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THE INFLUENCE OF BIOCOMPATIBLE MAGNETIC FLUIDS ON THE CONTENT OF MINERAL ELEMENTS IN LETTUCE

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Abstract: *Our research assessed the accumulation of minerals (K, Ca, Mg, Fe, Zn and Mn) in lettuce under the influence of treatments with biocompatible magnetic fluids. We used magnetic fluid based on wate $MF/(H_2O)$, with saturation magnetization $Ms = 32\ Gs$. The magnetic fluid was administered on leaves in four watery dilutions: 0.05%, 0.1%, 0.5% and 1% and compared with a control variant. The content of K, Mg, Ca and Fe was positively influenced by the magnetic fluid, in a proportionality relation with the magnetite concentration. At the same time, we noted that the content of Zn and Mn decreased with the increase in magnetic fluid concentration. Multivariate statistical analysis highlights the association of the distribution of minerals in lettuce with the concentrations of magnetic fluid used. Nevertheless, their distribution is also the result of interspecific relations, positive and negative, among elements. The analysis shows very significantly positive correlations between K – Mg (r = 0.970), K – Fe (r = 0.991), Fe – Mg (r = 0,973) and very significantly negative between K – Zn (r = -0.915), K – Mn (r = -0.984), Mg – Mn (r = -0,976), Fe – Mn (r = - 0.992). Evaluation of results through cluster analysis reveals the distinct position of the variants with magnetic fluids as compared to the control variant, in relation to the mineral elements determined. The cophenetic coefficient with the determined value of 0.9538 indicates that the dendrogram reflects the similarity structure of the data obtained, with high degree of significanc.*

Key words: *magnetic fluids, magnetite, lettuce, mineral elements, correlations, cophenetic index*

INTRODUCTION

As ultra-stable complex media, magnetic fluids contain magnetic nanoparticles of sizes ranging from 10(20) to 200 nm, distributed in colloidal suspension in a base fluid. The mixture behaves as a homogenous medium, displaying sensitivity to an exterior magnetic field, MALCHENKO et al. 1992, NAKATANI et al. 1992 (a, b).

The relation of ferrofluids with vegetal organisms and microorganisms, which has been revealed in recent years by a number of studies, opens various directions of interest in nanoscience and nanotechnologies with applications on plants.

GONZALEZ et al. 2008, CIFUENTES et al. 2010, CORREDOR et al. 2010 investigated the way magnetic nanoparticles penetrate the vegetal organism, their translocation and circulation in different vegetal tissues. SALA, 1999, communicated results on the influence of magnetic fluids on seed germination.

An additional relation studied was the influence of magnetic fluids on vegetal pigments which play a part in assimilation, especially of the chlorophyll content (a, b) and carotenoids in maize leaves, since it is well-known that iron is involved in the synthesis of chlorophyll, PINTILIE et al. 2006, MIHAELA RĂCUCIU, DORINA-EMILIA CREANGĂ, 2007.

CORNEANU et al., 1998, revealed the stimulating effect of magnetic fluids on starch accumulation in the vegetal cell (TEM investigations), while GODEANU et al., 1998, highlighted some stimulating effects on plant growth. Performing such a study on Mammilaria duwei cultivated in growth medium treated with magnetic fluids (in water and petroleum based magnetic fluids), the authors noticed that the metabolic activity in living tissues was increased.

Thus, use of the magnetic fluid resulted in the vitalization of senescent tissues, a decrease in the process of necrosis and acceleration of sprouting, MIHAELA RĂCUCIU and DORINA CREANDĂ, MIHAELA RĂCUCIU et al. 2007.

Presently, researchers focus on controlling and conducting some chemical substances for increasing the control over substances in the process of plant protection by use of chemicals that can be controlled magnetically, REMYA NAIR et al. 2010.

Having guidelines in the studies and results that revealed the penetration and circulation of magnetic nanoparticles in vegetal tissues and the involvement of magnetic fluids in the synthesis of chlorophyll and chlorophyll pigments, we tested the influence of linear magnetic actuators (LMA) on the content of some mineral elements in lettuce.

Lettuce, *Lactuca sativa*, is highly cultivated, due to its importance as food source, through its vitamin and mineral content.

Lettuce contains significant quantities of minerals such as iron, calcium, magnesium and potassium, which are very important in the metabolism of the human body.

U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling" (15) mentions the following mineral content for quality lettuce: K = 232.18 mg, Fe = 0.91 mg, Mn = 0.15 mg, Ca = 31.02 mg, Mg = 13.16 mg, P = 28.20 mg, Cu = 0.05 mg, Mo = 5.64 mcg, (for 94 g lettuce).

At the same time, lettuce displays receptivity for treatments because it has rich foliage and thin leaf epidermis, which results in a high rate of absorption of substances applied on leaves in the form of solutions.

Our research assessed the content of some mineral elements: K, Ca, Mg, Fe, Zn, Mn accumulated in lettuce under the influence of various concentrations of biocompatible magnetic fluids applied on leaves.

MATERIAL AND METHODS

The research focused on the bioactive influence of biocompatible magnetic fluids on accumulation of minerals in lettuce.

We used a water-based magnetic fluid, $MF/(H_2O)$, with saturation magnetization $Ms = 32\ Gs$. The magnetic fluid was conditioned in watery dilutions of 0.5%, 0.1%, 0.5% and 1% and compared with a control variant.

The biologic material was represented by species *Lactuca sativa*, var. capitata.

We applied two treatments, the first in the three-pairs-of-leaves stage and the second ten days later.

The magnetic fluid solutions were applied by spraying with a pump spray for ensuring uniformity.

Lettuce was grown on uniform substratum with the following average characteristics: pH_{H_2O} = 7.92, $H = 6.46$, $P_{mobil} = 365\ ppm$, $K_{mobil} = 1798\ ppm$, $N_{total} = 0.40\%$, $Fe_{total} = 30755\ ppm$, $Zn_{total} = 91.9\ ppm$, $Mn_{total} = 448\ ppm$.

In view of evaluating the influence of magnetic fluids on the regime and content of mineral elements in lettuce, we determined the content of the following elements: K, Ca, Mg, Fe, Zn and Mn. Harvest of lettuce samples was performed 25 days after the second treatment.

The determinations were made with the flame photometric method (atomic absorption spectrophotometry).

Suitable statistical methods were employed in processing the results: statistic analysis, correlations, variance-covariance and data distribution through cluster analysis.

RESULTS AND DISCUSSION

Regarding the objectives of our study, the influence of magnetic fluids was felt by the generation of variations in the content of mineral elements in lettuce. Table 1 presents the experimental data, together with the standard error (SE) for each parameter under study.

We generally notice a variation in the content of elements studied, proportionally with an increase in the concentration of magnetic fluid applied. For some elements (K, Ca, Mg, Fe), the variation is increasing, while for others (Zn, Mn) it is decreasing.

Table 1

Variation in the mineral content in lettuce (*Lactuca sativa*) under the influence of treatments with magnetic fluids

Parameter	K	Ca	Mg	Fe	Zn	Mn
Variant	(ppm)					
Mt	2573.310	410.000	0.036	11.400	4.680	3.440
LMA 0.5%	3486.420	400.000	0.051	16.900	4.360	2.300
LMA 0.1%	3569.430	430.000	0.054	17.400	3.860	2.370
LMA 0.5%	3735.450	490.000	0.057	17.500	3.850	2.210
LMA 1%	3948.480	480.000	0.055	18.700	3.640	2.090

$SE_K = 235.93$; $SE_{Ca} = 18.27$; $SE_{Mg} = 0.003$; $SE_{Fe} = 1.27$; $SE_{Zn} = 0.19$; $SE_{Mn} = 0.24$

The potassium content in lettuce was identified in quantities of 2573.310±235.93 ppm K in the control variant, and it oscillated between 3486.42 and 3948.48±235.93 ppm K in the variants treated with magnetic fluid. The difference between the concentrations of treated plants as compared with the control variant range from 913.11 to 1375.17 ppm K and the differences among the variants treated with magnetic fluid range from 83.01 to 462.06 ppm K, increasing with the magnetite concentration gradient.

Calcium was identified in a quantity of 410.00 ppm in the control variant and oscillated between 400.00 – 490.00± 18.27 ppm in the variants treated with magnetic fluids. The increase is proportional to the concentration of magnetite administered in the treatments. We registered higher calcium content in the variants treated with magnetic fluid in concentrations of 0.5 % and 1%.

Magnesium, an important element in photosynthesis, as the central atom in the chlorophyll molecule, was identified in quantities of 0.036 ± 0.003 ppm Mg in the control variant and 0.051 – 0.057 ± 0.003 ppm in the variants treated with magnetic fluids.

The iron content was of 11.400 ± 1.27 ppm in the control variant and it oscillated between 16.900 and 18.700 ± 1.27 ppm in the variants treated with magnetic fluids.

The zinc concentrations we identified were 4.680 ± 0.19 ppm in the control variant and it oscillated between 4.360 and 3.640 ± 0.19 ppm in the variants treated with magnetic fluids. The zinc content is in inverse relation with the concentration of magnetic fluid, and with the quantity of magnetite in the applied solution, respectively.

The manganese concentration was 3.440 ± 0.24 ppm in the control variant and it oscillated between 2.300 – 2.090 ± 0.24 ppm in the treated variants. The manganese content, much like the zinc content, decreases when the concentration of magnetic fluid is increased.

Content of K, Ca, Mg and Fe is higher in the variants treated with magnetic fluids, having an increasing trend, with certain proportionality with the concentration of magnetic fluid and magnetite respectively. The content of Zn and Mn is lower in the treated variants as compared to the control, the two elements being in a negative/inverse relation with the concentration of magnetite applied.

At the same time, we found a series of correlations between the mineral elements under study. These are very significantly positive between Fe and Mg (r = 0.973), Fe and K (r = 0.991), K and Mg (r = 0.970) and very significantly negative between Fe and Mn (r = -0.992), K and Mn (r = -0.984), K and Zn (r = -0.915), Mg and Mn (r = -0.976), Table 2. Other pairs of elements present weaker negative or positive correlations (Ca – K, Mg – Ca, Fe – Ca).

The behavior of zinc and manganese must therefore be regarded also in terms of their relation with other elements, especially with K, Mg and Fe, with which they are in negative correlation, with very high significance level.

Table 2

Table of correlations among mineral elements in lettuce under the influence of magnetic fluids

	K	*Ca*	*Mg*	*Fe*	*Zn*	*Mn*
K	1					
Ca	0.669	1				
Mg	**0.970**	0.630	1			
Fe	**0.991**	0.571	**0.973**	1		
Zn	**-0.915**	-0.801	-0.878	-0.887	1	
Mn	**-0.984**	-0.556	-0.976	**-0.992**	0.838	1

We evaluated the relations between variables through multivariate statistic analysis, in order to better distinguish their tendency to associate and their interactions.

According to the variance and covariance analysis, the experimental values are distributed differently in relation to the mineral elements determined, and we could distinguish between two domains of distribution for these. One domain that comprises generally the variants treated with magnetic fluids, in which there is a field with a well-defined grouping of variants LMA 0.1% – LMA 0.5% – LMA 1% and with marginal placement of variant LMA 0.05%. The control variant, without magnetic fluids, is placed separately.

Of the mineral elements studied, iron has the orientation in the domain of distribution of variants with high concentrations of magnetic fluid, LMA 0.1 – LMA 0.5 – LMA 1%.

Other mineral elements, K, Ca and Mg have the orientation towards the distribution area of the variants treated with magnetic liquids with high concentrations, but in weak associations with these as compared to Fe. Of these, K has better association, expressed through stronger orientation gradient, Ca and Mg being close to the origin of the axes.

The other two minerals, Zn and Mn, have a spatial placement that reflects independence from magnetic fluids. Nevertheless, their position must be interpreted also through their antagonistic relations with other (K, Mg and Fe).

Assessing the results through cluster analysis also showed a distribution of variants in two clusters: the control variant as a distinct position and the group of variants treated with magnetic fluids, with two branches: the variant with the highest concentration (LM 1%) as a separate position, and the other three variants (LM 0.05%, LM 0.1% and LM 0.5%). This type of analysis also highlights the distinct position of variants with magnetic fluids as compared to the control variant, in relation to the mineral elements we determined.

The cophenetic coefficient, through its calculated value of 0.9538, indicates that the dendrogram reflects the similarity structure of the data obtained, with high level of significance, the graph being robust.

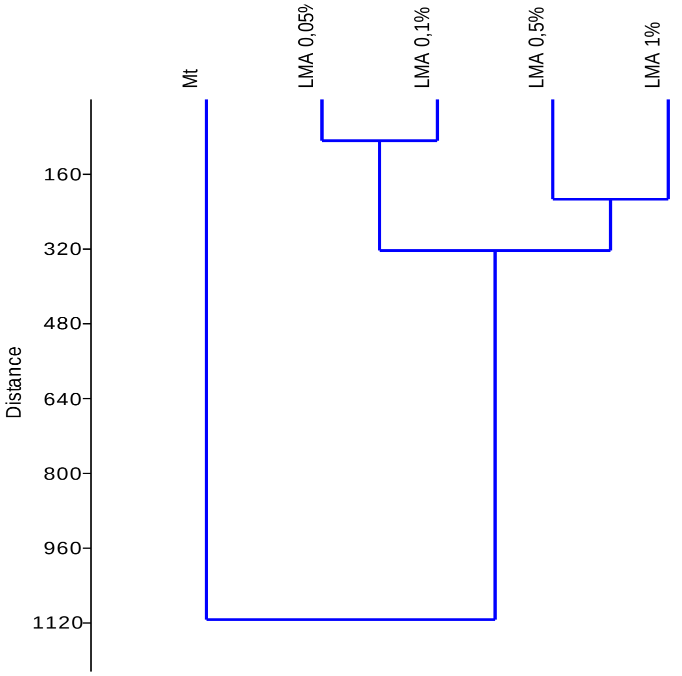

Figure 1. Grouping of experimental variants in single linkage clustering

CONCLUSIONS

Water-based magnetic nanofluids, with saturation magnetization M = 32 Gs, influenced the accumulation of mineral elements in lettuce (*Lactuca sativa*, var. capitata).

The distribution of the mineral elements in lettuce is the result of the influence of magnetic fluids as well as of their interspecific relations.

Of the mineral elements that made the object of the present study, Fe, K, Ca and Mg have the orientation in the distribution domain of the variants with high concentrations of magnetic fluid, LMA 0.1 – LMA 0.5 – LMA 1%. At the same time, there are very significantly positive correlations between them.

Interspecific relations play a part in the distribution of other minerals in lettuce, Mn and Zn being in negative relation with Fe, K, Ca and Mg.

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