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Artículo original

Water treated with a static magnetic field on photosynthetic pigments and carbohydrates of *Solanum lycopersicum* L

Agua tratada con campo magnético estático sobre pigmentos fotosintéticos y carbohidratos de *Solanum lycopersicum* L

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ABSTRACT

The effect of water treated with a static magnetic field (SMF) between 20 and 200 mTon the photosynthetic pigments and carbohydrates of *Solanum lycopersicum* L. var. HA-574. A completely randomized design was used in GREMAG irrigation technology. One group of plants was irrigated with water treated with SMF (20-80 mT), another group with SMF (100-200 mT), and the control with tap water. Photosynthetic pigments were determined in leaves and carbohydrate content in fruits. Statistical analysis was performed with the Tuckey test. Plants grown with water treated with SMF (100-200 mT) had the highest content of chlorophyll a, chlorophyll b, total chlorophylls and carbohydrates. High photosynthetic activity and better adaptation to cultivation conditions were achieved under the benefits of SMF treatment in irrigation water.

Keywords: tomato; photosynthetic pigments; carbohydrates; magnetically treated water.

RESUMEN

Se evaluó el efecto del agua tratada con campo magnético estático (CME) entre 20 y 200 mT sobre los pigmentos fotosintéticos y carbohidratos de plantas de *Solanum lycopersicum* L. var. HA-574. Se utilizó un diseño completamente aleatorizado en la tecnología de riego GREMAG. Un grupo de plantas se irrigó con agua tratada con CME (20- 80 mT), otro grupo con CME (100- 200 mT) y el control con agua corriente. En las hojas se determinaron los pigmentos fotosintéticos y en los frutos el contenido de carbohidratos. El análisis estadístico se realizó con la prueba de Tuckey. Las plantas cultivadas con agua tratada con CME (100- 200 mT) presentaron el mayor contenido de clorofila *a*, clorofila *b*, clorofilas totales y carbohidratos. Se logró una elevada actividad fotosintética y una mejor adaptación a las condiciones de cultivo bajo los beneficios del tratamiento con CME en el agua de riego.

Palabras clave: tomate; pigmentos fotosintéticos; carbohidratos; agua tratada magnéticamente.

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Introduction

Research on the effects of magnetic fields is an effort to help plants develop with better morphological, physiological and yield qualities. Various research studies have shown that the application of magnetic fields induces favourable changes in different plant species, facilitates the absorption of nutrients and favours growth and development.(1,2)

One of the plants in which electromagnetic fields have been applied is *Solanum lycopersicum* L. (tomato). This vegetable of great importance in the world is consumed fresh or in the form of processed products.(3) It is one of the most demanded crops and has agreatnutraceutical value, as it plays a therapeutic rolein the prevention of diseases. It is an important source of chemical compounds, specifically secondary metabolites with antioxidant action, such as polyphenols, hydroxycinnamic acids, carotenoids and vitamins, among others.(4)

In addition, due to its genetic and molecular advantages, the *Solanum lycopersicum* L. is considered a biological model for morphological, physiological and genetic studies.[5] Thanks to the experience derived from its use, it can be extrapolated to other horticultural species with some similarity. An aspect that has justified its use to evaluate the effects of electromagnetic fields (EMF).

In agriculture, the effects of the application of EMF on plants have beenevident. This physic agent by direct exposure and through magnetic treatment to the water used forirrigation. Positive effects in the application of EMF and the water treated with a static magnetic field (SMF)have been obtained in plants of *Solanum lycopersicum* L. An acceleration in the seed germination, vigour, growthof plants, due to the favorable morphological andphysiological changes. An increased in the yield and the stimulation the active compounds of this plant have been explained. An easy applicated in the agriculture and with a less impact on the environment can be obtained with the use of water undermagnetic treatment.[6-10]

Although these benefits are known, there is not enough experimental evidence and there are few references related to the influence of magnetically treated water on photosynthetic pigments and carbohydrates in *Solanum lycopersicum* L. between 20 and 200 mT. These pigments carry out photosynthesis, which is essential for proper plant growth and development. However, this process can be modified by the characteristics of the water used during the cultivation of the plant species. In this research, the effect of water treated with a static magnetic field (SMF) between 20 and 200 mT on the photosynthetic pigments of *Solanum lycopersicum* L. var. HA 574, was assessed.

Materials and methods

The research was conducted at the National Centreof Applied Electromagnetism (CNEA, Spanish acronym), jointly with the Marianaje Farm, attached to the Santiago Military Agricultural and Livestock Company.

Seeds of *Solanum lycopersicum* L. (tomato) variety HA-574, in good phytosanitary conditions and certified by the Santiago de Cuba’s Provincial Seed Laboratory attached to the Ministry of Agriculture (MINAG) of Cuba, were used.A Voucher species was deposited and stored at the Eastern Center for Ecosystems and Biodiversity (BIOECO, Spanish acronym), Santiago de Cuba, with registration: BSC 21509.

The seeds were sown in the seedling house and the seedlings were obtained after approximately 15 days. These were transplanted to semi-controlled conditions in protected cultivation houses where they continued to grow. The houses were made of plastic mesh, of the 612 m^2 tunnel type.

All the attentions required by the *Solanum lycopersicum* L. crop were maintained according to normative.[11] During the cultivation period, the environmental conditions of temperature (28,6 ºC), rainfall (72,31 mm) and relative humidity (70,1 %) were considered.

The total sample was composed of 240 plants; each experimental group had 40.

Magnetic treatment in irrigation water

GREMAG® technology was employed for the magnetic treatment of irrigation water. The said technology has been used in different plant species with satisfactory results.[1] The two devices for the magnetic treatment, composed of permanent magnets, were designed, built and characterized at the CNEA.[12] The equipment consisted of a non-uniform or heterogeneous static magnetic field (SMF), one between 20 and 80 mT and the other between 100 and 200 mT.

Irrigation was carried out once a day through a drip system, for 30 minutes. The magnetic treatment of the irrigation water was carried out at the time of irrigating the plants, throughout the crop cycle until the development of the fruits. The conditions established for irrigation considered water speed (1,4-1,6 ms^{-1}) and pump flow (2,54-2,91 m^3h^{-1}).The physical-chemical characteristics of the irrigation water were determined in the National Company for Technical Analysis and Services attached to the Santiago de Cuba's branch of the National Institute of Hydraulic Resources.

The three experimental groups used are described below:

- Control (NMT): *Solanum lycopersicum* L. plants irrigated with water with no magnetic treatment.

- SMF-t (20-80 mT): *Solanum lycopersicum* L. plants irrigated with water treated with a static magnetic field with a magnetic induction between 20 and 80 mT.

- SMF-t (100-200 mT): *Solanum lycopersicum* L. plants irrigated with water treated with a static magnetic field with a magnetic induction between 100 and 200 mT.

Determination of photosynthetic pigments

At day 80 of the biological cycle of the crop, a set of plant leaves were collected from the two experimental groups. For the determination of photosynthetic pigments, the modified Meyer-Berthenrath method [(13)] was used. One (1) gram of leaves was weighed on a digital analytical balance (Sartorious® BS 124S, China; accuracy: 0,1 mg). It was cut into small pieces and placed in a mortar with 5 mL of 70 % ethanol. The pieces were completely crushed and decanted into a 50 mL volumetric flask through filter paper (Whatman No. 4). The solution was completed with 70 % ethanol; 5 mL of the solution were taken, transferred to a 50 mL volumetric flask and completed with 70 % ethanol. Five (5) mL of the solution wereput intoa 50 mL volumetric flask and completed with ethanol. The absorbance was measured at a wavelength of 472, 645, 663 nm on a uv/vis spectrophotometer (Genesys 10s Vis, Germany). The concentration of the pigments was calculated according to the following equations:

$$- Cl\ a = 12{,}3\ E\ (663)\ -0{,}86\ E\ (645)\ v\ /\ 1000ps \qquad (1)$$

$$- Cl\ b = 19{,}3\ E\ (645)\ -3{,}6\ E\ (663)\ v\ /\ 1000ps \qquad (2)$$

$$- t.c = 10E\ (472)\ v\ /\ 2485ps \qquad (3)$$

where:

Cl a and Cl b = chlorophyll a and b content (mg . g^{-1}), t.c = total volume of carotenoids (mg . g^{-1}), E (l) = wavelength, d = cell width (1 cm), v = volume 70 % ethanol extracts (mL): 25 mL, w = tissue weight (g): 1 g of sample in fresh weight.

The total chlorophyll content was determined by the following equation described[(14)]

$$C\ (a + b) = (20{,}2\ A649) + (8{,}02\ A665) \qquad (4)$$

The results were expressed as milligrams per g of fresh weight (mg . gfw^{-1}).

Determination of carbohydrates

Carbohydrates were quantified through the phenol-sulphuric colorimetric method.[15] One (1) mL of tomato juice from each of the experimental groups was used. To prepare the standard glucose solution, 50 mg of glucose was dissolved in 100 mL of distilled water. Absorbance was measured at a wavelength of 492 nm, on a spectrophotometer (Genesys, 10 UV, United States). The results were expressed as D-glucose from a calibration curve in the range of 0,6 to 1,6 $mg.ml^{-1}$. The total carbohydrate content was expressed in mg of $glucose.ml^{-1}$. Distilled water was used as a blank in the three replications made for each experimental group.

The mathematical equation used for calculating the concentration of the sample was:

$$CEx = CEq\ .\ D\text{-}glucose * Fd \qquad (5)$$

where:

CEx = Extract concentration, CEq . D-glucose = Equivalent concentration of D-glucose.

Fd =Mathematical dilution factor.

The equivalent concentration of D-glucose for the samples is the one obtained by solving in the equation of the fitted model, which is obtained for the calibration curve.

Statistical processing

For the statistical analysis, the STATGRAPHICS Centurion XV software, version 15.2.14 (1982-2007), for Windows (Graphics Software Systems, STCC, 2000, USA) was used. In the results obtained for the experimental groups, the normality of distributions hypothesis was initially tested using the Kolmogorov-Smirnov test. The quantitative variables the results were expressed in for each experiment were averaged outby means of the arithmetic mean, as a measure of the central tendency; and the standard error of the mean, as a measure of dispersion. The Tukey'stest was performed with a statistical significance or confidence of 95 %.

Results and discussion

Table 1 shows the results of the physical-chemical analysis performed on the irrigation water during the cultivation of *Solanum lycopersicum* L. var-HA 574 fruits.

Table 1. Physical-chemical analysis of the irrigation water for the cultivation of *Solanum lycopersicum* L.

Characteristics	Average values		
	Tap water	**Water treated with a SMF (20-80 mT)**	**Water treated with a SMF (100-200 mT)**
Turbidity (NTU)	0,7	0,7	0,7
Acidity or basicity (pH) (u)	7,56	7,54	7,54
Electrical conductivity (μScm^{-1})	1005	1016	1016
Calcium (mgL^{-1})	112	112	112
Magnesium (mgL^{-1})	38,4	38,4	38,4
Sodium (mgL^{-1})	48,3	48,3	48,3
Potassium (mgL^{-1})	2,9	2,8	2,8
Hydrogen carbonate (mgL^{-1})	500,2	500,2	500,2
Chlorine (mgL^{-1})	74,4	74,4	74,4
Sulphate (mgL^{-1})	26	27	27
Nitrite (mgL^{-1})	4	4	4
Nitrate (mgL^{-1})	<0,01	<0,01	<0,01
Phosphate (mgL^{-1})	<0,1	0,15	0,15
Total Phosphorus (mgL^{-1})	<0,3	0,46	0,46
Iron (mgL^{-1})	<0,2	<0,2	<0,2
Manganese (mgL^{-1})	<0,05	<0,05	<0,05
Chromium (mgL^{-1})	<0,001	<0,001	<0,001
Total Hardness (mg Calcium carbonate L^{-1})	440	438	438
Silicon Oxide (mgL^{-1})	29	28	28
Total alkalinity (mgL^{-1})	410	410	410

Colour A U	25	25	25
Total Dissolved Solids (mgL^{-1})	806	806	806

The values obtained for turbidity, pH and the determined chemical elements, in addition to total alkalinity and color; they remained very similar in running water and in water treated with a static magnetic field. This result shows that under the experimental conditions used, the magnetic treatment in the irrigation water did not modify the concentrations of these physical-chemical indicators. So there were no influences on them with the SMF used. It was shown that this physical agent can be used in experienced magnetic inductions.

The determinations made on the tap water and the one that received the SMF treatment showed differences in electrical conductivity of approximately 5 units only.

It can be assumed that the increase in electrical conductivity in the SMF-treated water samples was influenced by an increase in ion mobility. Some authors reported changes in conductivity for aqueous solutions treated with a SMF in the range of 10 to 160 mT.(16) These authors stated that these variations depend on the movement of charged ions, which are related to size distribution changes in the polymeric species of aqueous solutions.

Moreover, was demonstrated changes in the microscopic structures of water under the action of a MF, and in turn, an increase in its electrical conductivity.(17) In others studies an increase of 3,66 % in the electrical conductivity of the water was evidenced after being treated with a SMF, with respect to tap water.(18)

Results in the determination of photosynthetic pigments

Light plays an important role in the growth and development of plants, as it is a source of energy for the photosynthesis process. When sunlight falls on plant leaves, it is absorbed by photosynthesizing pigments.(19) The effect of the water treated with a static magnetic field on the photosynthetic pigments in the leaves of the *Solanum lycopersicum* L. plants was determined (table 2).

Table 2. Concentration of photosynthetic pigments in *solanum lycopersicum* l.with different treatments in irrigation water

Experimental Groups	Chlorophyll *a* (mg . gpf^{-1})	Chlorophyll *b* (mg . gpf^{-1})	Carotenoids (mg . gpf^{-1})	Total Chlorophylls (mg . gpf^{-1})	Carbohydrates (mg of glucose . mL^{-1})
NMT (control)	2,88 ± 0,64	1,63 ± 0,31	0,02 ± 0,00	4,05 ± 0,86	1,54± 0,0^{b}
SMF-t (20-80 mT)	3,20 ± 0,98	1,82 ± 0,50	0,02 ± 0,00	4,52 ± 1,33	1,98± 3,0^{b}
SMF-t (100-200 mT)	3,25 ± 0,99	1,97 ± 0,52	0,02 ± 0,00	4,56 ± 1,43	2,36± 1,07^{a}

Legend: The data show the mean values ± the standard error of three experiments. *Different letters in the same column indicate significant statistical differences* (p> 0,05), (Tukey's test). Control (NMT): *Solanum lycopersicum* L. plants irrigated with water with no magnetic treatment. SMF-t (20-80 mT): *Solanum lycopersicum* L. plants irrigated with water treated with a static magnetic field, with a magnetic induction between 20 and 80 mT.SMF-t (100-200 mT): *Solanum lycopersicum* L. plants irrigated with water treated with a static magnetic field, with a magnetic induction between 100 and 200 mT.(mg . gfw^{-1}): milligrams per g of fresh weight. Total carbohydrates: expressed in mg of glucose . mL^{-1}

In the three experimental groups, the pigment concentration values were obtained from highest to lowest in the following order: chlorophyll *a*> chlorophyll *b*> carotenoids. This behaviour can be considered adequate, according to the evidence found by several authors in *Solanum lycopersicum* L. plants. In general, values very close to each other were obtained in the content of each of the pigments in the experimental groups. In the plants grown with magnetically-treated water (MTW), concentrations higher than those of the control group were obtained, but there were no statistically significant differences. When evaluating carotenoids, the values were similar for all experimental groups.

The content of chlorophyll *a* and chlorophyll *b* can be found in a 3:1 or 4:1 ratio, which coincides with the results obtained in this research. These may be related to the exposure of plants to irrigation with water treated with a SMF. Chlorophyll *a* is the main pigment responsible for photosynthesis, directly involved in the conversion of solar energy into chemical energy, which is finally stored in the form of sugars. Chlorophyll *b* and carotenoids are auxiliary or accessory pigments for photosynthesis. An increase in the content of chlorophyll *a* may imply an increase in photosynthetic efficiency, was indicated.[20] All of which could be evidenced in the plants of the groups irrigated with magnetically treated water.

Magnetic fields have been shown to increase the energy contained in chloroplasts due to their paramagnetic properties. This causes the chloroplast atoms to align themselves in the direction of the external magnetic field, which consequently accelerates metabolism and germination due to the accumulation of energy.[21] Apparently, the magnetic stimulation in the irrigation water facilitated light energy transfer reactions, for the elaboration of the primary metabolites of the plant, according to the results exposed. It could result in an accumulation of chemicals, which have been shown to be able to increase and be used in the metabolic processes of the cell and regulate vegetative development. It has been shown that metabolic variation can be reflected in the composition of chlorophylls and carotenoids.[(21)]

The behaviourreported in this research can be considered adequate, when compared with the evidences obtained by several authors in plants of *Solanum lycopersicum* L.A significant increase in the concentration of chlorophyll *a*, chlorophyll *b* and carotenoids in leaves of *Solanum lycopersicum*, *Triticumaestivum* (wheat) and *Pisumsativum* (pea) irrigated with water treated with a SMF by means of a Magnetron magnetizer, model U.T.1., made by Magnetic Technologies L.C.C., from Russia were obtained.[(7)]

Moreover, were obtained results comparable to those obtained in this research, when studying the *Pitenza* and *Floradade* varieties of this plant species.[(22)] These researchers determined values of 4,5; 2,6 and 1,2 mggextract^{-1} for chlorophyll *a*, chlorophyll *b* and carotenoids, respectively.

In other hand, *Capsicumannuum* L. plants were irrigated with MTW in the range of 3,5 to 136 mT, and there was a positive effect on the total chlorophyll content.[(23)]

Solanum lycopersicum L. seeds to an electromagnetic field (EMF) generated by a non-uniform sine wave of 120 mT for 10 min and 80 mT for 5 min.[(11)] These researchers found an increase in the content of chlorophyll *a*,chlorophyll *b*, carotenoids and total pigments in plants growing from seeds treated with an EMF, with respect to the content of plants from the control group. In addition, they explained that EMFs can increase photosynthesis during the vegetative growth of plants.

Results of the determination of carbohydrates

The carbohydrate concentration in the *Solanum lycopersicum* L. fruits that received the MTW was higher than that found in the control group plants (table 2). In the group in which water treated with a SMF between 100 and 200 mT was used, the highest concentration of carbohydrates was obtained, with statistically significant differences, with respect to the rest of the experimental groups. It was shown that irrigation with this physical agent had a positive effect on the presence of carbohydrates and is related to the increase of photosynthetic pigments in this experimental group.

Related to these results are those obtained in *Solanum lycopersicum* L. fruits of the Eagean variety irrigated with MTW.[1] These authors qualitatively determined, by phytochemical screening, a higher carbohydrate content in these fruits in relation to those irrigated with running water. On the other hand, a higher values of carbohydrates in leaves of plants of this plant species grown with MTW from a Magnetron magnetizer model UT1 in the variety Super Strain B, when compared with control plants.[7]

The results of a study revealed an increase in carbohydrates of *Capsicum annum* L. fruits grown with magnetically treated water between 3,5 and 136 mT.[23] In *Viciafaba* L. plants using water treated by a Magnetic Funnel magnetizer (Magnetic Technologies Dubai),was obtained an increase in carbohydrates in the leaves, stems and roots of these plants, compared to plants grown with running water.[24] Therefore, in the literature, the results for this parameter could be determined by the species, the variety and the cultivation conditions.

This evidence shows that the effects of magnetic fields on photosynthetic pigments and carbohydrates can be different. These effects will be influenced by various factors, which can affect plants in a variable way.

Conclusions

The water treated with a static magnetic field (SMF) between 100 and 200 mT slightly stimulated the concentration of chlorophyll a, chlorophyll b, total chlorophylls and carbohydrates in the plants of *Solanum lycopersicum* L. var. HA-574 under the experimental conditions used. This may indicate a high photosynthetic activityand, with it, a better adaptation to the cultivation conditions and an influence onthe growth, development and yield of *Solanum lycopersicum* L. var. HA-574, with the benefits of the application of a SMF treatment in irrigation water.

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Conflicts of interest

The authors express that there are no conflicts of interest in the submitted manuscript.

Author contributions

Albys Esther Ferrer Dubois, Dannielly Zamora Oduardo, Pedro Rodríguez Fernández: active participation in the discussion of the results: Review and approval of the final version of the work.

Yilan Fung Boix, Elizabeth Isaac Aleman: review and approval of the final version of the work.

All author shave read and agreed to the published version of the manuscript.