.847^{bc}	0.734^{abc}	11.684^{bc}
	Magnetic Water		68.145^{e}	31.370^{a}	36.775^{abc}	12.663^{c}	3.670^{bc}	0.863^{abc}	8.921^{c}

FC = Field Capacity; Control = Tap water; Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 4
Effect of drought stress and magnetized water treatments on the concentrations of photosynthetic pigments in the leaves of wheat cultivars Sakha 93 and Sids 9 in the 2nd growing season.

Treatments			Characters					
			Chlorophyll a	Chlorophyll b	Total Chlorophyll a + b	Carotenoids	Chlorophyll A/B	Total Chlorophyll/Carotenoids
FC%	Magnetic Treatments	Cultivar	(mg/g dry weight)					
100	**Control**	**Sakha 93**	2.351^{cd}	1.319^{bc}	3.669^{de}	1.340^{ab}	1.787^{bc}	3.047^{a}
	Magnetic Water		3.072^{ab}	1.865^{a}	4.937^{a}	1.457^{a}	1.681^{bc}	3.516^{a}
	Control	**Sids 9**	2.097^{de}	1.020^{f}	3.116^{fg}	0.824^{cd}	2.113^{abc}	3.800^{a}
	Magnetic Water		2.464^{c}	1.558^{ab}	4.022^{cd}	0.972^{cd}	1.642^{c}	4.185^{a}
75	**Control**	**Sakha 93**	1.952^{e}	0.837^{ef}	2.789^{gh}	0.855^{cd}	2.365^{abc}	3.261^{a}
	Magnetic Water		3.325^{a}	1.221^{bcd}	4.546^{ab}	1.389^{ab}	2.722^{ab}	3.288^{a}
	Control	**Sids 9**	1.594^{f}	0.713^{f}	2.307^{i}	0.717^{d}	2.238^{abc}	3.221^{a}
	Magnetic Water		2.347^{cd}	0.985^{cdef}	3.332^{ef}	0.945^{cd}	2.385^{abc}	3.527^{a}
50	**Control**	**Sakha 93**	1.921^{e}	0.684^{f}	2.605^{hi}	0.703^{d}	3.128^{a}	3.814^{a}
	Magnetic Water		2.970^{b}	1.319^{bc}	4.289^{bc}	1.113^{bc}	2.263^{abc}	3.860^{a}
	Control	**Sids 9**	2.116^{de}	0.871^{def}	2.987^{fgh}	0.933^{cd}	2.442^{abc}	3.218^{a}
	Magnetic Water		2.197^{cde}	1.126^{cde}	3.323^{ef}	0.806^{cd}	2.031^{bc}	4.151^{a}

FC = Field Capacity; Control = Tap water; Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 5
Effect of drought stress and magnetized water treatments on some minerals concentration and some chemical constituents in the leaves of wheat cultivars Sakha 93 and Sids 9 in the 2nd growing season.

Treatments			Characters									
			Mineral Elements							Total Soluble Sugars	Total Free Amino Acids	Proline
			N	P	K	Fe	Zn	Mn	Ca	mg/g Dry weight		μmol/g Fresh weight
FC%	Magnetic Treatments	Variety	%		ppm							
100	**Control**	**Sakha 93**	1.12^{cde}	0.33^{ab}	90.6^{d}	2.73^{cd}	0.55^{ab}	0.61^{ab}	381.1^{g}	49.69^{l}	121.50^{d}	1.10^{e}
	Magnetic Water		1.44^{bc}	0.38^{a}	97.00^{b}	2.58^{cde}	0.35^{a}	0.77^{a}	396.0^{e}	65.63^{g}	129.60^{a}	1.38^{e}
	Control	**Sids 9**	1.54^{ab}	0.35^{ab}	104.7^{a}	3.38^{b}	0.40^{ab}	0.65^{c}	450.4^{b}	60.63^{j}	98.55^{g}	1.31^{e}
	Magnetic Water		1.84^{a}	0.43^{bc}	95.6^{c}	3.92^{a}	0.38^{ab}	0.72^{d}	474.9^{a}	71.88^{e}	129.60^{a}	2.04^{d}
75	**Control**	**Sakha 93**	1.10^{cde}	0.22^{bc}	83.8^{g}	2.79^{c}	0.51^{ab}	0.40^{ab}	234.6^{l}	60.01^{k}	113.40^{e}	1.85^{d}
	Magnetic Water		1.40^{bcd}	0.32^{a}	87.3^{e}	2.88^{c}	0.44^{ab}	0.45^{ab}	352.4^{h}	72.51^{d}	128.25^{b}	2.91^{c}
	Control	**Sids 9**	1.44^{bc}	0.34^{ab}	77.5^{j}	2.63^{cde}	0.42^{ab}	0.49^{ab}	394.3^{f}	64.38^{h}	97.20^{h}	2.18^{d}
	Magnetic Water		1.77^{ab}	0.44^{ab}	96.8^{b}	3.94^{a}	0.39^{ab}	0.50^{bc}	408.3^{c}	77.19^{b}	121.50^{d}	3.63^{b}
50	**Control**	**Sakha 93**	1.03^{de}	0.29^{a}	77.1^{k}	1.97^{f}	0.37^{ab}	0.33^{e}	334.4^{j}	62.94^{i}	98.55^{g}	1.97^{d}
	Magnetic Water		1.13^{cde}	0.38^{cd}	82.1^{h}	2.33^{e}	0.50^{b}	0.57^{bc}	351.7^{i}	75.63^{c}	110.70^{f}	3.12^{c}
	Control	**Sids 9**	0.90^{e}	0.36^{cd}	78.9^{i}	1.30^{g}	0.39^{ab}	0.50^{ab}	297.1^{k}	69.07^{f}	98.55^{g}	2.98^{c}
	Magnetic W.		1.00^{e}	0.39^{cd}	85.3^{f}	2.40^{de}	0.44^{ab}	0.52^{ab}	397.8^{d}	80.94^{a}	125.55^{c}	5.16^{a}

FC = Field Capacity; Control = Tap water; Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 6
Effect of drought stress and magnetized water treatments on yield components of wheat cultivars Sakha 93 and Sids 9 in the 2nd growing season.

Treatments			Characters					
FC%	Magnetic Treatments	Variety	Spike weight (g/plant)	Grains Number/Spike	Grains weight (g)/Spike	100 grains weight (g)	Grains Yield (g/Plant)	Straw yield (g/plant)
100 (cont)	**Control**	**Sakha 93**	0.428^{ab}	17.333^{bc}	0.612^{bc}	1.650^{ab}	0.73^{b}	0.870^{b}
	Magnetic Water		1.800^{c}	20.000^{bc}	0.870^{bc}	3.925^{c}	1.39^{bc}	1.067^{ab}
	Control	**Sids 9**	0.503^{b}	15.000^{c}	0.455^{ab}	2.100^{bc}	0.55^{ab}	1.095^{ab}
	Magnetic Water		1.452^{c}	22.000^{bc}	1.255^{c}	3.075^{bc}	1.76^{c}	1.517^{a}
75	**Control**	**Sakha 93**	0.353^{ab}	8.000^{ab}	0.305^{ab}	1.650^{ab}	0.31^{ab}	0.970^{ab}
	Magnetic Water		0.603^{bc}	8.667^{ab}	0.408^{ab}	2.525^{bc}	0.49^{ab}	1.657^{ab}
	Control	**Sids 9**	0.387^{ab}	9.000^{ab}	0.335^{ab}	1.850^{bc}	0.40^{ab}	0.899^{ab}
	Magnetic Water		0.595^{b}	10.000^{ab}	0.495^{abc}	3.350^{bc}	0.69^{b}	0.933^{ab}
50	**Control**	**Sakha 93**	0.195^{a}	7.000^{ab}	0.230^{a}	1.450^{ab}	0.14^{a}	0.465^{b}
	Magnetic Water		0.412^{b}	8.667^{ab}	0.387^{ab}	1.950^{b}	0.31^{ab}	0.614^{ab}
	Control	**Sids 9**	0.280^{ab}	5.667^{a}	0.200^{a}	1.650^{ab}	0.12^{a}	0.608^{ab}
	Magnetic Water		0.447^{ab}	11.667^{bc}	0.442^{ab}	2.200^{bc}	0.44^{ab}	0.636^{b}

FC = Field Capacity; Control = Tap water; Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 7
Measurements (μm) of some histological characters in transverse sections through the blade of flag leaf developed on the main stem of wheat cv. Sakha 93 as affected by magnetized water under different levels of drought stress (Means of three sections from three specimens) in the 2nd growing season.

Characters		Treatments							
		100% FC			50% FC				
		Normal tap water (Control)	Magnetized water (Magnetic treatment)	± % to Control	Normal tap water (Drought treatment)	± % to Control	Magnetized water (Combined treatment)	± % to Control	± % To drought treatment
Thickness of midvein		271	349	+28.8	235	−13.3	283	+4.4	+20.4
Thickness of lamina		188	210	+11.7	169	−10.1	184	−2.1	+8.9
Histological features of midvein bundle	- Length	112	119	+6.3	95	−15.2	102	−8.9	+7.4
	- Width	120	114	−5.0	104	−13.3	109	−9.2	+4.8
	Diameter of metaxylem vessel	30	36	+20.0	25	−16.7	28	−6.7	+12.0
	Thickness of phloem tissue	31	34	+9.7	28	−9.7	29	−6.5	+3.6

FC = Field Capacity.

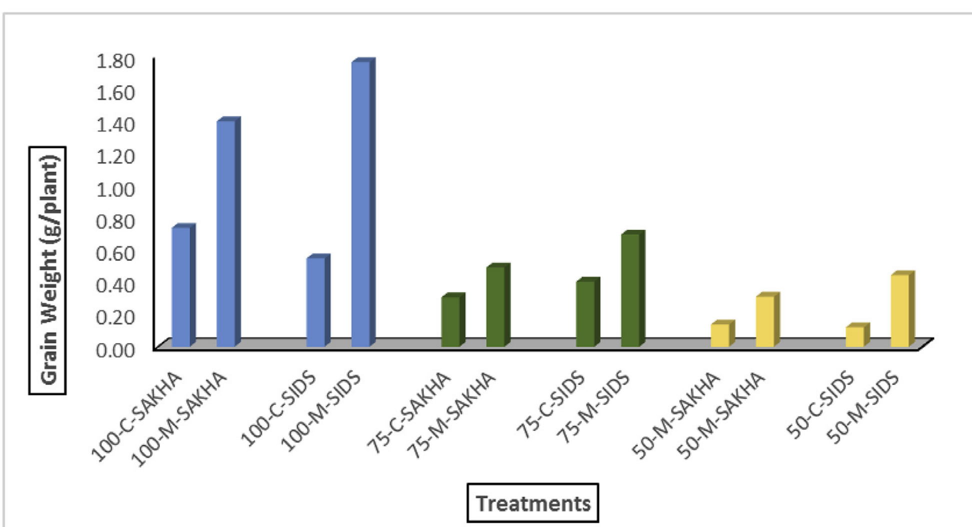

Fig. 1. Grain yield (g/plant) in two wheat cultivars (Sakha 93 and Sids 9) as a response of irrigation with tap water (control; C) and magnetized (M) under different levels of water stress (100, 75 and 50% field capacity).

Plants have adaptive characteristics to tolerate drought and avoid low tissue water content through osmotic adjustment by accumulation of soluble sugar and proline (Basu et al., 2016). Also, the concentration of N, P, K, Ca and Fe in plant cells (Table 5) prevents denaturation of cellular protein by increasing osmotic pressure and cellular elasticity. Irrigation of the wheat plants with magnetic water maximized water uptake by increasing the vessel diameter in stems or leaves (Table 7).

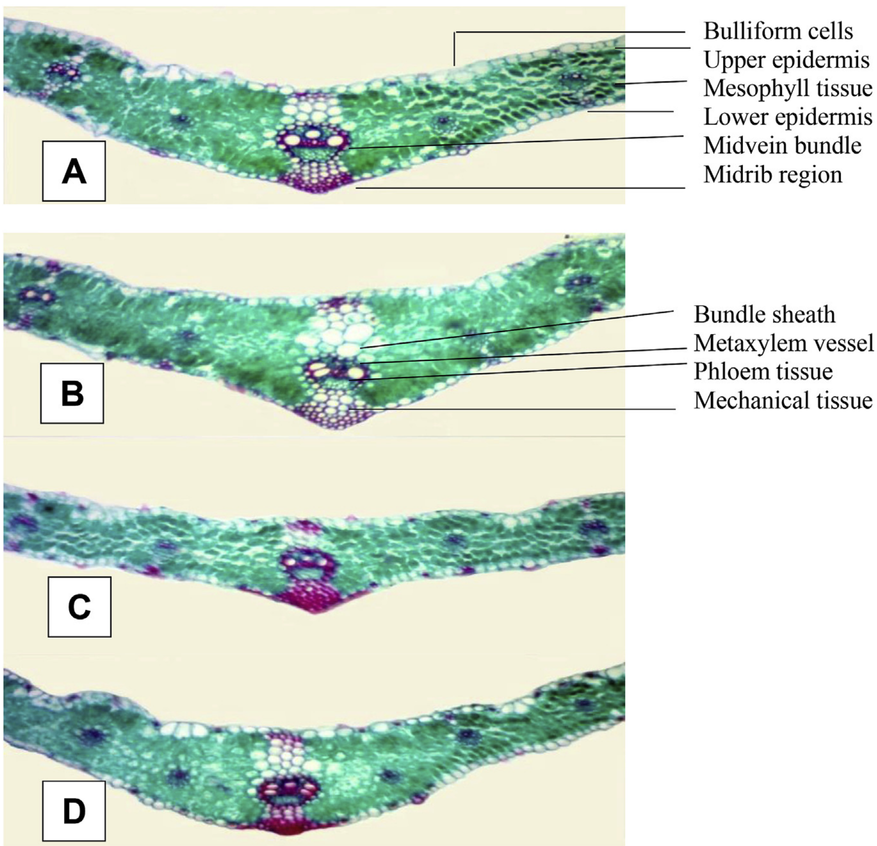

Fig. 2. Transverse sections through the blade of flag leaf developed on the main stem of wheat cv. Sakha 93, at heading stage, for: (X 136). A. Control (from plants irrigated with normal tap water at 100% FC). B. Magnetic treatment (from plants irrigated with magnetized water at 100% FC). C. Control drought treatment (from plants irrigated with normal tap water at 50% FC). D. Magnetic drought treatment (from plants irrigated with magnetized water at 50% FC).

3.3. Chemical measurements

3.3.1. Photosynthetic pigments

Table 4 shows that as the drought stress intensified, the concentration of photosynthetic pigments in wheat plants decreased significantly compared to the control. Conversely, irrigating the wheat plants with magnetic water resulted in a marked increase in photosynthetic pigments. The concentration of chlorophyll a, chlorophyll b, total chlorophyll (a + b) and carotenoids was about 55, 93, 58 and 65% higher, respectively, compared to the control, under drought stress of 50% FC in Sakha 93. The increase of photosynthesis pigments was more pronounced in Sakha 93 than in Sids 9. These findings are in agreement with those of Sadeghipour (2016) in cowpea plants, who found that treating plants with magnetic technologies caused a significant increase in concentrations of photosynthetic pigments. Higher levels of photosynthetic pigments when using magnetic water indicate the activation effect of magnetic fields on the concentration of ions such as $K+$ and GA_3 (Selim et al., 2009), which leads to an increase in the number of chloroplasts per cell. The increase of photosynthetic pigment in the current study may also be explained by a greater leaf area related to mesophyll tissue thickness (Table 7). Novitskaya et al. (2006) suggested that magnetic technology increased the phospholipids/sterol ratio, causing an increase in the fluidity of the membrane lipid bilayer, whereas sterols act as a barrier to prevent leakage in the biological membranes.

3.3.2. Mineral concentrations

As shown in Table 5, the macro and micro minerals decreased as the drought stress increased. The concentration of the elements N, P, K, Fe, Zn, Mn and Ca under drought stress of 50% FC decreased by about 42, 14, 25, 62, 3, 23 and 34% compared to the control in Sids 9. Conversely, irrigation with magnetic water resulted in a marked increment in the concentration of all minerals under all drought stress levels. Under 50% FC, the concentration of N, P, K, Fe, Zn, Mn and Ca increased by around 11, 30, 8, 85, 13, 4 and 34%, respectively, in Sids 9. Similar results were found in Sakha 93. These results are in accordance with those of Radhakrishnan and Kumari (2012), who reported that magnetized water caused an increase in nutrient uptake. Mulook Al-Khazan et al. (2011) found that irrigation with MTW at different moisture regimes increased the content of Mn, Ca and K, and this influence was preserved even in lower moisture regime treatments in plants of jojoba (*Simmondsia chinensis*). The desired effect of magnetic water on nutrient uptake may be attributed to an increase in membrane permeability (Table 3) by reorientation of membrane phospholipids, which subsequently affects sodium and calcium channels in the membrane, leading to the entry of ions into the cell (Rosen, 2003).

3.3.3. Total soluble sugars

The data of Table 5 reveal that the total soluble sugar content in wheat plant leaves was higher with increasing drought levels (about 13% at 75% FC and 18% at 50% FC). These results are in agreement with those obtained by Mohammadkhani and Heidari (2008) in maize plants. It was also observed that Sids 9 had higher total soluble sugar levels than Sakha 93. Regarding the total soluble sugar concentration in leaves, application of the magnetically treated water caused an increase of about 21 and 20% in Sakha 93, and 20 and 17% in Sids 9 at the drought levels 75 and 50% FC, respectively, compared with the untreated plants. Similarly, Selim et al. (2009) found that the soluble sugar content of watermelon seedlings improved after treatment with magnetic water under stress conditions.

Soluble sugars in plants function not only as substrates in biosynthetic processes and energy production but also as sensing and signaling systems. The increase in soluble sugars under drought stress, and even more so after irrigation with magnetic water, may be an attempt to counter osmotic stress, because soluble sugars can act as a typical osmoprotectant, stabilizing cellular membranes and maintaining turgor

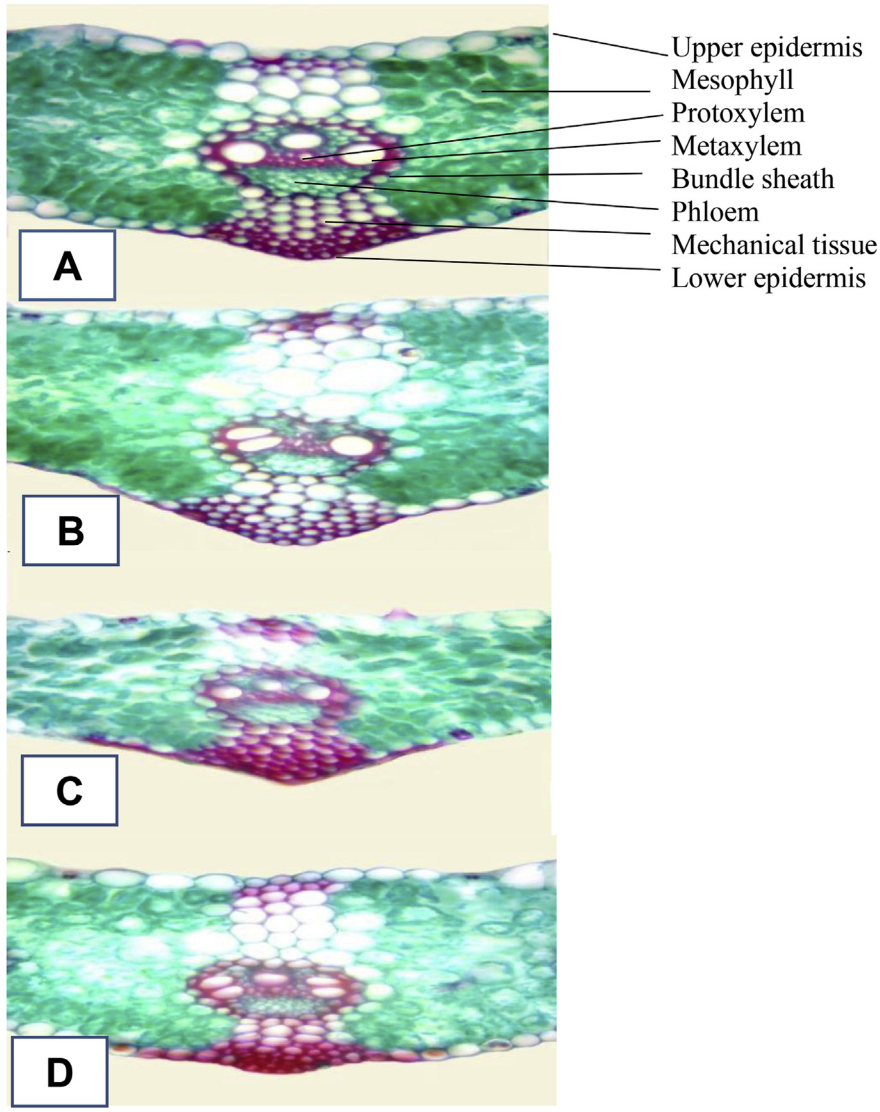

Fig. 3. Transverse sections through the midvein of blade of flag leaf developed on the main stem of wheat cv. Sakha 93, at heading stage, for: (X 310). A. Control (from plants irrigated with normal tap water at 100% FC). Cont. B. Magnetic treatment (from plants irrigated with magnetized water at 100% FC). C. Control drought treatment (from plants irrigated with normal tap water at 50% FC). D. Magnetic drought treatment (from plants irrigated with magnetized water at 50% FC).

(Mohammadkhani and Heidari, 2008).

3.3.4. Total free amino acids and proline concentrations

As shown in Table 5, with increasing drought levels, total free amino acids decreased, while the concentrations of proline clearly increased. The reduction in total free amino acids was about 7 and 11%, whereas the increments in proline were about 75 and 127% at the drought levels 75 and 50% FC, respectively, in comparison with the control. These results are in accordance with Mohammadkhani and Heidari (2008), who found that the free proline level in maize varieties increased significantly under drought stress conditions. Marked increases in total free amino acids and proline (19 and 60%, respectively) were observed in wheat plants irrigated with magnetic water compared with the untreated control plants. Magnetic treatments had a positive effect on total free amino acids and proline contents under all drought levels. At FC 75%, magnetic water increased total free amino acids and proline by about 13 and 57% in Sakha 93 and 25 and 67% in Sids 9, respectively. At the higher drought level of 50% FC, the increments in total free amino acids and proline were about 12 and 58% in Sakha 93 and 27 and 73% in Sids 9, respectively, over the controls. The cultivar Sids 9 exhibited the highest increase in total free amino acids and proline under drought stress conditions. A similar trend was reported by Selim and El-Nady (2011) in tomato plants.

Accumulation of proline in drought-stressed wheat plants may be due to its role as an osmoregulator, its action as a "compatible solute" that can accumulate in high concentrations in the cell cytoplasm without interfering with metabolism, its role in stabilization of macromolecules, as a sink of carbon and nitrogen for use after drought relief, and in regulation of cellular redux status (Vendruscolo et al., 2007).

3.4. Yield components

As shown in Table 6, as the drought stress intensified, the spike weight (g/plant), grain number/spike, grain weight (g)/spike, weight of 100 grains (g), grain yield (g/plant) (Fig. 1) and straw yield (g/plant) decreased significantly in both Sakha 93 and Sids 9. In contrast, compared to the control, irrigation with magnetic water resulted in a significant increase in these four yield characteristics (Fig. 1) by about 68, 34, 124 and 32%, respectively, under drought stress of 50% FC in Sakha 93. Similar findings were reported by Sadeghipour (2016) in cowpea plants, with an increase in seed yield, yield components and the cowpea

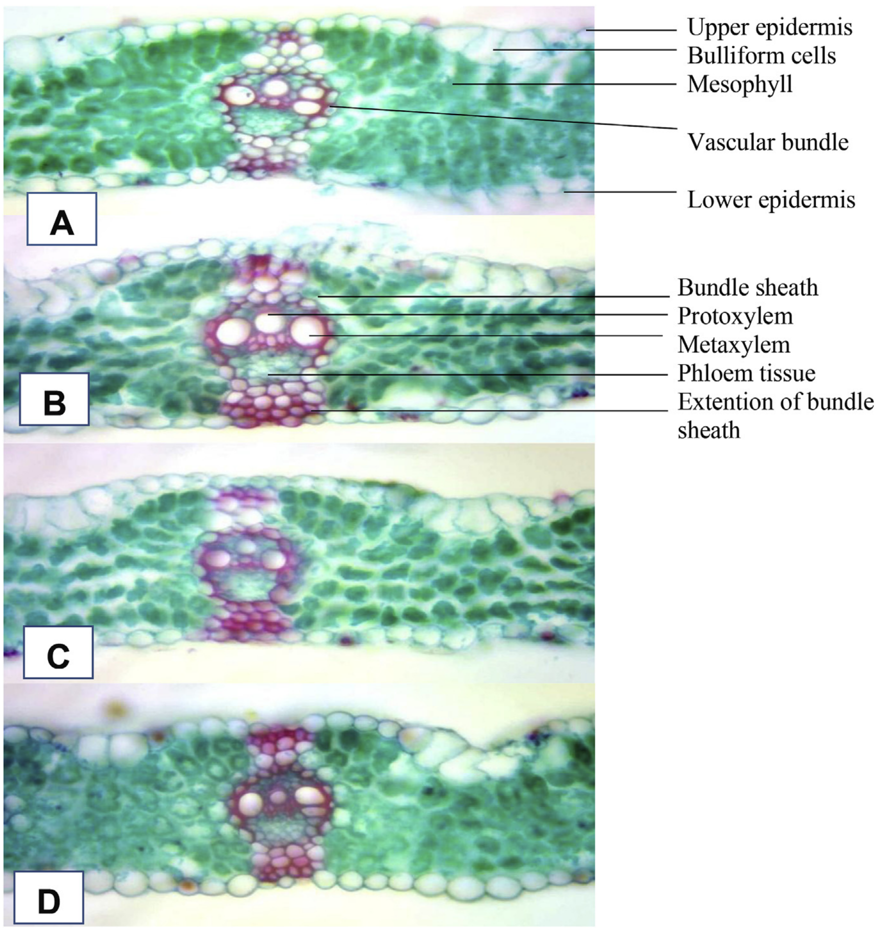

Fig. 4. Transverse sections through the marginal portion of blade of flag leaf developed on the main stem of wheat cv. Sakha 93, at heading stage, for: (X 310). A. Control (from plants irrigated with normal tap water at 100% FC). B. Magnetic treatment (from plants irrigated with magnetized water at 100% FC). C. Control drought treatment (from plants irrigated with normal tap water at 50% FC). D. Magnetic drought treatment (from plants irrigated with magnetized water at 50% FC).

harvest index of 23, 26 and 10%, respectively, over the control plants after magnetic water irrigation. The enhancement of growth and yield of wheat plants irrigated with magnetic water may be due to changes in the transport of assimilates, enzyme activity, growth regulators, ions and water uptake (Leelapriya et al., 2003), and/or to an energetic excitement of one or more parameters of the cellular substratum such as proteins and carbohydrates (Ogolnej et al., 2002). Comparing the two wheat varieties, irrigation with magnetic water had more positive effects on spike weight (g/plant) and straw yield (g/plant) in Sakha 93 than in Sids 9, which responded more for the other traits (Table 6).

3.5. Anatomical structure of leaf blade

The magnetic water treatment had a strong positive effect on all the studied morphological traits of plant growth in both Sakha 93 and Sids 9, and also alleviated the adverse effects of drought on growth.

Further study on the internal structure of the flag leaf of wheat plants grown under water deficit and exposed to magnetic technology is needed. A preliminary comparative study of the microscopic traits of flag leaf specimens from both cultivars was carried out. As structural differences were insignificant between the cultivars, further detailed examinations were confined to Sakha 93.

Microscopically observed traits of flag leaves developed on the main stem of Sakha 93 in conditions of water deficit and magnetic water treatments are shown in Table 7. Histological traits of both the control and treated plants are also shown in microphotographs in Figs. 2–4.

Magnetic water treatment increased the thickness of both the midvein and lamina of the Sakha 93 flag leaf by about 29 and 12%, respectively, compared to the control. In the midvein bundle the treatment increased the length by 6% compared to the control, which more than compensated for a concomitant 5% decrease in width. The vascular tissue of the midvein bundle was also positively affected. The diameter of the metaxylem vessel increased by 20% compared to the control to cope with the vigorous growth induced by the magnetic treatment. Moreover, phloem tissue increased in thickness by 10%. These findings are in accordance with the results reported by Mousa et al. (2013).

Regarding the effect of drought stress on the anatomical structure of the flag leaf, when the wheat plants were irrigated with normal tap water at 50% FC, the leaves were thinner due to a reduced thickness of both midvein and lamina by 13 and 10%, respectively, compared to the control. Also, the midvein bundle decreased in length by 15% and in width by 13%. Similarly, the diameter of the metaxylem vessel and thickness of phloem tissue were decreased by 17 and 10%, respectively.

To our knowledge, studies on the effect of drought stress on the anatomical structure of the flag leaf of wheat cv. Sakha 93 are not available. However, Selim and El-Nady (2011) reported in tomato plant leaves that a water deficit of 60 and 40% FC decreased the thickness of the lamina, palisade tissue, spongy tissue and vascular bundle, which is in accordance with our results.

As clearly shown by the data Table 7 and Figs. 2–4, the magnetic water treatment overcame or at least alleviated the harmful effects of water deficit on the anatomical structure of wheat leaves. Similar findings were reported by Selim and El-Nady (2011) in tomato plants. Compared to the control and drought conditions, magnetic water enhanced the flag leaf anatomical structure in the stressed wheat plants. In comparison with the drought-stressed plants, the thickness of midvein and lamina increased by 20 and 9%, respectively, and the length and width of the midvein bundle increased by 8 and 5%; the diameter of the metaxylem vessel and thickness of phloem tissue increased by 12 and 4%, respectively.

4. Conclusions

Drought stress had negative effects on the growth, and physiological, biochemical and anatomical traits of wheat plant cultivars Sakha 93 and Sids 9. Irrigation with magnetic water overcame or alleviated the adverse effects of drought stress on all the studied traits. In addition, after application of magnetic water, the grain yield in both cultivars increased by about 2–3 fold compared to the control and stress conditions. Using magnetic water in the irrigation of wheat plants could be economically profitable, since it reduces the irrigation water required by more than 25% and can be recommended for use under 75% FC drought stress. Although both cultivars grew better with magnetized water under drought stress conditions, Sids 9 showed a better response to the treatment.

CRediT authorship contribution statement

Dalia Abdel-Fattah H. Selim: Conceptualization, Data curation, Investigation, Writing – original draft. **Rania Mohamed A. Nassar:** Formal analysis. **Mohamed S. Boghdady:** Methodology, Validation. **Mercedes Bonfill:** Supervision, Writing – review & editing.

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References

Al-Khazan, Mulook, Batoul, M., Al- Assaf, Nabila, 2011. Effects of magnetically treated water on water status, chlorophyll pigments and some elements content of Jojoba (*Simmondsia chinensis* L.) at different growth stages. Afr. J. Environ. Sci. Technol. 5 (9), 722–731.
A.O.A.C, 1995. Association of Official Agriculture Chemists. Official Methods of Analysis, twelfth ed. Washington, D.C.
Araus, J.L., Amaro, T., Zuhair, Y., Nachit, M.M., 1997. Effect of leaf structure and water status on carbon isotope discrimination in fieldgrown durum wheat. Plant Cell Environ. 20, 1484–1494.
Basu, S., Ramegowda, V., Kumar, A., Pereira, A., 2016. Plant adaptation to drought stress. 5. F1000 Faculty Rev, pp. 1554. https://doi.org/10.12688/f1000research.7678.1. F1000Research.
Bates, L.S., Waldren, R.P., Teare, I.D., 1973. Rapid determination of free proline for water-stress studies. Plant Soil 39, 205–207.
Bremner, R.A., Taha, M.N., 1966. Studies in potato agronomy: the effect of variety, seed size and spacing on growth, developed and yield. J. Agric. Sci. 66, 241–252.
Dubios, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A., Smith, F., 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28, 350–356.
Fadeel, A.A., 1962. Location and properties of chloroplasts and pigments determination in roots. Plant Physiol. 119, 975–986.
FAOSTAT, 2016. Statistics Division. Food and Agriculture Organization of the United Nations, Rome, Italy.
Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., Basra, S.M.A., 2009. Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev. 29, 185–212.
Ferrari, F., Almeida Klar, L.A., Ferreira da Silva, J., Pires, C., Ludwig, R., 2015. Response of lettuce crop to magnetically treated irrigation water and different irrigation depths. Afr. J. Agric. Res. 10, 300–308.
Garcia-Reina, F., Arza-Pascual, L., 2001. Influence of a stationary magnetic field on water relations in lettuce seeds. Part I: theoretical considerations. Bioelectromagnetics 22, 589–595.
Gosev, N.A., 1960. Some Methods in Studying Plant Water Relation Leningrade. Academy of Science USSR.
Grewal, H.S., Maheshwari, B.L., 2011. Magnetic treatment of irrigation water and snow pea and chickpea seeds enhances early growth and nutrient contents of seedlings. Bio. Electromagn. 32, 58–65.
Hussain, M., Malik, M.A., Farooq, M., Ashraf, M.Y., Cheema, M.A., 2008. Improving Drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. J. Agron. Crop Sci. 194, 193–199.
Kalapos, T., 1994. Leaf water potential, leaf water deficit relationship for ten species of semiarid grassland community. Plant Soil 160, 105–112.
Kreeb, K.H., 1990. Methoden Zur Pflanzenökologie und Bioindikation. Gustav Fisher Jena 327 pp.
Leelapriya, T., Dilip, K.S., Sanker-Narayan, P.V., 2003. Effect of weak sinusoidal magnetic field on germination and yield of cotton (*Gossypium sp*.). Electromagn. Biol. Med. 22, 117–125.
Leopold, A.G., Musgrave, M.E., Williams, K.M., 1981. Solute leakage, resulting from leaf desiccation. Plant Physiol. 68, 222–1225.
McKay, J.K., Richards, J.H., Mitchell-Olds, T., 2003. Genetics of drought adaptation in Arabidopsis thaliana. Pleiotropy contributes to genetic correlations among ecological traits. Mol. Ecol. 12, 1137–1151. https://doi.org/10.1046/j.1365-294X.2003.01833.
Mohammadkhani, N., Heidari, R., 2008. Drought-induced accumulation of soluble sugars and proline in two maize varieties. World Appl. Sci. J. 3, 448–453.
Monneveux, P., 1991. Quelles stratégies pour l'amélioration génétique de la tolérance au déficit hydrique des céréales d'hiver ? In: L'amélioration des plantes pour l'adaptation aux milieux arides (AUPELF - UREF. John Libbey Eurotext, Paris, pp. 165–186.
Mousa, E.M., Gendy, A.A., Maria, A.M., Selim, D.A., 2013. Physio-anatomical responses of salinity stressed wheat plants to magnetic field. Minufiya J. Agric. Res. 38, 31–41.
Nassar, M.A., El-Sahhar, K.F., 1998. Botanical Preparations and Microscopy (Microtechnique). Academic Bookshop, Dokki, Giza, Egypt, pp. 219 (In Arabic).
Novitskaya, G.V., Kocheshkova, T.K., Novitskii, Y.I., 2006. The effects of a weak permanent magnetic field on the lipid composition and content in the onion leaves of various ages. Russ. J. Plant Physiol. 53 (5), 638–648.
Ogolnej, K., Uprawy, R., Rolnieza, A., 2002. The effect of magnetical biostimulation of sowing material, spring wheat on its development and crops. Folia Univ. Agric. Stetin. Agricultura 226, 77–82.
Patakas, A., Nicolaou, N., Zioziou, E., Radoglou, K., Noitsakis, B., 2002. The role of organic solute and ion accumulation in osmotic adjustment in drought stressed grapevines. Plant Sci. 163, 361–367.
Radhakrishnan, R., Kumari, P.D.R., 2012. Pulsed magnetic field: a contemporary approach offers to enhance plant growth and yield of soybean. Plant Physiol. Biochem. 51, 139–144.
Rosen, A.D., 2003. Mechanism of action of moderate-intensity static magnetic fields on biological systems. Cell Biochem. Biophys. 39, 163–174.
Sadasivam, M., Monikom, A., 1992. Biochemical Methods for Agricultural Sciences. Wiley Eastern Limited 246 pp.
Sadeghipour, O., 2016. The effect of magnetized water on physiological and agronomic traits of cowpea (*Vigna unguiculata* L.). Int. J. Res. Chem. Metall. Civil Eng. (IJRCMCE) 3, 195–198.
Selim, A.-F., El-Nady, M., 2011. Physio-anatomical responses of drought stressed tomato plants to magnetic field. Acta Astronaut. 69, 387–396.
Selim, D.A., Gendy, A.A., Maria, A.M., Mousa, E.M., 2009. Response of pepper plants to magnetic technologies. In: 1st Nile Delta Conf on Export Crops Fac of Agric Minufiya Univ, pp. 89–104.
Shehab, El-Din, T.,R.A., Mitkees, M.M., El- Shamy, M.A., Gouda, M.M., AbdeAleem, A.M., Abdel- Ghani, N.S. Hanna, Iman, M.M., Sadek, A.M., AboWarda, M.Kh, Mosherf, E.A.M., El-Sayed, Hayam, S., Mahgoub, A.K., Mostafa, M.G., Mosaad, A.H., Bassiouni, M.M.A., El-Monofy, S.Kh, Mahmoud, M.A., Mahrous, A.A., Ageez, M.A.M., Eid, M.H., Iskandar, M.A., Mostafa, A.A., Hamada, Y.G., Abdel- Gwad, A.M., Mousa, S.A., AbdelMajeed, A.M., Tammam, Nagwa, R., Abdel- Fatah, H., Ashoush, F.A., Hefnawy, H., Hendawy, S., El-Din Ali, M.B., Toweefles, A.A., Abdel-Karim, A.A., Khattab, A.A., Gomaa, O.H.S., Khalill, Kadria, F., Hegazi, Enayat, H., Ghanem, A.A., Ali, F.F., El-Sayed, Ikhlas, Safik, S., AboNaga, 1999. Sakha 93 and Giza 168:Two new high yielding and rust diseases resistant bread wheat cultivars. J. Agric. Sci., Mansoura Univ. 24, 2157–2168.
Simane, B., Peacock, J.M., Struik, D.C., 1993. Differences in developmental plasticity and growth rate among drought resistant susceptible cultivars of durum wheat (*Triticum trugidum* L., var. durum). Plant Soil 157, 155–166.
Taiz, L., Zeiger, E., 2006. Plant Physiology, fourth ed. Sinauer Associates Inc Publishers, Sunderland, MA.
Takatshinko, Y., 1997. Hydromagnetic systems and their role in creating microclimate. In: International Symposium on Sustainable Management of Salt Affected Soils. Cairo, Egypt, pp. 22–28 Sept, 1997.
Toledo, E.J.L., Ramalho, T.C., Magriotis, Z.M., 2008. Influence of magnetic field on physical-chemical properties of liquid water: insights from experimental and theoretical models. J. Mol. Struct. 888, 409–415.
Vendruscolo, E.C.G., Schuster, I., Pileggi, M., Scapim, C.A., Molinari, H.B.C., Marur, C.J., Vieira, L.G.E., 2007. Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. J. Plant Physiol. 164, 1367–1376.
Wang, Y., Zhang, B., Gong, Z., Gao, K., Ou, Y., Zhang, J., 2013. The effect of a static magnetic field on the hydrogen bonding in water using frictional experiments. J. Mol. Struct. 1052, 102–104.