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Chitosan and Humate Spray Fertilization Impact on the Si-uptake and Productivity of Magnetically Treated Barley Seeds under Calcareous Soil Conditions

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ABSTRACT

Calcareous soil surface crusts, subsoil layers cementation, low organic content, and nutrient availability are crucial difficulties that restrict their handling and yield. The objective of this study is to indicate the effect of magnetic treatment (MT) of barley seeds before sowing when fertilized by the foliar-sprayed chitosan (CHS) with and without the K-humate (K-H) on the crop yield and quality in calcareous soil. Field experiments were carried out during the 2022/2023 - 2023/2024 winter seasons at El-Nubaryia Agricultural Research Station in a split-plot design in triplicate. The main factor was the MT of barley seeds. The sub-main factor was the CHS three application rates: CHS1, CHS2, and CHS3 using 10, 20, and 40 mL, respectively, from the stock solution per 1 L water with and without the K-H (9.6 kg ha^{-1}). Results have indicated that the CHS3+K-H treatment has significantly increased the soil available N by 100.8% relative to the corresponding C and by 50.2% relative to the same treatment without MT. The CHS3+K-H treatment without MT of seeds has produced the most significant increase for the biological and grain yield (Mg ha^{-1}) relative to the C by 75.5% and 53.7%, respectively. The absorbed Si, Zn, and Mn (mg kg^{-1}) was increased but the Fe was decreased compared to the control . It is recommended to activate the barley seeds before sowing by the MT with repeated fertilization by CHS/K-H to enhance the nutrient absorption, growth parameters, and effectively improve the calcareous soil productivity of barley.

Keywords: Cereal Crops, Calcareous Soil, Chitosan, K-Humate, Pre-sowing magnetic treatment

INTRODUCTION

Calcareous soils require specific agricultural practices to sustain their productivity because of the soil crusting, low organic matter (OM), and high $CaCO_3$ content that decreases the plant nutrients' availability. Recent techniques to increase crop productivity include treating the seeds before cultivation with growth regulators, laser, electric, and magnetic field (MF) (Sarraf *et al*., 2020; Samarah *et al*., 2021; El-Sedfy *et al*., 2023; Mohaseb *et al*., 2023).

The pre-sowing magnetic treatment (MT) of seeds by their exposure to an MF is a modern agricultural, ecological and green technology that uses the physical treatment of seeds to activate their germination, seedling strength, and crop yield. It is non-destructive, free of toxic residues and has been tested instead of chemical treatments for vegetables and grain crops and exhibited high performance in terms of different growth attributes. Priming of seeds before planting under an MF called magneto-priming has increased the abiotic/biotic stress tolerance, crop yield, and micro-nutrient concentrations in cereals (Hussain *et al*., 2020; Nile *et al*., 2022). The MT of barley seeds had increased the grain yield in 13 of 19 field trials in southern Alberta during the years 1972 and 1975 (Pittman, 1977). The magnetized onion grains after exposure to non-uniform MF induced by an electromagnet at 160 mT for 15 min showed a significantly higher germination than the non-magnetized seeds under laboratory and field conditions. The seeds' magnetization significantly enhanced grainling germination, emergence, vegetative, bulb forming and maturity stages, and yield (De Souza *et al*., 2014). Seeds of bitter gourd were exposed to 25, 50, and 75 mT created by an electromagnet for 15, 30 and 45 min each and grown under field conditions. The germination, emergence index, means germination time, and vigour index were increased to 54.52%, 50.92%, 35.98%, and 24.93%, respectively. The growth parameters and chlorophyll contents were also enhanced (Iqbal *et al*., 2016). Tomatoes have been also enhanced under saline conditions (Samarah *et al*., 2021). Exposure of sunflower grains to batch static MF strength from 0 to 250 mT in steps of 50 mT for 1–4 h in steps of 1h has accelerated their germination, seedling length, and dry weight under laboratory germination tests (Vashisth and Nagaraja, 2010). The influence of a low-frequency MF(16 Hz) treatment on the germination of wheat, soybean, and maize grains was also studied (Rochalska and Orzeszko-Rywka, 2005). Furthermore, exposure of the dry broad bean grains to an MF induced by an electromagnet at 165 mT for 2 min has significantly enhanced the plants' growth attributes, especially the number of grains, with a 21% increase under pot conditions.

The biophysical mechanism of the MF stimulating the physiological processes is not elucidated enough. The ferromagnetic characteristics in the living organism, energy level, and variations in the electron spins in the atom and molecules can play a role in the cellular responses to the MF. The MF may influence some chemical/biological processes by shifting the electron spin location, making some electromagnetic-induced physiological and biochemical

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variations in the biological entities. The MF may penetrate the seed plasma membrane, inducing alterations alterations, and transferring water and energy signals into the cell. Variations in the ionic fluxes across the cell membrane may induce the water uptake mechanism. The treated grains can absorb water faster. Magnetic treatment may improve the ion mobility across plasma membranes, enhance the amino acid uptake, and biosynthesis of the chlorophyll and carotenes nutritive for seedlings (Shabrangy *et al*., 2021). The gel components of the lipids increase while the fluid component decreases. Therefore, the magnetically stimulated ions, molecules and charged particles are re-distributed at both sides of the cellular membranes, affecting the biological materials and stimulating the germination, growth, and yield (De Souza *et al*., 2014; Iqbal *et al*., 2016). All plant metabolic activities, such as photosynthesis, growth, and mineral nutrition are allied to Ca^{2+} ions mobility in the cell. Variation in the Ca^{2+} ions' concentration in the cell or across the membrane inhibits or enhances the stated activities. So, a better root-shoot system supports the plant better (Hussain *et al*., 2020).

Pre-sowing seed treatment with an MF also inhibits the plant's oxidative damage. The activity of free radical ions in plants can be increased by the MT influencing the antioxidant activity (Altalib *et al*., 2022). The MF perhaps promotes the grain release from the dormant state by inducing the seed's enzymatic activity. It may regulate the rapid germination of the magnetized soybean grains and regulate the expression of different enzymes. It may also activate some enzymes such as amylase, phosphatase, and protease, resulting in the protein synthesis acceleration. Being environment-friendly, it can provide a defence against heat stress and pathogens due to accelerated antioxidant enzymatic protection of the seedling from oxidative stress during growth (De Souza *et al*., 2014; Radhakrishnan, 2019).

It has been found that the maximum stimulating effect of MF in the pre-sowing seed treatment was obtained when grains were immediately sown after the treatment (Sokolov *et al*., 2022). The soil temperature and moisture surrounding the grain may be magnetically induced. Different machines of diverse units were used to expose the grains to the MF. For example, two-magnet units consisting of two 6-kg horseshoe magnets were mounted l0 cm apart on opposite sides of a wooden chute. The MF strength generated was adjusted by varying the voltage applied to the coils and tested by a magnetometer (Pittman, 1977).

On the other hand, there is a global orientation towards agricultural sustainability by encourage of environment friendly alternating fertilizers out of natural resources (Pandey *et al*., 2018). The fertilization by the potassium humate and chitosan (CHS) has been well established to enhance the nutrient use efficiency (NUE), plant growth and quality, soil biological, physical, and chemical properties along with the yield components (Bocharnikova *et al*., 2010; Hussein and Hassan, 2011; Tubana *et al*., 2016; Neu *et al*., 2017). For example, spraying with a 4 cm/L K-H increased the yield, growth parameters, and quality, as well as the N-P-K contents in the straw and grains of pea and maize under plant stress conditions (Ismail *et al*., 2017).

Chitosan (CHS) is a natural, biodegradable, and biocompatible biopolymer (Burrows *et al*., 2007; Ahing and Wid, 2016; Takarina and Fanani, 2017; Ibrahim *et al*., 2019). It is a bio-fertilizer that can activate plant natural mechanisms, enhance crop growth, regulate antioxidant enzymes activity, and used as a growth promoter, antimicrobial agent, and increase water use efficiency (Hidangmayum *et al*., 2019; Hafez *et al*., 2020; Ali *et al*., 2021; Jayanudin *et al*., 2021; Kocięcka and Liberacki, 2021). The soil-applied CHS as a soil amendment at 0.05-0.30% (w/w) has enhanced the lettuce growth and increased the leaf chlorophyll index. It can increase the water-stable soil aggregate and water-holding capacity (Adamczuk *et al*., 2021; Faqir *et al*., 2021). Foliar applied CHS at 2-4 g/L concentration affected the endogenous hormone content, alpha-amylase activity, and chlorophyll content in the maize leaves and improved the physiological properties of the faba bean plants (750 ppm) (Waly *et al*., 2019; Quynh *et al*., 2020; Waly *et al*., 2020; Fouda *et al*., 2022).

The suggested action mechanisms of CHS and humate derivatives are chemical chelation interaction between the poly cationic/anionic groups and the poly-ionic structures like lipo-polysaccharides, proteins, and metal ions present in the cell wall and plasma membrane. The cationic groups can bind the negatively charged phosphate groups of the DNA, which can result in specific modifications in the protein expression (Burrows *et al*., 2007).

Barley (*Hordeum vulgare* L.) is the fourth most important cereal crop in the world being very essential for feed, food and other malt-based food products (Shabrangy *et al*., 2021; Kahraman *et al*., 2024). This study aims to indicate the effect of magnetic treatment (MT) of barley seeds before sowing when fertilized by the foliar sprayed chitosan (CHS) with and without K-humate on the crop yield and quality under the calcareous soil conditions.

MATERIALS AND METHODS

The experimental area and materials used in the study

The experimental field study (2022/2023 and 2023/2024 winter seasons) has been set at the El-Nubaryia Agricultural Research Station (latitude of 30° 30' N longitude of 30° 20' E) Agricultural Research Center (ARC, Egypt). It is a calcareous soil [*Aridisol*] in an arid climate with a hot dry summer and cool winter (FAO, 2014). Data of the initial soil testing before sowing are in Table 1.

Commercial grades of the chitosan (5% CHS in stock solution) and K-humate powder (K-H, 60% humic, 12% K_2O) were used in this study as they are handled for agricultural crop fertilization.

Table 1. Physicochemical characteristics of the studied soils before the experiment

Particle size distribution (%)		Chemical analyses	
Sand (%)	57.13	O.M (%)	0.7
Silt (%)	16.38	$CaCO_3$ (%)	27.2
Clay (%)	26.49	pH (1:2.5 soil suspension)	7.89
Texture class	Sandy clay loam	EC (dS m^{-1})	1.48
Soil Available (mg kg^{-1})			
N	P	K	
15.8	4.0	204.84	
Soluble ions ($cmol_c$ kg^{-1})			
Ca^{2+}	4.5	K^+	0.85
Mg^{2+}	3.5	HCO_3^-	1.5
Na^+	6.0	Cl^-	6.86
		SO_4^{2-}	6.49

The experiment layout and cultivation practices

The experiment area was laid out in a split-plot design with three replicates. The main plots were for the magnetically treated barley seeds (F1). The sub plots were for the spray fertilization (F2) using the CHS three application rates: CHS1, CHS2, and CHS3 using 10, 20, and 40 mL, respectively, from the stock solution per 1 L water with and without the K-H as a constant rate 9.6 kg ha^{-1} = 10 g per plot (10.5 m^2). A control C treatment without application of CHS or K-H was included. All plots, including the control (C) without magnetic treatment (MT) and without CHS, were fertilized by the 100% RD of the mineral N-P-K fertilization (519.05 kg ha^{-1} ammonium sulphate (20% N), 238.1 kg ha^{-1} superphosphate (15.5% P_2O_5), and 119.1 kg ha^{-1} potassium sulphate (48% K_2O). The CHS as foliar spray and K-H as soil application were applied three times at 90, 120, and 150 days after sowing.

Before sowing, barley grains (*Hordeum vulgare* L., Giza 123 variety) were magnetically treated by exposure to a magnetic field (MF 1.4 T intensity). The required amount of barley grains was placed inside a magnetic tube (70 cm length × 1.5-inch diameter, Fig. 1) for 30 min. Sowing was carried out on the same day of the magnetic treatment (MT) on the 11th of November 2022 and 2023 in a plot area (10.5 m^2). Fertilization and agronomic practices were applied following the recommendations of the Egyptian Ministry of Agriculture.

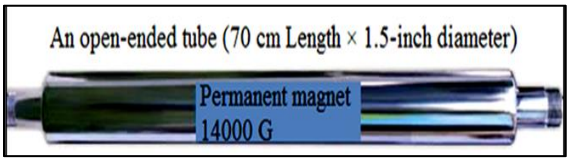

Fig. 1. The perminant magnet instrument used for the pre-sowing MT of barley grains.

Sampling and Testing of the soil and plant

Representative samples from all plots were picked up after harvesting for testing and analysis (Black, 1965; Black, 1982). The plant height (cm), number of spikes/m^2, shelling (%),1000-grain weight (g), biological yield (Mg ha^{-1}), grains, and straw yield (Mg ha^{-1}) have been calculated based on the plot area data, and the two seasons' mean was obtained. The shelling ratio (%) was calculated by dividing the yield (Mg ha^{-1}) of the grains by that of the straw, then multiplying by 100.

The available N-P-K in soil were extracted by 1% K_2SO_4, 0.5 N $NaHCO_3$, and 1 N NH_4OAc (pH 7.0), respectively (Jackson, 1973). Barley grains and straw were dried at 70ºC for 48 h and ground.An 0.5 g of powdered plant sample was wet digested using the acid mixture (1:1 H_2SO_4/$HClO_4$) (Chapman and Pratt, 1961). Total concentrations of the N, P, and K in plant and soil extracts were measured (by distillation: Kjeldahl apparatus, colorimetric: the UV-Vis Spectrophotometer, and by flame photometer, respectively) (Rayment and Lyons, 2011; Piper, 2019). Soluble concentrations of the Fe, Mn, Zn, and Si in the grains' extract were measured by the ICP Spectrometry (ICP-*Ultima 2 JY* Plasma). The grains' uptake of the estimated nutrients was calculated by multiplying the nutrient concentration (g kg^{-1}) in the grains by the grains' yield (kg ha^{-1})

Agronomic efficiency (AE) :

for the mineral N, P, and K fertilizers (Craswell and Godwin, 1984; Roozbeh *et al*., 2011) by Eq. (1):

$$\textbf{Agronomic Efficiency (AE)} = \frac{Y_f - Y_0}{Fertilizer rate\ (N, P\ or\ K, kg ha^{-1})} \quad \textbf{(1)}$$

Y = grains' yield (kg ha^{-1})
f = sprayed plots
0 = non-sprayed plots (C treatments)

Statistical Analysis

The least significant difference (LSD) of the treatments was calculated at *P ≤ 0.05* significance level by the two-way ANOVA as well as Duncan's letters using the Co-Stat Software Package (Ver. 6.311), Cohort Software Inc., Berkley, California (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Results

Effect of the studied treatments on the macronutrient availability in soil

The mineral fertilization in the present study was applied using the RD of the N, P, and K nutrients for all plots, including the C, except the initial soil before cultivation. The soil available N-P-K nutrient concentrations (mg kg^{-1}) in Table 2 have significantly varied due to the studied factors. Spraying the CHS at rate 3 and/or K-H on plant and soil during the early germination and growing-up stages has significantly increased the soil available N by 52.4% relative to the C treatment without MT of grains. The combination of the MT pre-sowing and spraying both the CHS at rate 3 and K-H in the CHS3+K-H treatment has significantly increased the soil available N by 100.8% relative to the corresponding C and by 50.2% relative to the same treatment CHS3+K-H without MT. Added to that, the sprayed CHS, and K-H have increased the available N (mgkg^{-1}) in soil, and the CHS2 as well as the CHS2+K-H and CHS3+K-H treatments have exhibited the most significant increase of the available P without MT by 86% relative to the control C. Also, the CHS2+K-H and CHS3+K-H have increased the soil available K significantly relative to the C by 39.7% and 30.9%, respectively. When using the MT of grains, the mentioned treatments have decreased the available P significantly by 35.7 and 28.6% while increasing the available K by 21 and 33%, respectively.

This trend can be attributed to the additional N-content in the CHS compound structure, which is rich in the ─NH_2 functional groups. This N-content is added to the applied RD in a biocompatible, more available organic form loaded on carboxylic groups (─COOH) in the commercial product. Also, the humate functional groups provide additional biocompatible organic available forms of the N and P nutrients and the dissolved K^+ ion from the K-H salt.

The MT of seeds before sowing perhaps stimulates the biological and chemical components inside the grain, which are responsible for the absorption of nutrients from the soil solution during the germination and growth stages. The significant increase in the soil available N-P-K may refer to a more controlled absorption of the N, P, and K nutrients from the soil solution due to the MT of grains. The soil available concentrations of the P and K (mg kg^{-1}) in the case of the MT were increased with increasing the application rate of spray fertilization from 1 to 3, but were less than the corresponding treatment without MT. This result may be due to either increased absorption by plants, fixation in soil, or loss by leaching. The single (F1, F2) and combined (F1×F2) factors under study have significantly changed the soil available N-P-K contents, so spray fertilization and/or pre-sowing MT can be applied separately or in a combination, as indicated in Table 2.

Table 2. Effect of the studied treatments on the macronutrient availability in soil

Treat.		Soil Available (mg kg^{-1})					
		N		P		K	
		– M	+ M	– M	+ M	– M	+ M
Initial		15.8^{e}		4.0^{d}		204.84^{h}	
C		17.45^{e}	19.9^{e}	5.0^{d}	7.0^{bc}	316.52^{cd}	232.76^{h}
K-H		26.6^{d}	30.58^{cd}	8.0^{ab}	7.0^{bc}	344.44^{b}	253.70^{gh}
CHS1		19.90^{e}	26.6^{d}	8.0^{ab}	8.5^{ab}	302.56^{cdef}	274.64^{efg}
CHS2		19.95^{e}	33.25^{bc}	9.3^{a}	5.5^{cd}	316.52^{cd}	267.66^{fg}
CHS3		26.6^{d}	33.25^{bc}	6.0^{cd}	5.5^{cd}	302.56^{cdef}	288.60^{defg}
CHS1+K-H		19.95^{e}	29.95^{cd}	7.0^{bc}	5.5^{cd}	330.48^{c}	281.62^{defg}
CHS2+K-H		26.6^{d}	36.58^{ab}	9.3^{a}	4.5^{d}	442.16^{a}	281.62^{defg}
CHS3+K-H		26.6^{d}	39.95^{a}	9.3^{a}	5.0^{d}	414.24^{a}	309.54^{cde}
LSD$_{0.05}$	F1	1.24 **		1.24 *		17.93 **	
	F2	2.49 ***		1.18 **		22.05 ***	
	F1×F2	***		***		***	

F1: main factor (pre-sowing MT of barley grain), F2: sub-factor (spray fertilization by the CHS and/or K-H), LSD: least significant difference at *P ≤ 0.05*, SL: Significance of Level

Effect of the studied treatments on the barley yield and some yield components

The MT of barley seeds and the CHS/K-H treatments have significantly increased the plant height (cm), no. of spikes/m^2, 1000-grain weight (g), and the yield (Mg ha^{-1}) as indicated by Table 3 at P≤0.05 compared to the C treatment. The CHS3+K-H treatment without MT of seeds has produced the most significant increase relative to the C by 33.3%, 55.1%, 75.5%, and 53.7% for the plant height, no. of spikes/m^2, biological yield, and the grains yield (Mg ha^{-1}), respectively. The CHS/K-H treatments were more effective than the single CHS application. Additionally, the MT of barley seeds before sowing has shown a significant increase relative to the corresponding treatments without MT by 1.3%, 54.9%, 23.4%, and 141.2% for the plant height, no. of spikes/m^2, 1000-grain wt., and grain yield, respectively. The interactive effect of the combination of the MT before sowing and spraying of the CHS with K-H (F1×F2) has significantly improved the plant height, no. of spikes, and both the biological and grain yield of the barley plant.

Increasing the CHS application rate to rate 3 in combination with the K-H application in the CHS3+K-H treatment along with the MT of grains has increased the plant height by 13.9%, no. of spikes/m^2 by 14.9%, 1000-grain wt by 15.5%, biological yield by 52.7%, and the grains yield by 82% compared to the single CHS3 treatment. Such results are often caused by the significantly varied content of the soil available N, P, and K nutrients as affected by the applied treatments.

Impact of the applied treatments on the shelling ratio (%) of the barley plant

The pre-sowing MT of the barley grains combined with the sprayed fertilizers has increased the shelling ratio (%) shown in Fig. 2 by 12.7% and 11.8% by increasing the application rate from CHS1 to CHS3 and CHS1+K-H to CHS3+K-H, respectively. The shelling ratio was increased by 34.2% and 121.5% for the CHS3 and CHS3+K-H treatments with MT (+M), respectively, in comparison with the corresponding treatments without MT (−M). This effect may be caused by the magnetic induction that stimulates the biological and physiological content of the grain during its early germination stages. Such magnetic activation perhaps increases the germination percentage and the plant growth parameters so that the total amount of grains increases. This behaviour is in consistence with the data in Table 3, referring to the enhanced yield parameters under the combined effect of the MT and spraying the CHS and humate.

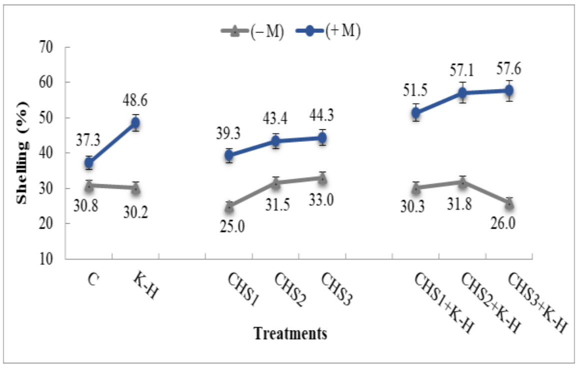

Fig. 2. Impact of the applied treatments on the shelling ratio (%) of the barley plant

Table 3. Effect of the studied treatments on the barley yield and some yield components

Treat.		Plant height(cm)		Number of spikes/m^2		1000-Grain Wt. (g)		Biological yield (Mgha^{-1})		Grain yield (Mgha^{-1})	
		– M	+ M	– M	+ M	– M	+ M	– M	+ M	– M	+ M
C		100.0^{h}	102.5^{gh}	196.0^{k}	328.0^{e}	40.9^{h}	44.05^{ef}	11.45^{i}	15.56^{fgh}	2.7^{j}	4.23^{fg}
K-H		105.0^{g}	121.0^{c}	288.0^{h}	428.0^{b}	42.0^{gh}	48.45^{c}	16.14^{efg}	18.75^{cd}	3.74^{hi}	6.13^{d}
CHS1		100.0^{h}	105.0^{g}	208.0^{j}	376.0^{d}	$41.6g^{h}$	44.65^{ef}	13.97^{h}	16.24^{efg}	2.79^{j}	4.58^{f}
CHS2		100.0^{h}	112.5^{ef}	224.0^{i}	402.0^{c}	$41.7g^{h}$	45.45^{de}	15.04^{gh}	17.26^{def}	3.61^{i}	5.22^{e}
CHS3		100.0^{h}	118.5^{cd}	232.0^{i}	410.0^{c}	$41.8g^{h}$	46.8^{d}	15.07^{gh}	17.92^{de}	3.74^{hi}	5.5^{e}
CHS1+K-H		110.0^{f}	127.5^{b}	292.0^{gh}	436.0^{b}	43.0^{fg}	49.85^{c}	$16.14^{e}fg$	19.95^{c}	3.75^{hi}	6.78^{c}
CHS2+K-H		115.0^{de}	134.0^{a}	300.0^{fg}	470.0^{a}	43.7^{f}	51.9^{b}	16.45^{efg}	22.19^{b}	3.97^{ghi}	8.06^{b}
CHS3+K-H		133.3^{a}	135.0^{a}	304.0^{f}	471.0^{a}	43.8^{ef}	54.05^{a}	20.1^{c}	27.37^{a}	4.15^{gh}	10.01^{a}
LSD$_{0.05}$	F1	7.69 *		16.79 ***		4.32 *		8.33 ns		0.81 **	
	F2	2.69 ***		6.70 ***		1.11 ***		1.20 ***		0.26 ***	
	F1×F2	***		***		***		**		***	

F1: main factor (pre-sowing MT of barley grain), F2: sub-factor (spray fertilization by the CHS and/or K-H), LSD: least significant difference at *P ≤ 0.05*, SL: Significance of Level, ns: non-significant

Effect of the studied treatments on the macro- and micro-nutrients concentrations (g kg^{-1}) and uptake (kg ha^{-1}) in the barley grains

The absorption of the N, P, and K macronutrients by the plant depends on their available concentrations in the soil solution. It is also controlled by chemical and biological equilibrium related to the physiological content inside the germinated grains and plant roots. Increasing the rate of application from CHS1 to CHS3 without MT of grains in Table 4 has significantly increased the N (g kg^{-1}) in grains by

40%, while decreasing the P and K in grains non-significantly by 20% and 4.3%, respectively . In combination with the humate K-H, the N, P, and K concentrations in grains (g kg^{-1}) were decreased by 14.3%, 3%, and 6.4%, respectively, for the CHS3+K-H treatment compared to the CHS1+K-H one. Also, the pre-sowing MT of the barley grains combined with either spraying the CHS alone or with humate in CHS+K-H treatments has decreased the N, P, and K in grains by 7.1%, 15.7%, and 5.4%, respectively with the single CHS spray and by 7.7% and 1.1% for the N and K respectively, by the combined CHS+K-H spray at the rate 3 relative to the rate 1. The MT increased the P (g kg^{-1}) by 13.8% by CHS3+K-H.

Table 4. Effect of the studied treatments on the total concentration (g kg^{-1}) of the N-P-K macro-nutrients in the barley grains and straw

Treat.		Total concentration (g kg^{-1})											
		Grains						Straw					
		N		P		K		N		P		K	
		–M	+M	–M	+M	–M	+M	–M	+M	–M	+M	–M	+M
C		9.31^{a}	8.65^{ab}	2.6^{a}	3.0^{a}	6.16^{a}	6.09^{a}	3.99^{d}	5.32^{bc}	1.1^{cd}	0.6^{e}	5.39^{d}	6.58^{d}
K-H		9.31^{a}	8.65^{ab}	3.3^{a}	2.95^{a}	6.72^{a}	6.09^{a}	6.65^{a}	5.99^{ab}	1.2^{cd}	0.75^{e}	14.0^{a}	12.04^{abc}
CHS1		6.65^{c}	9.31^{a}	4.0^{a}	3.5^{a}	6.58^{a}	6.51^{a}	6.65^{a}	6.65^{a}	1.2^{cd}	1.4^{c}	10.36^{c}	11.34^{bc}
CHS2		7.98^{b}	8.65^{ab}	3.0^{a}	3.45^{a}	6.44^{a}	6.3^{a}	3.99^{d}	4.66^{cd}	2.4^{a}	2.5^{a}	10.78^{bc}	12.11^{abc}
CHS3		9.31^{a}	8.65^{ab}	3.2^{a}	2.95^{a}	6.3^{a}	6.16^{a}	2.66^{e}	5.99^{ab}	1.3^{c}	1.4^{c}	11.48^{bc}	11.9^{abc}
CHS1+K-H		9.31^{a}	8.65^{ab}	3.3^{a}	2.9^{a}	6.58^{a}	6.44^{a}	2.66^{e}	6.65^{a}	2.2^{ab}	1.15^{cd}	11.2^{bc}	12.18^{abc}
CHS2+K-H		9.31^{a}	6.65^{c}	3.3^{a}	3.4^{a}	6.16^{a}	6.44^{a}	3.99^{d}	5.32^{bc}	2.0^{b}	0.9^{de}	13.3^{ab}	10.5^{c}
CHS3+K-H		7.98^{b}	7.98^{b}	3.2^{a}	3.3^{a}	6.16^{a}	6.37^{a}	5.32^{bc}	5.32^{bc}	1.2^{cd}	0.75^{e}	11.34^{bc}	11.34^{bc}
LSD$_{0.05}$	F1	0.31 ns		0.62 ns		0.93 ns		0.62 *		0.40 ns		2.48 ns	
	F2	0.58 ***		1.16 ns		0.43 ns		0.52 ***		0.23 ***		1.55 ***	
	F1×F2	***		ns		ns		***		***		ns	

F1: main factor (pre-sowing MT of barley grain), F2: sub-factor (spray fertilization by the CHS and/or K-H), LSD: least significant difference at $P \leq 0.05$, SL: Significance of Level, ns: non-significant

However, the effect of the pre-sowing MT of barley grains on the N-P-K concentration variation in grains was non-significant. The CHS/K-H spraying effect on the grains P and K was also non-significant. The interactive effect of both mentioned factors was significant for the N in grains but non-significant for the P and K in grains. This behaviour may be related to the nature and type of the chemical, biological, and physiological components of the barley plant that are perhaps induced magnetically by the MT before cultivation, which affected the N-P-K absorption, reception, and translocation through the plant organs. This effect is in addition to the fertilization role of the CHS and/or K-H that provide biocompatible N, P, and K forms for plant nutrition.

In the case of barley straw, it was found that the combination of the pre-sowing MT of grains and repeated spray of the CHS3 significantly increased the straw concentrations (g kg^{-1}) of the N, P, and K by 125.2%, 7.7%, and 3.7%, respectively relative to the CHS3 without MT. The CHS1+K-H treatment with the MT exhibited almost the maximum increase in the N and K in the straw by 150% and 8.8%, respectively, but decreased the P in straw by 47.7% relative to the CHS1+K-H without MT. Compared to the corresponding C with MT, the CHS1+K-H treatment with MT has increased the N, P, and K in the straw by 25%, 91.7%, and 85.1%, respectively.

Overall, the single effect of the MT factor on the N-P-K concentrations (g kg^{-1}) in grains and on the P-K in straw was non-significant. The single effect of the CHS and humate spray fertilization was highly significant on the N (g kg^{-1}) in the barley grains and on the N-P-K (g kg^{-1}) in the barley straw. The combination between both factors F1 and F2 was highly significant for the grains' N and straw N-P-K at $P \leq 0.05$.

Regarding the micro-nutrients, it was observed from Table 5 that increasing the application rate from 1 to 3 has resulted in a significant decrease in the grain concentrations of the Fe, Mn, Zn, and Si for both the single CHS and combined CHS+K-H treatments, with and without MT, except for the Fe for the CHS1 to CHS3 with MT at a significant level $P \leq 0.05$. The combination of the pre-sowing MT of the barley grains with spraying the CHS1 has increased the grains Fe by 9.7%, Mn by 16%, and Si by 42.3% but decreased the Zn (mg kg^{-1}) by 21.5% significantly relative to the corresponding C.

Table 5. Total concentration of the micro-nutrients (mg kg^{-1}) in the barley grains

Treat.		Total Concentration in Grains (mg kg^{-1})								∑Fe+ Mn+ Zn+ Si	
		Fe		Mn		Zn		Si			
		–M	+M	–M	+M	–M	+M	–M	+M	–M	+M
C		306.4^{d}	164.2^{l}	30.4^{g}	32.4^{e}	19.2^{ef}	29.8^{a}	139.0^{g}	169.6^{c}	495.0	396.0
K-H		392.4^{b}	166.4^{l}	36.4^{d}	27.4^{h}	27.2^{b}	20.2^{e}	140.4^{g}	186.4^{b}	596.4	400.4
CHS1		296.4^{e}	180.2^{k}	37.0^{cd}	37.6^{c}	18.6^{fg}	23.4^{d}	166.2^{d}	241.4^{a}	518.2	482.6
CHS2		265.8^{i}	186.2^{k}	39.0^{b}	25.8^{i}	19.0^{efg}	20.0^{e}	162.2^{e}	144.0^{f}	486.0	376.0
CHS3		283.4^{fg}	243.8^{j}	24.6^{j}	21.4^{k}	14.6^{i}	18.6^{fg}	128.2^{i}	166.0^{d}	450.8	449.8
CHS1+K-H		514.8^{a}	287.4^{f}	43.8^{a}	25.6^{ij}	17.8^{gh}	23.2^{d}	168.2^{cd}	127.2^{ij}	744.6	463.4
CHS2+K-H		277.4^{gh}	274.8^{h}	31.8^{ef}	31.2^{fg}	13.8^{i}	24.8^{c}	131.8^{h}	129.0^{hi}	454.8	459.8
CHS3+K-H		319.0^{c}	161.6^{l}	38.0^{bc}	26.6^{hi}	16.6^{h}	14.2^{i}	142.6^{g}	124.2^{j}	516.2	326.6
LSD$_{0.05}$	F1	6.21 ***		0.71 ***		1.86 *		2.41 **		- -	
	F2	5.24 ***		0.72 ***		0.87 ***		2.22 ***		- -	
	F1×F2	***		***		***		***		-	

F1: main factor (pre-sowing MT of barley grain), F2: sub-factor (spray fertilization by the CHS and/or K-H), LSD: least significant difference at $P \leq 0.05$, SL: Significance of Level

The combination between the humate spraying the CHS along with the MT in the CHS1+K-H treatment has increased the Fe in grains significantly by 75% but decreased the Mn, Zn, and Si by 21%, 22.1%, and 25%, respectively. Therefore, the same treatment without MT has increased the Fe in grains by 68%, the Mn by 44.1, and the Si by 21% while decreasing the Zn significantly by 7.3%. This behaviour is often also related to negatively charged carboxylic ─COO̅, hydroxyl ─OH̅, and phenolic ─phen─OH̅ in addition to the amino NH_4^- present in both the CHS and humate ligands that chelate the transition elements such as the Fe, Mn, and Zn nutrients. They form bio-chemical complexes via coordination covalent bonds with multi-dentate CHS and humate, while the Si is not complexed but covalently bonded to form silane Si─O̅ and silanol Si─OH groups with different biological compounds. The significant effect of the studied treatments on the micro-nutrient availability in soil solutions and absorptivity by plants is usually controlled by chemical and biological equilibrium along with the selectivity of different receptors to catch a specific nutritional element and bind it in the root zone and inside the plant matrix. This complex pattern may be plant-specific depending on the type of crop.

Regarding the barley plant in the present study, it is obvious that the application rate 1 of the CHS with and without the humate (CHS1 and CHS1+K-H) has resulted in the most significant increase in the Fe, Mn, and Si in the grains relative to the control without the MT of grains before sowing. The pre-sowing MT of the barley grains has significantly decreased the amount absorbed by grains from the Fe, Mn, and Si while increasing the Zn content (mg kg^{-1}) in grains compared to the non-magnetized (−M) values of concentration. The magnetism (magnetic susceptibility) of each element may play a strong role in the response of its elemental and compound (or complexed) chemical form to the magnetic induction exerted by the pre-sowing MT of grains. This role can decide whether the amount absorbed increased /or decreased under the effect of the MT.

The grains uptake (kg ha^{-1}) of the N, P, K (Fig. 3a) and Fe, Mn, Zn, Si (Fig. 3b) indicates greater uptake of the mentioned nutrients by the barley grains for the studied treatments with MT (+M) compared to the C and the treatments without MT (−M). It is observed that the combined treatments CHS+K-H+MT are showing higher uptake of the N, P, K, Fe, Mn, Zn, and Si by the barley grains than treatments without MT (−M). This result may be a consequent of the increased grains' yield (Mg ha^{-1}) that would uptake a more significant amount of the nutrients from the applied fertilizers. It may also result from the enhanced absorption of the magnetically activated seeds, which is reflected in an increased nutrient uptake. Additionally, the organic part of the CHS and K-humate repeatedly sprayed on both the growing plant and soil surface are predicted to be adsorbed and retained on the soil particles' surfaces so that their charged functional groups help in keeping the applied fertilizers from loss by leaching. This role increases the nutrients' availability in the soil matrix and enhances the plant nutrition status that increases the yield and yield parameters owing to the enhanced nutrients' uptake.

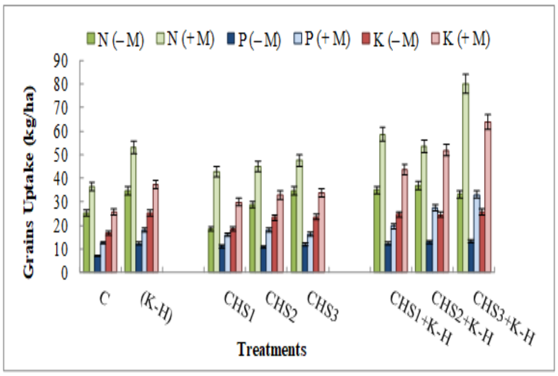

Fig. 3a. The grains uptake (kg ha^{-1}) of the N, P, and K as affected by the different treatments

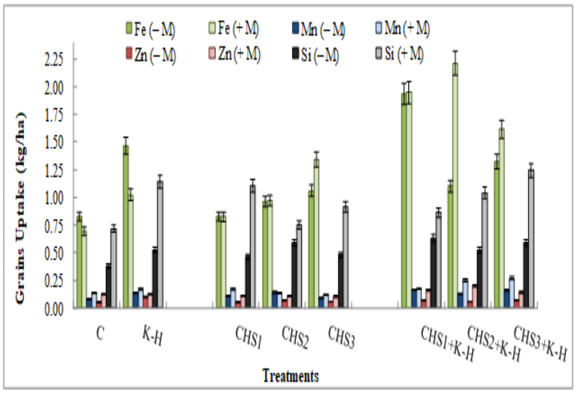

Fig. 3b. The grains uptake (kg ha^{-1}) of the Fe, Mn, Zn, and Si as affected by the different treatments

Effect of the pre-sowing MT on the ratio of the concentration of Si to Fe, Mn, and Zn in the barley grains

The molar ratio (i.e., stoichiometry) of the plants' macro- and micro-nutrients perhaps plays a vital role in their uptake by plants under the specified soil conditions. Although their availability in the soil solution may affect or disturb such stoichiometry equilibrium, it may still controlled by the chemical/biological and/or physiological selectivity for the different nutrients depending on the type of the plant species. Table 6 presents a simple approximation to predict the ratio between Si and Fe, Mn, and Zn concentrations in the barley grains affected by the studied factors. In general, the pre-sowing MT of the barley grains has almost increased the Si/Fe and Si/Mn ratios significantly for the CHS and CHS+K-H application rates compared to the corresponding non-magnetic treatments (−M).

Table 6. Ratio of the concentration of Si to Fe, Mn, and Zn in the barley grains

Treat.	Si/Fe		Si/Mn		Si/Zn	
	−M	+M	−M	+M	−M	+M
C	0.45^{fgh}	1.03^{b}	4.57^{g}	5.23^{de}	7.24^{e}	5.69^{f}
K-H	0.36^{gh}	1.12^{b}	3.86^{ij}	6.80^{b}	5.16^{f}	9.23^{bc}
CHS1	0.56^{def}	1.34^{a}	4.49^{gh}	6.42^{c}	8.94^{bcd}	10.32^{a}
CHS2	0.61^{de}	0.77^{c}	4.15^{hi}	5.58^{d}	8.54^{cd}	7.20^{e}
CHS3	0.45^{fgh}	0.68^{cd}	5.21^{de}	7.76^{a}	8.78^{bcd}	8.92^{bcd}
CHS1+K-H	0.33^{h}	0.44^{fgh}	3.84^{ij}	4.97^{ef}	9.45^{bc}	5.48^{f}
CHS2+K-H	0.49^{efg}	0.47^{efgh}	4.14^{hij}	4.13^{hij}	9.55^{ab}	5.20^{f}
CHS3+K-H	0.45^{fgh}	0.77^{c}	3.75^{j}	4.67^{fg}	8.59^{cd}	8.75^{bcd}

Vertically, across the application rates, the CHS1 and CHS2 treatments without MT have shown the maximum Si/Fe with a significant increase by 24.4% and 35.6%, respectively, followed by the CHS2+K-H treatment by 8.9% relative to the C. The CHS1 rate with the MT has increased the Si/Fe significantly by 30.1%, while the CHS1+K-H rate has decreased this ratio by 57.3% relative to the C at $P \leq 0.05$. Regarding the critical limits of the micro-nutrients in the barley plant, some values of their ratios may fall in the poisoning zone or beyond the critical limits of nutrients.

The ratio of the micro-nutrient concentration with MT (+ M) to the concentration without MT (– M) in the barley grains

In this study, the ratio between the absorbed concentration (mg kg^{-1}) of the micro-nutrients by seeds with MT (+M) and that without MT (−M) was calculated to try to predict their absorption behaviour under the effect of treatments under study as well as to predict their optimum ratio (+M/−M) giving an optimized grains' yield. Magnetization of the barley seeds before sowing has increased the concentration (mg kg^{-1}) absorbed of Si, Zn, and Mn but decreased the Fe according to the C values in Fig. 4.

Spraying the humate with MT (+M) has increased the Si concentration only but decreased the Zn, Mn and Fe absorbed by the grains. Depending on the maximum grains yield (Mg ha^{-1}) values obtained by the combined CHS+K-H+MT treatments, it can be observed that the CHS2+K-H+MT showed almost the same amount absorbed from the Si, Mn, and Fe while increasing absorbed Zn. The values mentioned in Fig. 4 may be used as a guide to avoid the over-dose absorption of the Si, Zn, Mn, and Fe possible to result from the studied treatments in the case of the barley plant. The enhanced uptake of nutrients due to the studied treatments is often controlled by many factors related to the type of plant species and its biological and physiological need and selectivity to particular nutrients. The over-dose uptake may poison the plant or cause health risks due to the accumulation of the N-P-K elements or heavy metals like Fe, Mn, and Zn.

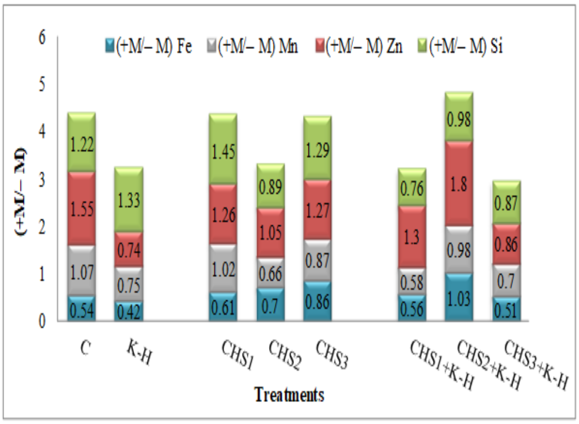

Fig. 4. Ratio of the micro-nutrient concentration with MT (+ M) to the concentration without MT (– M) in the barley grains

The trend of the +M/−M ratio may be caused by that the amount of the available micro-nutrients for plant uptake is more divided into smaller doses to satisfy the more significant amount of grains to give a greater grains' yield (Mg ha^{-1}) using the same rate of the applied fertilization. The increased Si absorption perhaps mitigates the absorption of other nutrients by directing their receptors towards the leaves for the chlorophyll synthesis and/or limiting them in the plant roots to control their accumulation in the grains, which leads to toxicity levels.

The ratio between the sum of total concentrations of micronutrients (∑Fe+Mn+Zn+Si) with and without MT

In the same context, the ratio between the sum of the total concentrations of micro-nutrients with MT (+M) and without MT (−M) indicated in Fig. 5 equal each other, not affected by the MT for the treatments CHS3 and CHS2+K-H and almost CHS1. Although the variation in the individual concentration of the Fe, Mn, Zn, and Si in Table 5 follows a trend that is significantly dependent on both MT and sprayed fertilizers, their summation was controlled by such an equilibrium that maintains a total nutrient content at a particular level. It can be said that the absorbed concentrations (mg kg^{-1}) of the micro-nutrients by the barley grains are re-equilibrated under the effect of the MT and sprayed fertilizers but limited by the sum of the total mineral content. Perhaps the effect of the MT is more pronounced in the case of the K-humate application than in the CHS application. This difference in the MT effect may be due to the difference in their chemical structure. The CHS is an aliphatic cycle, while the humate moiety is rich in aromatic rings containing double bonds. Their tendency to complex the micro-nutrients are also different.

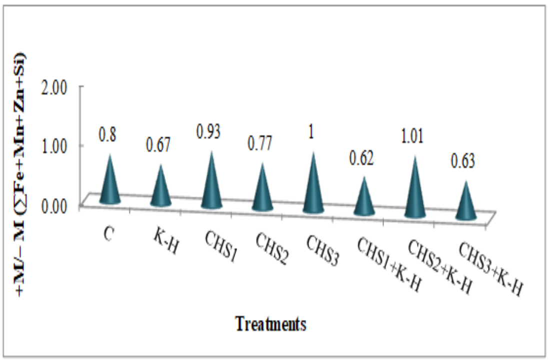

Fig. 5. Ratio between the sum of total concentrations of micronutrients (∑Fe+Mn+Zn+Si) with and without MT

Correlation between the biological yield and the grains yield (Mg ha^{-1}) with the absorbed nutrients

The correlation coefficient (r^2) between the barley biological yield (Mg ha^{-1}) and concentration of the N, P, K, and Mn in grains and the N and P in the straw was non-significant, as indicated in Table 7.

Table 7. Correlation coefficient (r) between the yield of the grains and Biological yield (Mg ha^{-1}) with the absorbed nutrients

	Grains			N-Straw	P-Straw	K-Straw	Grains			
	N	P	K				Fe	Mn	Zn	Si
Biological yield (Mg ha^{-1})	-0.006 ns	0.012 ns	0.171 ns	-0.219 ns	0.128ns	0.291*	0.396 **	0.269 ns	-0.532 ***	-0.369 **
Grains yield (Mg ha^{-1})	0.092 ns	0.055 ns	0.069 ns	-	-	-	0.575 ***	0.421 **	-0.461 ***	-0.348*

Also, correlation between the grains yield and N, P, and K in grains was non-significant. There was a positive correlation between the K in straw and the biological yield and a positive correlation between the Mn in grains and the grains yield. There was a more significant positive (+ve) correlation between the biological and/or grains yield with the concentration of Fe, but with that of Zn and Si, it was negative (−ve). This trend may refer to the fact that higher Fe doses may positively enhance the barley biological and grains yield, but higher Zn or Si doses may have negative impacts on the barley crop yield.

Agronomic efficiency of the N, P, and K mineral fertilization under the effect of the treatments under study

The agronomic efficiency (AE) index plotted in Fig. 6 was calculated based on the yield (Mg ha^{-1}) values relative to the applied fertilizer (kg ha^{-1}) the cultivated barley crop in the present study has received the RD of the N-P-K fertilization. The maximum AE of the mineral fertilization without MT (−M) was increased by 40%, 39.4%, and 39.7% relative to the corresponding C for the N-, P-, and K-fertilizers, respectively, as a result of the CHS3+K-H spraying only. This treatment with the pre-sowing MT has increased the AE by 204.4%, 204.2%, and 204.5% for the N-, P-, and K-nutrients, respectively, relative to the C. The overall result may be due to the activation of the barley seeds before sowing that optimized the absorption of the mineral and organic forms of the nutrients and improved the germination and growth parameters via better utilization of the applied mineral and organic fertilization.

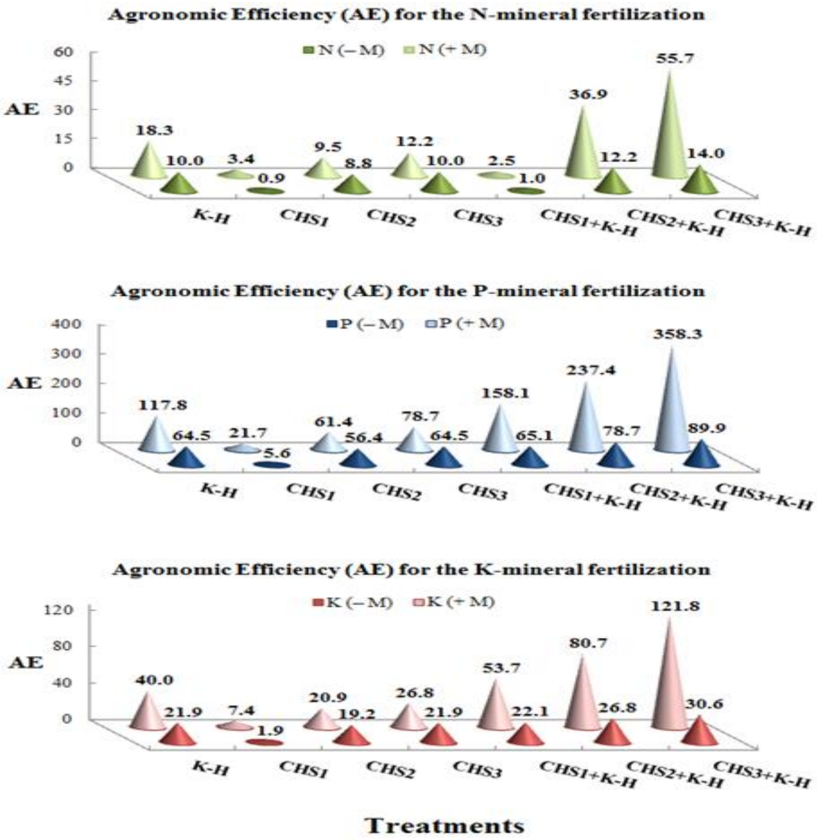

Fig. 6. Agronomic efficiency of the N, P, and K mineral fertilization under the effect of the treatments under study.

Discussion

The nutritional quality of cereal grains as a significant supply of mineral nutrients, particularly Fe and Zn for humans, depends on the nutrients' concentrations, speciation bioavailability, and distribution in the grain. The accumulation and distribution of nutrients in a cereal grain differs between elements relative to different morphologic features. For example, Cu and Zn elements are distributed in a pattern not limited to the aleuronic layer but extended into the endosperm, while Fe and Mn were less marked across different tissues. The correlation between the elements has revealed that physiological processes regulate the transport and storage of elements. Different transporters may be responsible for the relative differences in the nutrient distribution (Lombi *et al*., 2011).

Iron (Fe) is an essential element for all living because of its redox properties that show ferrous (Fe^{2+})/ferric (Fe^{3+}) reversible valence conversion, which is vital for photosynthesis and N-fixation cellular processes but excess Fe becomes toxic. It is contained in several proteins and some anti-oxidative enzymes. The Fe insufficiency is a nutritional alarm, reduces the crop productivity and nutrition quality, especially under calcareous soil conditions (Hasheminasab *et al*., 2023).

Some studies have indicated that Si plays a role to alleviate the Fe insufficiency stress in the barley plant that has a Fe-chelation-based strategy. Silicon successfully ameliorated Fe deficiency in barley as it decreased the accumulated reactive oxidative species (ROS) in the fresh leaves, decreased the chlorophyll and biomass damage, but enhanced the anti-oxidative enzyme activity. Silicon also decreases the accumulated micronutrients in fresh leaves of Fe-poor plants by their retention in the roots. It increases the gene expression in Strategy II Fe acquirement in roots at the Fe-deficiency stress early stage, while decreases their expression in a continued stress response. Iron phyto-siderophore complexes are trans-located to the roots by means of particular transporters that are non-proteino-genic amino acids. Organic acids are the main Fe ligands. Silicon mediates genes participate in the bio-synthesis of Fe-chelation organic acids and phenolics that increase the Fe mobilization from the rhizosphere and re-utilization of roots apoplastic Fe, plus xylem translocation of Fe in the direction of the shoots. Silicon enhances the Fe re-translocation from old to young leaves. Silicon significantly decreased the Mn, Zn, and Cu concentrations in the youngest fully expanded leaves. Silicon protective action in Fe-deficient barley avoids a diminished yield and plant health that reduce the crop nutritional significance (Nikolic *et al*., 2019).

CONCLUSION

The magnetic induction of the barley seeds for 30 min using 1.4 T magnetic field strength before sowing, as well as spray fertilization by CHS combined with the K-humate, can be efficient agricultural practices for enhancing the barley crop yield and quality under calcareous soil conditions of the present study. The agronomic efficiency (AE) of the mineral N-, P-, and K-fertilizer with the pre-sowing MT was significantly increased relative to the corresponding control as a result of the CHS3+K-H spraying more than the treatment without MT. A key reason for such results may be the magnetically affected uptake of the N, P, K, Fe, Mn, Zn, and Si nutrients by the grains. Increased uptake of the Si may control the accumulation and distribution of different nutrients in the barley plant so that its yield and quality are improved under calcareous soil conditions. It is recommended to activate the barley grains before sowing by the MT with repeated spray fertilization by CHS/K-H combination to enhance the nutrients absorption and growth parameters that effectively improves the calcareous soil productivity of barley.

List of abbreviations:

AE: Agronomic Efficiency	C: Control
CHS: Chitosan	K-H: K-humate
MT: magnetic treatment	(+M): Treatment with MT
(−M): Treatment without MT	RD: Recommended Dose

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

Availability of data and material: Not applicable.

Competing interests: The authors declare that they have no conflict of interest in the publication.

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تأثير التسميد بالرش بالشيتوزان والهيومات على إمتصاص السيليكون وإنتاجية حبوب الشعير المعاملة مغناطيسيا تحت ظروف التربة الجيرية

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الملخص

الهدف من هذه الدراسة هو التعرف على تأثير المعاملة المغناطيسية لبذور الشعير قبل الزراعة عندما يتم التسميد بالرش بالشيتوزان مع و بدون هيومات البوتاسيوم K-H على إنتاجية وجودة المحصول فى الأرض الجيرية . أُجريت تجربتان حقليتان خلال موسمى شتاء عامى ٢٠٢٣/٢٠٢٢ - ٢٠٢٤/٢٠٢٣ بمحطة البحوث الزراعية بالنوبارية فى تصميم قطع منشقة مرة واحدة بثلاث مكررات . كان العامل الرئيسى هو المعاملة المغناطيسية لحبوب الشعير والعامل تحت الرئيسى هو معدلات إضافة الشيتوزان الثلاث : CHS1و CHS2 وCHS3 بإستخدام ١٠ و٢٠ و٤٠ مل , على التوالى , من المحلول الأصلى لكل ١ لتر ماء مع و بدون هيومات البوتاسيوم K-H (٩,٦ كجم/هكتار) . شملت المعاملات معاملة كنترول بدون إضافة CHSأو K-H. بيَنت النتائج أن المعاملة CHS3+K-H أدت إلى زيادة معنوية فى النيتروجين المُيسر فى التربة بنسبة ١٠٠,٨ ٪ نسبةَ إلى الكنترول المقابل وبنسبة ٥٠,٢ ٪ نسبة إلى نفس المعاملة CHS3+K-H بدون معاملة مغناطيسية . كذلك أدت المعاملة CHS3+K-H مع المعاملة المغناطيسية للبذور قبل الزراعة إلى أعلى زيادة معنوية لكل من الإنتاجية الحيوية وإنتاجية الحبوب (ميجاجرام/هكتار) نسبة إلى الكنترول بنسبة ٧٥,٥ ٪ و ٥٣,٧٪ على التوالى. كذلك زاد التركيز الممتص (ملجم/كجم) من السيليكون Si والزنك Zn والمنجنيز Mn لكن تركيز الحديد Fe إنخفض نسبة إلى قيم الكنترول. يُوصى بتنشيط بذور الشعير بالمعالجة المغناطيسية قبل الزراعة مع التسميد المتكرر بالشيتوزان وهيومات البوتاسيوم لتحسين إمتصاص المُغذيات وعوامل النمو مما يحسن إنتاجية الأرض الجيرية للشعير بكفاءة .