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Physio-Biochemical Behaviour, Water Use Efficiency and Productivity of Wheat Plants Exposed to Magnetic Field

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ABSTRACT

The aim of this study was to evaluate the capability of magnetized field in improving the growth, physiological and biochemical aspects and yield attributes of wheat crop (*Triticum aestivum* L. cv Giza 168) as one of the important economically strategic crops. Pot experiments were executed in a glass greenhouse belonged to the experimental farm, Faculty of Agriculture, Menoufia University, Shibin El-Kom, Egypt during two winter growing seasons 2015/2016 and 2016/2017. Magnetic treatments were magnetic grains, magnetic water and combined magnetic grains and water in addition to the control group. Vegetative growth of wheat plants was significantly increased by treating with different magnetic treatments compared to the control plants. Application of magnetic treatments caused significant increases in total leaf water content, relative water content, water use efficiency (WUE), membrane permeability and succulence degree, whereas the transpiration rate and leaf water deficit were significantly reduced. Most growth characteristics and WUE were more positively affected by the magnetized water treatment than other magnetic treatments. The concentrations of photosynthetic pigments and growth promoters (IAA, GA and Cytokinins) showed significant increases in the treated wheat plants with all magnetic treatments. A marked increase was observed in the uptake of N, P, K, Ca, Mg, Fe, Cu and Mn, but Na uptake was decreased in wheat plants by the application of magnetic field. Magnetic treatments caused a significant increase in the spike characters, grain and straw yield, and harvest index of wheat plants as well as some chemical constituents in grains compared with the control plants.
Keywords: Magnetic field, wheat, growth, water relations, photosynthetic pigments, phytohormones, mineral uptake, WUE, yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important and economically strategic crop and the basic staple food of the major civilizations all over the world. Nowadays, increasing wheat production is still a challenge in many countries especially in Egypt, not only to meet higher demands by growing populations and reduce the increasing gap between production and consumption of wheat grains**,** but also to meet the climate changes and environmental stress (Namvar and Khandan 2013).That can be achieved by increasing wheat yield per unit area either by introducing high yielding varieties and/ or using new modern methods to increase the yield.

Magnetic field has been suggested to be a cosmic power that affects living system such as other powers like sunlight, temperature, and humidity. In recent years, the Earth's magnetic field is decreasing. It is about 10 percent weaker than it was before (Roach 2004). Many researches gleaned over years in that field and till now to understand the physiological, biochemical and molecular changes in plants affected by static magnetic field. Moreover, theses researches may provide the humanity by new sources of energy that can be used in agriculture for raising plant productivity with taking care of human health (Aladjadjiyan 2003). Podlesny *et al.* (2005) presented that the agriculture production enhanced by physical treatments like magnetic field could be considered harmless for the environment and effective in modifying the physiological and biochemical processes in plants. Magnetic field not only affects the chemical pathways in the plant, but also changes various physical properties of solutes inside the plant cell as cytoplasm and outside it like the growth medium and the water of irrigation (Galland and Pazur 2005). Moreover, some investigators indicated that magnetic field had significant effects on seed germination, growth, yield, enzymes activity, water relations, chemical components of some plants (Alikamanoglu and Sen 2011; Selim and El-Nady 2011; Radhakrishnan and Kumari 2012 and Selim *et al.*2019). On contrast, Kordas (2002) found that the growth of spring wheat was weakened as affected by a constant magnetic field, the plants were shorter, and so were their culms and ears. Moreover, the effect of a magnetic field on the crop of spring wheat and its structure was small.

The present investigation was done to demonstrate that magnetic field treatments can play an important role in increasing the growth and yield and its components, also improving the physiological and biochemical characteristics of wheat crop (*Triticum aestivum* L. cv Giza 168).

MATERIALS AND METHODS

Pot experiments were carried out in a glass greenhouse under natural conditions at the experimental farm of the Faculty of Agriculture, Menoufia University, Shibin El-Kom, Egypt during two winter growing seasons 2015/2016 and 2016/2017 with the objective of study the effects of four treatments on some vegetative growth parameters, water relation parameters, some physiological and biochemical characteristics and yield attributes of wheat plants.

1. The treatments were designed as follows:

1. Normal grains + Normal water (Control).
2. Magnetized grains + Normal water (Mag_{grains}).
3. Normal grains + Magnetized water (Mag_{water}).
4. Magnetized grains + Magnetized water ($Mag_{grains+water}$).

A magnetron model U.T.I of one-inch diameter was used for treating water and magnetic funnel for treating grains. Magnetized water is tap water after magnetization through passing in a magnetron (model U.T.I. 1 inch, output 4-6 m^3/h, its magnetized field intensity 50 mT, production by Magnetic Technologies L.C.C., Russia, branch United Arab Emirates) and the magnetized grains are normal grains passed through a magnetic funnel.

2. Experimental design

Four treatments (4 replicates/treatment) were executed and the pots were arranged in a completely random design. Polyethylene pots (30-cm diameter and 40-cm in depth) were used with three bottom drainage holes blocked with sponge to slow drainage. The pot was loaded with 8 kg air-dried soil (pH of soil extract=8.1, EC_e=2.4 $dS.m^{-1}$, field capacity=40.8% and N, P and K were 69.05, 2.82 and 283.2 mg/kg, respectively). The plants used in this study was wheat (*Triticum aestivum* L. cv Giza 168). Wheat grains were obtained from Agriculture Research Center, Giza, Egypt. Twenty grains were sown on 15thand 18th November in the 1st and 2nd seasons, respectively, they put in each pot and thinned to ten uniform seedlings after emergence.

3. Irrigation

Pots were irrigated by water according to the treatments mentioned before with equal amounts whenever they needed by the soil field capacity.

4. Fertilization

Phosphorus fertilizer in form of superphosphate (15.5% P_2O_5) and potassium fertilizer in form of potassium sulfate (48% K_2O) were added to the soil before sowing at the rates of 1.8 and 0.6 g pot^{-1}, respectively. Nitrogen in form of ammonium sulfate (20.5% N) was added at the rate of 1.8 g. pot^{-1} in three doses.

5. Experimental Samples

During the two growing seasons, two plant samples were randomly taken. The first one was taken 70 days after sowing (DAS) to determine the plant endogenous hormones and second sample was taken 100 DAS to measure the growth, physiological and biochemical parameters.

1. Growth characteristics:

Plant height (cm) was measured from the soil surface to the top of plant, number of tillers and leaves per plant, fresh weights of the root, shoot and whole plant ($g.plant^{-1}$), dry weights of root, shoot and whole plant (dried in an electric oven at 70˚C; $g.plant^{-1}$ were measured, the dry matter of these organs were ground to a fine powder and kept in small plastic bags for chemical analysis), shoot/root ratio. Total leaf area ($cm^2.plant^{-1}$) was measured using the formula of Aase (1978). Assimilation rate (*AR*, $mg.cm^{-2}$), specific leaf area (*SLA*, $m^2.kg^{-1}$) and leaf area index (*LAI*)were estimated according to Simone *et al*. (1993). Some characters of flag leaf: Flag leaf length and width (cm), fresh and weights of flag leaf (g), and leaf area, were measured.

2. Water relations:

Total water content (TWC, %), in leaves were determined according to the method described by Gosev (1960). Relative water content (RWC, %) and leaf water deficit (LWD, %) and sclerophylly degree (ScD, %) using the methods described by Kalapos (1994).

Degree of succulence: The degree of succulence was calculated applying the following formula:

Degree of Succulence = FWt / DWt

Transpiration rate: was estimated according to Kreeb (1990).

3. **Measurement of cell membrane stability (Membrane permeability)** was estimated as descried by Yan *et al*. (1996) with some modifications as follow; fully expanded young fresh leaves (4th) were selected from each treatment and replication then washed. Twenty pieces (1 cm diameter) cut from these leaves were put into distilled water contained in test tubes. The tubes were kept in 30^{o}C for 3 hr. and then the electrical conductivity (C_1) of the solution was measured by an electrical conductivity meter (Model: CD-4301). After boiling the samples for 2 min, their electrical conductivity (C_2) were measured again when the solution was cooled to room temperature. The percentage of electrolyte leakage was calculated according to the formula:

$$[MI\ \% = (C_1/C_2) \times 100].$$

4. Photosynthetic pigments:

Chlorophyll a, b and carotenoids were estimated in the 4th leaf, using spectrophotometer method (SPEKOL spectrophotometer) as described by Wettstein (1957). The concentration of pigments was then expressed in mg. g^{-1}DWt.

5. **Phytohormones:** Plant hormones in fresh shoots of wheat plants were extracted and determined according to Shindy and Smith (1975), hormone analysis was performed by using HPLC according to Crocier and Moritz (1999). Phytohormones were calculated as µg.100 g^{-1}FWt.
6. **Mineral elements:** 0.2 gm of dried ground roots and shoots (stems and leaves) of the tested plants was digested in H_2SO_4 (concentrated), H_2O_2 (5:1) for chemical analysis of minerals: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) sodium (Na), iron (Fe), manganese (Mn) and copper (Cu) according to A.O.A.C. (1995) while Cl according to Perez-Alfocea *et al*.(1993). The concentration of the N, P, K, Ca, Mg, Na and Cl elements were expressed in (%) of dry weight, whereas the elements Fe, Mn and Cu were expressed in ppm, then the uptake of elements by pant systems was calculated in mg/plant for macro-elements and µg. $plant^{-1}$ for micro-elements.

6. Yield and its components:

At the harvest time, the measurements of yield attributes for wheat plants were recorded as follows: Spike length (cm),weight of spikes per plant ($g.plant^{-1}$), number of grains per spike, weight of grains per spike ($g.spike^{-1}$), grain yield ($g.plant^{-1}$& $g.m^{-2}$), straw yield ($g.plant^{-1}$; $g.m^{-2}$), 1000 grains weight (g) and harvest index. The total carbohydrates (mg. g^{-1}DWt) in grains according to Sadasivam and Manikam (1992) and total protein in grains (%) according to A.O.A.C. (1995) were determined.

7. **Water Use Efficiency** for grain and straw production (*WUE*, g $DM.kg^{-1}$ H_2O) was determined according to Vites (1965).
8. **Statistical analysis:** The obtained data were analyzed using COSTAT software (1985) and the significance of the differences between treatment means were checked by using LSD test at 5% significance level according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

1. Growth parameters:

The obtained results in the first growing season showed almost the same trend as those of the second one, so data of the second season 2016/2017were found enough to be presented.

The impact of different magnetic treatments on growth of wheat (*Triticum aestivum* L. cv Giza 168) at age of 100 days as shown in Table 1a reveal that the plant height, number of tillers and leaves, leaf area, assimilation rate, fresh and dry weights of root, shoot and whole plant of wheat plants, and leaf area index were significantly increased by applying magnetic treatments. The magnetized water treatment gave the highest increases in most above-mentioned growth characteristics, as compared with other magnetic treatments. The induced increases by magnetized water treatment reached 49.7, 100, 258.8, 188.6, 57.3, 145.7, 376.3, 3394, 638.5, 3384, 367.2, 188.6% over the untreated plants, for the above-mentioned growth characters, respectively. As for flag leaf growth characters (Table 1b), it was found that the magnetic treatments have similar effects to that those of the plant growth characters mentioned before, but the best treatment varied among leaf characters.

The highest increment in flag leaf length and width (16.1 and 20 %) was observed by the magnetic water treatment, whereas the highest one in fresh and dry weights (60, 48%) and leaf area (27%) were observed by the combined magnetized grains and water. These results are in accordance with those obtained by Carbonell *et al.* (2011) on pea; Radhakrishnan and Kumari (2012) on soybean; Selim *et al.* (2013) on pea, tomato and wheat plants, who found that, the plant height, root length, leaf area, dry weights of root, shoot and whole plants significantly increased as a result of irrigating plants with magnetized water.

The enhancement of growth as a result of magnetic treatments may be due to magnetic system changes the physiochemical characteristics of natural water, plays a role in increasing the absorption of essential elements, may play a relevant role in cation uptake capacity and has a positive effect on immobile plant nutrient uptake (Eşitken and Turan 2004), subsequently increasing the formation and division of leaf cells that may increase the initiation of more leaves primordial leading to increase of the photosynthesis by increasing the active surface of leaves, so the vegetative growth of plant and its biomass may increase (Takachenko 1995). Also, magnetic treatments enhance the soil acidity and water relations in the rooting medium, this enhancement increases the availability and absorption of nutrients leading to more initiation and elongation of stem cells (Hilal *et al.* 2002). Additionally, magnetic field promoted IAA (auxin), cytokinins and GA syntheses and decreases the synthesis of ABA as shown from our results in Table 5, this may bring about promoting cell division and enlargement (De Souza *et al*. 2005; Selim *et al*. 2013).

Table 1. Effect of different magnetic techniques on vegetative growth characteristics of wheat plants at 100 DAS during the growing season 2016/2017.

a. Whole plant

Characters Magnetic Treatments	Plant height (cm)	Tillers No. per plant	Leaves No. per plant	Leaf area (cm^2. $Plant^{-1}$)	Specific leaf area ($m^2.kg^{-1}$)	Assimilation rate ($mg.cm^{-2}$)	Fresh weight(g/plant) Root	Fresh weight(g/plant) Shoot	Fresh weight(g/plant) Whole	Dry weight(g/plant) Root	Dry weight(g/plant) Shoot	Dry weight(g/plant) Whole	Shoot / Root ratio	Leaf Area Index
Control	53.667	2.000	5.667	199.914	16.383	1.925	0.620	3.260	3.880	0.087	0.817	0.903	9.722	1.592
Mag_{grains}	74.667	3.000	11.000	326.823	11.563	2.387	0.567	6.687	7.253	0.220	1.800	2.020	8.574	2.602
Mag_{water}	80.333	4.000	20.333	576.853	9.403	3.028	1.523	15.527	17.050	0.640	3.580	4.220	6.678	4.593
$Mag_{grains+water}$	81.333	3.667	13.000	354.099	9.029	3.076	0.550	8.770	9.320	0.160	2.100	2.260	13.514	2.819
LSD 5%	6.101	0.515	6.556	165.179	4.182	0.625	0.451	6.255	6.532	0.251	1.349	1.575	2.056	1.895

b. Flag leaf

Characters Magnetic Treatments	Flag Leaf Length (cm)	Flag Leaf Width (cm)	Flag Leaf F.Wt (g)	Flag Leaf D.Wt (g)	Flag Leaf area (cm^2)	Specific Leaf area ($m^2.kg^{-1}$)
Control	29.000	1.667	0.613	0.186	66.741	11.385
Mag_{grains}	31.333	2.000	0.783	0.215	72.748	9.348
Mag_{water}	33.667	2.000	0.900	0.259	81.774	9.060
$Mag_{grains+water}$	32.667	1.833	0.980	0.274	85.026	8.663
LSD 5%	1.415	0.210	0.195	0.117	5.145	1.940

2. Water relations:

Data recorded in Table 2 indicate that the application of different magnetic treatments improved total water content (*TWC*), relative water content (*RWC*) and leaf water deficit (*LWD*), succulence degree (*SuccD*), sclerophylly degree (*SclD*), transpiration rate (*TR*) and membrane integrity (*MI*) of wheat plants. The magnetic grains treatment was the best in increasing *TWC* (371%) and *RWC* (34%), and reducing *LWD* (77%) and *SclD* (51%) as compared with the control and the other magnetic treatments. The highest value of *SuccD* was recorded by the magnetized treated water (125%) followed by magnetized treated grains (95%) then the magnetized treated grains and water (88%). Transpiration rate was significantly decreased as the result of application of magnetic technologies by 30% for the magnetized treated grains, 31% for the magnetized treated water treatment and 65% for the magnetized treated grains and water treatment compared with the untreated control plants. The membrane integrity percentage was increased by about 29, 97 and 43% with treating plants by magnetized grains, magnetized water and the combination of magnetized grains and water, respectively, compared with the control plants. These results are in accordance with those reported by Selim *et al*. (2013) on some economic crops, Selim and El-Nady (2011) on tomato. The plant water status of wheat plants and the cell membrane permeability were improved by the magnetic treatments. Rokhinson and Baskin (1996) found that the magnetic fields change the normal water properties and improve the moisture supply of plant. Moreover, Bondarenko *et al.* (1996) found a marked improvement in the permeability of plant cell membranes as well as the quantity of total free water in the seeds as a result of treating the seeds with magnetic fields.

Table 2. Effect of different magnetic techniques on plant water relationships of wheat plants at 100 DAS during the growing season 2016/2017.

Characters Magnetic Treatments	Total Water Content (%)	Relative Water Contet (%)	Leaf Water Deficit (%)	Sclerophylly Degree (%)	Succulence degree	Transpiration rate ($mg.cm^{-2}.h^{-1}$)	MI (%)
Control	61.111	69.571	30.429	31.282	5.456	1.607	29.900
Mag_{grains}	83.805	92.883	7.117	15.208	10.612	1.127	17.799
Mag_{water}	78.103	82.840	17.160	18.863	12.300	1.117	27.189
$Mag_{grains+water}$	77.176	88.393	11.607	20.731	10.246	0.858	13.818
LSD 5%	9.546	13.443	13.443	10.645	1.656	0.512	6.269

3. Photosynthetic Pigments

The concentrations of chlorophyll a, b, total chl. (a+b) and carotenoids as well as the ratios of chl. a/b and total chl./carotenoids significantly increased when the wheat plants exposed to the three magnetic treatments compared to the untreated plants (Table3). It was observed that, treating wheat plants with magnetized water gave the highest increases in leaf chlorophyll a, b and total chl. (a+b) concentrations and the ratio of chl a/b by 160, 56, 106, 59%, respectively over the control. The magnetized grains and water treatment gave the highest carotenoids content with an increase by about 56%, whereas the magnetized grains gave the highest ratio of total chl/carotenoids (64%) comparing with the other magnetic treatments. Our results are confirmed with those reported by Novitskii *et al.* (2001), who demonstrated that an increase in chlorophyll content by about 70% in onion plant, as well as Atak *et al.* (2003) on *Glycine max* found that magnetically treated plants have more concentration of photosynthetic pigments than the untreated plants, Racuciu *et al.* (2005) argued for the stimulatory influence of chronic exposure to the magnetic field on the biosynthesis of chlorophyll and carotenes, with an increase up to 21%, likewise Yaycili and Alikamanoglu (2005) explained that magnetic field treatment increased chlorophyll a, b and total chlorophyll levels in *Paulownia* plants. The increase in the concentration of chlorophylls because of the magnetic treatments may be due to the increment in the concentration of GA_3 in plants (Selim *et al.* 2013) and our results in Table 4a, which induce an increase in the green pigments in the treated plants by induction the production of chlorophyll in leaves (Bethke and Drew 1992). In addition, the enhancing effect of magnetic system on the availability and absorption of essential elements specially the iron (Fe^{++}), magnesium (Mg^{++}) and nitrogen (NH_4^+) cations (Takachenko 1995 and Hilal *et al.* 2002), that are necessary for enzymes activation and formation of chloroplasts and chlorophyll. Aladjadjiyan (2007) stated that the effect of static magnetic field on photosynthetic apparatus may be due to the paramagnetic characteristics of chloroplasts.

Table 3. Effect of different magnetic techniques on photosynthetic pigments characteristics of wheat leaves at 100 DAS during the growing season 2016/2017.

Characters Magnetic Treatments	Chl. a	Chl. b	Total Chlorophylls(a+b)	Carotenoids	Chl a/b	Total Chl / Carotenoids
	mg/g DWt					
Control	2.794	1.312	4.105	3.809	2.189	1.180
Mag_{grains}	4.295	1.768	6.063	3.441	2.571	1.930
Mag_{water}	6.413	2.051	8.464	5.355	3.488	1.583
$Mag_{grains+water}$	4.605	1.340	5.944	5.947	3.399	1.054
LSD 5%	1.545	0.775	2.125	1.719	1.801	0.556

4. Phytohormones

Data in Table 4a indicate clearly that marked increases in the concentrations of gibberellic acid (GA), Indole Acetic Acid (IAA), Kinetin, Zeatin and Benzyladenine (BA) in shoots of wheat plants were found as a result of magnetic treatments if compared to the control plants. The maximum increases in theses phytohormones as growth promoters were achieved by the double magnetized grains and water compared with the other magnetic treatments. The % increases in phytohormones were about 76, 143, 64, 35, and 212, respectively over the control. On the other hand, a decrease in the concentration of Abscisic Acid (ABA) in wheat shoots as a result of magnetized grains, magnetized water and double magnetized grains and water treatments was noticed. The decrease was about 9, 14 and 22 %, respectively if compared with control. Wheat plants displayed a general increase in the ratio of promoters/inhibitors with all magnetic treatments, the double magnetized grains and water gave the highest ratio in this respect (Table 4a). The double treatment of magnetized grains and water and the magnetized water treatment increased it by about 129% and 100%, respectively over the untreated plants. These results are in line with those presented by Xia and Guo (2000), who observed that the auxin content of tomato plants could be increased by magnetic treatments, and Selim *et al.* (2013) who found that magnetized water increased hormonal contents of promoters (GA_s, IAA, and cytokinins) and reduced the concentration of ABA in leaves of some economic plants compared to the control plants. Magnetic field has a positive effect on growth promoters (IAA, GA and Cytokinins) and an adverse effect on the growth inhibitor (ABA) as shown in Table 4a. Auxin, cytokinin, and gibberellin have been shown to stimulate cell division whereas abscisic acid causes an inhibition. Plant phytohormones play important roles in all aspects of plant growth and development (Davies 2010).

5. Mineral uptake:

Data concerning the effect of magnetic treatments on the uptake of N, P, K, Ca and Mg as macro-nutrients as well as Fe, Mn and Cu as micro-nutrients in root and shoot of wheat plants recorded in Table 4b show that significant increases in uptake of these elements were found as a result of treating wheat plants with the magnetic treatments comparing with the control plants. The maximum increase in the uptake of the above-mentioned minerals was recorded by the magnetized water treatment and reached 514, 508, 430, 441, 338, 446, 407 and 446% in roots, 389, 542, 440, 392, 396, 338, 361 and 396% in shoots, respectively, over the control plants. On contrast, the uptake of Na by roots and shoots of treated wheat plants was decreased, but a slight increase in Cl uptake was observed. In this concern, these results go hand in hand with the results of Durate-Diaz *et al*. (1997) who found that irrigation with magnetically treated water increased nutrient uptake. Hilal *et al*. (2002) found that the leaves content of P and K was tripled increased by irrigation citrus with magnetic water treated by magnetron. Also, there was a marked increase in the uptake of Fe, Mn and Cu in wheat roots and shoots by using all magnetic treatments. The highest values of the Fe, Mn and Cu uptake in roots and shoots were generally observed by the magnetized water treatment. The obtained results are in accordance with those mentioned by Selim *et al*. (2013) on some economic plants; Selim (2016) on cucumber and Hilal *et al*. (2002) on citrus who found that irrigation with magnetic water treated by magnetron showed maximum increase in Mn content of leaves, followed by Zn while that of Fe was the least affected. Increasing the uptake of N, P, K, Ca, Mg, Fe, Mn, and Cu in roots and shoots of wheat plants treated with different magnetic treatments (Table 4b) may be ascribed to the enhancing effect of magnetic system on the availability and absorption of essential elements specially the iron (Fe^{2+}), magnesium (Mg^{2+}) and nitrogen (NH_4^+) cations (Takachenko, 1995).

Table 4. Effect of magnetic field treatments on some biochemical constituents in wheat plants during the growing season 2016/2017.

a.The concentrations and the ratios of phytohormones (promoters and inhibitors) in shoots of wheat plants after 70 DAS.

Characters Magnetic Treatments	Promoters: Gibberellic Acid (GA)	Promoters: Indole acetic acid (IAA)	Cytokinins (CKs): Kinetin	Cytokinins (CKs): Zeatin	Cytokinins (CKs): Benzyl-adenine(BA)	Cytokinins (CKs): Total	Inhibitors: Abscisic Acid (ABA)	Promoters/ Inhibitors ratio
	µg/100gm FW							
Control	1360.10	119.60	280.21	13.10	12.35	305.66	325.33	5.49
Mag_{grains}	1594.25	220.95	300.60	15.40	28.70	344.70	297.33	7.26
Mag_{water}	2312.75	285.33	438.33	15.85	31.55	485.73	280.75	10.98
$Mag_{grains+water}$	2395.40	290.30	458.75	17.70	38.47	514.92	254.70	12.57

b. some macro- and micro-elements uptake by root and shoot systems of wheat plants at 100 DAS.

Characters Magnetic Treatments	N	P	K	Ca	Mg	Na	Cl	Fe	Mn	Cu
	mg/ plant							µg/ plant		
Root										
Control	2.350	0.242	1.721	2.128	0.635	2.371	4.921	9.547	8.491	0.955
Mag_{grains}	4.540	0.560	3.540	4.372	1.264	1.156	5.780	20.334	16.506	2.034
Mag_{water}	14.430	1.469	9.114	11.523	3.468	1.464	5.513	52.150	43.071	5.216
$Mag_{grains+water}$	9.134	0.890	5.603	7.470	2.109	1.635	5.906	26.156	23.010	2.616
Shoot										
Control	15.607	1.226	19.775	16.580	4.944	8.498	31.114	84.166	66.134	7.436
Mag_{grains}	38.531	3.601	53.655	39.359	11.380	8.407	34.588	191.449	148.603	18.305
Mag_{water}	76.255	7.876	106.684	81.481	24.523	7.698	34.443	368.740	304.540	36.875
$Mag_{grains+water}$	59.770	4.779	60.705	50.054	15.690	7.455	31.298	223.346	182.044	22.334

6. Yield traits:

The application of magnetic treatments in wheat plants resulted in a significant increase in spike characters (length and weight, spikelet number), grains number and weight; grain and straw yield, 1000 grains weight and harvest index compared with the control (Table 5). The maximum increases were observed by treating with the magnetized water treatment in the above-mentioned attributes with exception of grain yield and harvest index which their maximum increases occurred by the magnetized grains and water treatment as well as weight of 1000 grains by the magnetized grains. These increases in the above-mentioned characters according to the best treatment reached 74, 373, 92, 85, 148, 196, 169, 35 and 17%, respectively. Also, the magnetized grains and water treatment recorded the highest content of total carbohydrates and total protein in grains. These results are closed to the results found by De Souza *et al*. (2006) on tomato plants and Selim (2016) on cucumber plants. The enhancement in yield of wheat plants produced from magnetically treated water and/or seeds may be ascribed to the increment of protein, mineral accumulation, water uptake and enzyme activities which leads to increase the growth and yield (Radhakrishnan and Kumari 2012; Leelapriya *et al*. 2003). Garcia-Reina and Fundora (2002) found a significance increase in the rate of water absorption accompanied with an increase in the total mass in lettuce seeds previously treated in stationary magnetic field. These positively desired effects of magnetic field may be attributed to the improvement in ions uptake (as shown in Table 4b), specially Ca^{+2}.

7. Water use efficiency (WUE):

Data presented in Table 5 show that water use efficiency of wheat plants was significantly increased by using the different magnetic treatments. The highest increases in WUE for grain production and total production were recorded by the magnetized grains and water treatment (196 and 178%) followed by the magnetized water (193 and 154%), whereas the best one for straw yield was the magnetized water (169%) followed by the combination of magnetized grains and water treatment (128%) compared with the untreated control wheat plants. These results are in conformity with those obtained by Selim and El-Nady (2011) who found that a significant increase in the water use efficiency based on dry matter production of tomato plants exposed to magnetic treatments was observed and the magnetized seeds and water treatment gave the highest increase in WUE.

Table 5. Effect of different magnetic techniques on yield and it components as well as WUE of wheat in the growing season 2016/2017.

Characters Magnetic Treatments	Spike length (cm)	Spike wt. (g.plant-1)	Spikelet No./ Spike	Grains No/ Spike	Grains wt. (g)/ Spike	Grain Yield		Straw Yield		1000 grains wt. (g)	Harvest Index	Grain		Water Use Efficiency (g DMt.kg-1 H2O2)		
						$g.plant^{-1}$	$g.m^{-2}$	$g.plant^{-1}$	$g.m^{-2}$			Total Carbohydrate (%)	Total Protein (%)	Grain productivity	Straw Productivity	Total Productivity
Control	11.67	0.75	12.33	17.33	0.58	0.68	96.25	1.11	157.11	33.47	36.99	60.73	11.03	0.43	0.69	1.12
Mag_{grains}	19.00	1.91	18.67	25.50	1.21	1.66	234.96	2.33	329.79	47.45	41.60	70.27	12.20	1.04	1.46	2.49
Mag_{water}	20.67	3.55	23.67	32.10	1.44	1.99	281.67	2.98	421.80	44.86	44.04	71.03	12.45	1.24	1.86	3.11
$Mag_{grains+water}$	20.33	2.75	22.25	31.30	1.41	2.01	284.50	2.53	358.10	45.05	43.30	71.27	12.44	1.26	1.58	2.84
LSD 5%	1.334	0.365	1.672	1.225	0.235	0.223	14.76	0.185	16.34	3.571	5.895	-----	-----	0.091	0.096	0.144

CONCLUSION

The present study clearly demonstrates the great benefits of magnetic field in enhancing the growth, increasing the quantity and quality of yield, improving the water productivity and regulating and/or enhancing the physiological and biochemical aspects of wheat plants. Therefore, it could be recommended the application of magnetic techniques (magnetized water or magnetized grains and water) as a safe alternative choice to improve and enhance the growth, physiology and productivity of wheat crop.

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السلوك الفسيولوجى والبيوكيميائي، كفاءة إستهلاك الماء والإنتاجية لنباتات القمح المعرضة للمجال المغناطيسي

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كان الهدف من هذا البحث هو دراسة قدرة المجال المغناطيسي على تحسين النمو والصفات الفسيولوجية والبيوكيميائية وصفات محصول القمح صنف (جيزة ١٦٨) كأحد المحاصيل الاقتصادية الهامة. أجريت التجارب في صوبة زجاجية في المزرعة التجريبية لكلية الزراعة، جامعة المنوفية، شبين الكوم، مصر خلال موسمين زراعة شتوية (٢٠١٦/٢٠١٥ و٢٠١٧/٢٠١٦). تمثلت معاملات المغنطة في (حبوب ممغنطة، ماء ممغنط، دمج حبوب ممغنطة مع الماء الممغنط بالإضافة للكنترول). ويمكن تلخيص أهم النتائج المتحصل عليها كالتالى: لوحظ زيادة معنوية في النمو الخضري لنباتات القمح المعاملة بمعاملات المغنطة المختلفة مقارنة بالكنترول. أدى تطبيق معاملات المغنطة إلى زيادة معنوية في محتوى الماء الورقي ومحتوى الماء النسبي وكفاءة استهلاك الماء ونفاذية الأغشية ودرجة الغضاضة، بينما أدى إلى إنخفاض معنوي في معدل النتح ونقص الماء الورقي. وجد أن معظم صفات النمو وكفاءة إستهلاك الماء هي الأكثر تأثراً بشكل إيجابي بالمعاملة بالماء الممغنط أكثر من المعاملات الأخرى. لوحظت زيادة واضحة في تركيز صبغات البناء الضوئي ومنشطات النمو الهرمونية (إندول حمض الخليك ، حمض الجبريلك والسيتوكينينيات) في جميع النباتات المعاملة بمعاملات المغنطة المختلفة. كما لوحظت زيادة معنوية في إمتصاص النيتروجين،الفسفور، البوتاسيوم،الكالسيوم، الماغنسيوم، الحديد، النحاس والمنجنيز، بينما إنخفض إمتصاص الصوديوم في نباتات القمح المعاملة بالمجال المغناطيسي . أدت معاملات المغنطة الي زيادة معنوية في صفات السنبلة، الحبوب،محصول القش ومدلول الحصاد لنباتات القمح وكذلك بعض المحتويات الكيميائية في الحبوب بالمقارنة مع نباتات الكنترول.