Magnetic treatment of culture medium enhance growth and minerals uptake of strawberry (*Fragaria × ananassa Duch*.) and tomato (*Solanum lycopersicum*) in Fe deficiency conditions.

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Abstract: The global climate change and competing water demands have put enormous pressure on water resources. Therefore, the optimal water management is essential to avoid risk to future water supplies and play a critical role in the sustainable development of agriculture. Magnetic treatment of water is a physical factors that improves water productivity and stimulates plant growth and development. This methods is getting more popular due to the harmless influence on the environment. The present study aims at gaining more insight on the effect of magnetic treatment of culture medium on growth and development of strawberry and tomato plants, and its effect on plants development and iron uptakes in a Fe deficiency condition. 5 weeks plants were cultivated for 3 weeks on BD liquid medium under four different treatments. Our results showed that the magnetic treatment lead to a significant increase in the number of leaves, the shoot length, the shoot fresh weight, the root length, the root fresh weight, and the Mg, Ca, Fe, K, P, and Na uptake. The use of magnetic treatment in Fe-deficiency condition represents a significant increase in all aforementioned growth parameters and in the ratio shoot-to-root. Also, plants irrigated with magnetic treated water have a higher photosynthetic pigments (ch a and ch b) than those observed in the control plants. These results suggest that magnetic treatment of culture medium improves plant growth and Fe uptakes which can be an interesting evolutionary solution to problems inherent in the calcareous soil.

keywords: Magnetic fields; Strawberry; Tomato; culture medium; Iron deficiency.

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Introduction

The impact of climate change, the increased prevalence of drought and the rising population are the major factors limiting agricultural production. Prolonged droughts periods have quickened soil degradation, soil organic matter loss and causing severe pressure on water resources. The attempts to tackle these phenomena by using different practice; such as heavy tillage, increased use of fertilizers, and intensive cropping under irrigation, besides the high costs, have caused more and more pollution of soil, water, and air.

Magnetic treatment of irrigation water has opened new research avenues in agriculture by improving water use efficiency. This technique is safe, simple, environmental friendly, cheap and harmless. This technology is widely-used for improving water quality [1]. It was used mainly in countries like Russia, Australia, Turkey, England, United states, Japan, China, Poland and Bulgaria [2]. Magnetic technology improve the productivity of water and thus saving water resources [3]. Magnetic treatment of irrigation water improves crop yields and quality, enhances seed germination and root growth, increase soil nutrient availability, and removes scale deposits in pipes and water containing systems [4–7]. Magnetic fields enhance water absorption, preservation, and ionization and lead to a better assimilation of nutrients and an increase in fertilizers efficiency during the vegetative growth period [8–10]. The mobility of nutrient elements in root was greatly improved when using magnetic treatment [11].

In calcareous soil, the bioavailability of iron to plants is often limited, even the total Fe content exceeds plant requirements [12]. Fe deficiency influences the metabolic process in leaves and roots [13]. The use of magnetic treatment can be very helpful in this context of calcareous soil, where mineral nutrients are less available. Studies concerning the effects of magnetic treatment on micronutrients assimilation; have received little attention up to now. Nevertheless, there are no recent studies reported, with valid scientific experiments; on the effect of magnetic treatment on plants growth, in Fe deficiency condition. The present study aims at gaining more insight on the effects of magnetically-treated culture medium on growth, development, minerals uptake, and Fe mobilization in strawberry and tomato plants.

Material and Methods

Plant material

- Tomato

Homogenous clean-healthy tomato seeds (S*olanum Lycopersicum* Var: Micro-Tom) was obtained from the laboratory physiology and biotechnology vegetal-faculty of science of Rabat- Morocco.

Seeds were disinfected in 50 % calcium hypochlorite for 20 min and rinsed four times with sterile distilled water. They were then sown in Petri dishes containing one half MS [14] medium with 1.5 % of sucrose and 0.8 % agar. The dishes were placed vertically in a growth chamber at 25 °C with a 16 h light photoperiod (0.1 mMol/m^2s).

- Strawberry

Bare root Strawberry plants (*Fragaria × ananassa Duch.* Vari: Camarosa) were obtained from "DIRAFROST" farm, region of Laaouamra at 20 Km south of Larache, Morocco (coordinates: 35°1'16''N and 6°9'47''W in MSD (Minutes and Seconds Degrees)).

Methods

- Acclimation

40 days old strawberries plants and 30 days old tomatoes seedlings were transplanted in pots (3 (plants)seedlings/pot), for establishing the plants growth, containing 500 ml of liquid BD medium [15] ($CaCl_2$= 2 M; KH_2PO_4= 1 M; $MgSO_4$= 0,5 M; K_2SO_4= 0,5 M; $MnSO_4$= 2 mM; H_2BO_3= 4 mM; $ZnSO_4$= 1 mM; $CuSO_4$= 0,4 mM; $CaSO_4$= 0,2 mM; Na_2MoO_4= 0,2 mM; $FeSO_4$= 0,02 M and KNO_3= 4,9 mM). The pH was adjusted to 6,6 - 6,8. They were placed in room culture at 24±2 °C with a 16 h light/ 8 h dark photoperiod (0.1 mMol/m^2s). After 2 weeks, three uniform size plants per pot were transplanted for further treatments.

- Magnetic treatment of culture medium

Culture medium was magnetically treated by passing once through a magnet device (Pressure loss: 0,15 bar.at, production by Aqua Unique company, in Denmark, cylindrical, weight: 1870 g, length : 24,5 cm) (Fig.1).

The magnet device contains a cylindrical magnet inside type NdFeB. Field lines takes the form of a flower with four petals. Four holes were placed at the maximum field points so that the water flow receives a maximum magnetic field.

Culture medium was passed in the magnetic treatment device at the flow rate of 17,5 ml/s. We have called such treated culture medium as magnetically treated culture medium (MTCM).

- Experiment procedure

The pots were divided into four main culture medium types:

- Magnetically treated culture medium with complete dose of iron (MTCM).
- Untreated culture medium with complete dose of iron (control).
- Magnetically treated culture medium with Fe deficiency (solution with only 1% of the complete dose of iron used for the control culture medium) (MTCMFeD).
- Untreated culture medium with Fe deficiency (NCMFeD).

Each culture medium type was renewed 48 hours interval.

Three replications were done for each treatment type. Each replication regroups three plants.

Pots were kept in room culture at 16 h light/8 h dark photoperiod, at relative humidity of 55-60% and in temperature 24±2°C.

- Data recorded

After 3 weeks of treatments, the plants were harvested and different parameters were tested.

Strawberry and tomato plants development evaluation: We compared plants cultivated in MTCM and control medium. Number of leaves, root length, shoot length and shoot and root fresh weight were recorded.

Some mineral nutrients content: Strawberry and tomato plants sample of shoots and roots, cultivated in MTCM and control culture medium types, were dried in an oven at 70 °C for 48 hours to constant mass. They were than mineralized using the method described by [16]. The Ca, Mg, Na, P, K and Fe contents were determined by ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectrometry (Ultima2 JY) following the method of [17].

Plants development and Fe content in Fe deficiency condition: We compared plants cultivated in MTCMFeD, NCMFeD and control culture medium types. For each treatment, the number of leaves, the root length, the shoot length, the shoot and the root fresh weight, the shoot-to-root (dry weights) ratio, the iron uptakes for the shoot, and the root parts; were determined.

Chlorophyll content: According to the procedure described by [18], 0,25 gram of most expanded fresh leaves were randomly taken from each treatment. The fresh tissue was fine ground in a mortar and pestles using 80 % acetone. The optical density (OD) of the solution was recorded at 663 and 645 nm wave lengths (for chlorophyll a and b, respectively) using a spectrophotometer. The chlorophylls content in leaves pigments were determined using the following equations:

$$chla(\frac{mg}{kg}FW) = 12{,}25 \times A663\ - 2{,}79 \times A645.$$

$$chlb(\frac{mg}{kg}FW) = 21{,}5 \times A645\ - 5{,}1 \times A663.$$

Where chl a = content of chlorophyll a; chl b= content of chlorophyll b and Aλ= absorbance value read at λ (nm) wave length.

- Statistical analysis

All the data recorded were subjected to the one-way analysis of variance (ANOVA) to test the significance of the differences between the means for plants cultivated in the different culture medium types. In cases where the ANOVA reveals a significant difference between the means, multiple comparisons, using the Student–Newman–Keuls (SNK) test at 0,05 significance level, were performed.

Results and discussion

- Effect of magnetic treatment on strawberry and tomato plants development

Strawberry plants cultivated in MTCM exhibited significant increases in the number of leaves, shoot fresh weight, root length, shoot length, and root fresh weight (Fig.2). Compared to the control, the increases reached 156,5 % for the number of leaves, 34,7 % for the shoot length, 108,3 % for the shoot fresh weight, 22,1 % for the root length, and 60,5 % for the root fresh weight.

Tomato plants cultivated in MTCM showed also significant increases in the number of leaves, the shoot length, and the root length (Fig.3), with an increment of 152,9 % in the number of leaves, 14,4 % in the shoot length, and 23 % in the root length. Furthermore, the root fresh weight was highly increased when tomato plants were cultivated in MTCM, with an increase of 74,7 % when compared to the control. However, the increase in the shoot fresh weight of tomato plants cultivated in a MTCM was not significant.

Our results showed that physical treatment of culture medium by a static magnetic field improved the growth parameters of tomatoes and strawberries plants. In general, the seedlings cultivated in MTCM grew taller and heavier than those cultivated in an untreated nutrient solution. Hozayn and Qados (2010) showed that fresh weight and plant height were significantly increased when flax plants were irrigated with magnetically treated nutrient solution (MTNS) [2]. These results are in line with those of De Souza et al. (2006) and El Sayed (2014) who observed that pretreatment of seeds with magnetic field or irrigation with MTNS increased leaf, stem and root fresh and dry weight of tomato and broad bean [19,20].

Eşitken and Turan (2004) have shown an enhancement of water productivity in both crop and livestock production, the number of flowers, and the total yield of fruits for strawberry plants [4]. Similar enhancing effect of MTNS were reported on other crops like cereal, sunflower, flax, pea, wheat, pepper, tomato, soybean, potato, cabbage and sugar beet. In these studies, the crop yield were increased [21–34]. Moreover, Reina et al. (2001) and Taia et al. (2007) reported significant increase in the rate of water absorption accompanied with an increase in total mass of lettuce [10,29]. Sadeghipour and Aghaei (2013), Al-Khazan et al. (2011) and Maheshwari and Grewal (2009) also observed an increase of water uses efficiency in cowpea, jojoba, celery, and snow pea when irrigated with MTNS [6, 35, 36].

Sadeghipour and Aghaei (2013) ascribed the stimulatory impact of MTNS to the increasing of cowpea root growth [35]. Turker et al. (2007) also reported an important influence on the root dry weight of sunflower plants [37]. These results correlate with our findings in root growth. Kronenberg (2005) showed that the magnetic treatment led to an increase in the availability of minerals in soil through increasing of the solubility of salts and minerals [38]. Thus, the positive effects of MTCM on growth parameters of strawberry and tomato plants can be attributed to the cumulative effect of better bioavailability of minerals in culture medium and an enhancement of root system.

- **Effect of magnetic treatment on some mineral nutrients uptake**

The average concentrations of Mg, Ca, Fe, K, P, and Na in shoots and roots of strawberry and tomato plants cultivated in MTCM were compared with the control.

In shoots of strawberry plants cultivated in a MTCM, we observed an increase of magnesium content by 26,8 %; calcium content by 30,2 %; iron content by 62,4 %; potassium content by 25,3 %; phosphorous content by 12,8 % and sodium content by 26,9 %. In roots, the minerals uptake were increased by 36,6 % for the magnesium; 23,1 % for the calcium; 184,8 % for the iron; 19,3 % for the potassium; 32,2 % for the phosphorous and 58,9 % for the sodium (Fig.4).

For tomato plants, data in Fig.5 showed that the highest leaves Mg, Fe, Ca, K, and Na contents correspond to plants cultivated in MTCM. The percentages of improvement when compared to the control were 14,9 % (Mg); 34,4 % (Fe); 23,4 % (Ca); 14,4 % (K) and 30,9 % (Na). However, the results show a slight increase in shoots P content. In roots, the minerals content improvement was 12,7 % (Mg); 84,3 % (Fe); 36,9 % (Ca); 95,8 % (P); 51,1 % (K) and 64,4 % (Na).

These results indicated that strawberry and tomato plants cultivated in a MTCM exhibited a highly significant increase in Mg, Ca, Fe, K, P, and Na content in both roots and shoots. These results are in line with those of El Sayed (2014) and Grewal and Maheshwari (2011); they observed an increase in potassium content in pea and broad bean after irrigation with MTNS [5,20]. Grewal and Maheshwari (2011) showed that MTNS led to a significant increase in N, K, Ca, Mg, S, Na, Zn, Fe, and Mn contents in snow pea [5]. In Canola plant, Hozayn et al. (2016) reported that MTNS caused significant increases in potassium, magnesium and calcium by 3,5; 6,7 and 0,8 %, respectively, compared with non treated nutrient solution [39]. El-Yazied et al. (2012) noticed that treated tomato seeds with magnetic field by 100 gauss for 15 minutes with MTNS increased total phosphorus content of tomato leaves [40]. Dhawi et al. (2009) and Radhakrishnan and Kumari (2012) showed that the magnetic treatment increased sodium content of date palm and soybean plant leaves [41,42].

The positive effect of MTCM on mineral element uptake in strawberry and tomato may be attributed to the role of magnetic treatment in increasing absorption and assimilation of nutrients. Various studies have demonstrated higher absorption of nutrients in tomato plants irrigated with MTNS [3,43]. Kronenberg (2005) explained that the magnetic application led to an increase in the availability of minerals in soil through the increasing of solubility of salts and minerals [38]. Grewal and Maheshwari (2011) reported that some changes occurred in the physical and chemical properties of water according to magnetic treatment, mainly hydrogen bonding, polarity, surface tension, conductivity, pH, and solubility of salts [5]. In these connections, Mohamed and Ebead (2013) and Todeshki et al. (2015) explained that MTNS has a high solubility and a lower surface tension; therefore, nutrients are more solvable in water [44,45]. In fact, when the nutrient solution is exposed to the magnetic field, it gets activated and the size of molecule group gets reduced below the diameter of capillaries in the roots of plant, allowing a better absorption of nutrient through the root [46].

- **Effect of magnetic treatment on plants development and Fe uptakes in Fe deficiency condition**

Among the mineral elements studied previously, the iron concentration showed the highest increase in the shoot and the root of strawberry and tomato plants when cultivated in MTCM.

These results support that the iron uptakes is affected by magnetic treatment. We compared the growth and Fe uptake in strawberry and tomato plants cultivated under the two doses of iron.

For strawberry plants cultured in untreated culture medium, Fe deficiency didn't affect growth parameters such as the number of leaves, the shoot length, the shoot fresh weight, the root fresh weight, and the ratio shoot-to-root (S/R). However, significant difference was found between the average root length and shoot and root Fe contents. On the other hand, strawberry plants cultivated in MTCMFeD marked a significant increase in almost growth parameters when compared to the control with a complete dose of iron. The increases reached 78,2 % for the number of leaves, 19,6 % for the shoot length, 27,9 % for the shoot fresh weight, 43,6 % for the root fresh weight, and 42,5 % for the ratio shoot-to-root (S/R), but, the increase for the root length was not significant (Fig.6). Data in Fig.6 also showed that the highest shoot and root Fe contents corresponded to strawberry plants cultivated in MTCMFeD, where the percentages of improvement of Fe content were 19,2 % for the shoot and 23,5 % for the root when compared to the control. Strawberry plants cultivated in MTCMFeD showed strong increment in all growth parameters when compared with those cultivated in NCMFeD (Fig.6).

For tomato plants cultured in untreated culture medium, Fe deficiency affect growth parameters such as shoot length, shoot fresh weight, root fresh weight, the ratio shoot-to-root (S/R), and shoot and root Fe contents. Whereas, no significant difference was found between the number of leaves or shoot length. Tomato plants cultivated in MTCMFeD showed a significant increase in all growth parameters when compared to the control with a complete dose of iron. The increases reached to 105,8 % for the number of leaves, 12,7 % for the shoot length, 42,7 % for the shoot fresh weight, 11,1 % for the root length, 44,9 % for the root fresh weight, and 15,7 % for the ratio shoot-to-root (S/R) (Fig.7). When compared, strawberry plants cultivated in MTCMFeD and the control plants (Fig.7), we observed a significant increase of iron by 8,4 % for the shoot and by 38 % for the root (Fig.7). Moreover, tomato plants cultivated in MTCMFeD revealed a highly significant improvement in all above parameters over those cultivated in a NCMFeD (Fig.7).

These results show that magnetic treatment improve all aforementioned growth parameters even under Fe deficiency condition. In addition, these improvement were also observed in plants cultivated in MTCMFeD when compared with those cultivated in untreated culture medium with a complete dose of iron. Same trend was marked for iron uptakes. Kronenberg (2005) explained that the forces of the magnetic fields intensified the internal vibration of the water clusters to the breaking point; so that their internal captive particles become free [38]. Once free, they act as centers (crystallization starting points) for mineral molecules in need of a crystallization center and form microcrystal which flowed with the water. Moreover, Amiri and Dadkhah (2006) suggested that the reduced surface tension of the MTNS may facilitate its penetration of cell walls [47].

Iron is an essential micronutrient for plant growth and development. However, Fe deficiency affect crop development. Earlier studies, reported that iron deficiency resulted in lower S/R values [48,49]. Our results showed that S/R ratio was significantly increased by magnetic treatment for strawberry and tomato plant cultivated under Fe deficiency condition. In fact, the literature reviews reported that plants irrigated with MTNS showed increasing in root-hairs formation on the young laterals roots [50]. This growth response facilitates Fe uptake through increased root surface area and transfer-cells formation, which is associated with the increased capacity to reduce $Fe3+$ in the epidermis [51]. These results are in line with our findings in root growth.

Thus, the positive effects of magnetic treatment on growth parameters of strawberry and tomato plants under Fe deficiency condition can be referred to the cumulative effect of an enhancement of root system and a better bioavailability of minerals in culture medium. The use of magnetic treatment as a response to Fe-deficiency stress obviously represents an interesting evolutionary solution to problems inherent in the calcareous soil.

- **Effect of magnetic treatment on chlorophyll content**

Chlorophyll synthesis is dependent on iron nutrition. Iron deficiency reduces the amount of the essential components of photosynthesis (cytochromes, ferredoxin and iron sulfur proteins) and also disrupts their optimal ultrastructural arrangement which interferes with function of the photosynthetic apparatus [52]. To examine the effect of magnetic treatment on chlorophyll content under Fe deficiency condition, Either a full nutrient solution or iron deficiency nutrient solution were subjected to magnetic treatment.

The results reveal that the amount of photosynthetic pigments (chlorophyll a & b) increased obviously in strawberry and tomato plants cultivated in a MTCM as compared to those cultivated in normal nutrient solution, for the both doses of iron (Fig. 8 & 9). With complete dose of iron, the increase of chlorophyll a content in strawberry and tomato plants cultivated in MTCM were 345,4 % and 99,1 % compared to the controls; respectively. The percentage of chlorophyll b content in strawberry and tomato plants cultivated in MTCM increased by 255,9 % and 108,4 % compared to the controls; respectively. Similar trends were observed in iron deficiency conditions. The average chlorophyll a content in strawberry and tomato plants cultivated in MTCMFeD increased by 266,9 % and 817,9 % compared to those cultivated in NCMFeD; respectively. The average chlorophyll b content in strawberry and tomato plants cultivated in MTCMFeD increased by 125,6 % and 1007,9 % compared to those cultivated in NCMFeD; respectively.

On the other hand, the average contents of chlorophyll a in strawberry and tomato plants controls were 34,7 mg/g fresh weight (FW) and 110,1 mg/g FW whereas they were 117,9 mg/g FW and 203,9 mg/g FW in the conventional plants cultivated in MTCMFeD; respectively. Add to this, the average contents of chlorophyll b in strawberry and tomato plants controls were 37,2 mg/g FW and 203,9 mg/g FW whereas they were 77,7 mg/g FW and 327,3 mg/g FW in the conventional plants cultivated in MTCMFeD, respectively.

Our results show that magnetic treatment increases chlorophyll a and b contents in strawberry and tomato plants. These results agree with those of Abdul Qados and Hozayn (2010) who found an increase of 17,46 and 67,8 % in Chla and Chl b contents in flax plants, respectively [53]. Similar results were obtained in many others plants: broad bean, chickpea, tomato, common bean, sunflower and sugar beet [9,19,20,25,54–56]. Abdul Qados and Hozayn (2010) suggested that these increase may be attributed to the increase in growth promoters (Indole Acetic Acid (IAA)) which increased protein contents [20,53]. In this context, Çelik et al. (2008) and Shabrangi and Majd (2009) found that the stimulation effect on photosynthetic pigment is due to the beneficial effect of magnetic field on protein synthesis [57,58]. Besides, Atak et al. (2000) explained the increases in all photosynthetic pigment through the increase in cytokines synthesis which is induced by magnetic fields [21]. In addition, El Sayed (2014) found that the irrigation of broad bean plant with MTNS increased significantly the GA3 and kinetin contents compared to the control [20]. They also added that the magnetic moments of the atoms in magnetic fields are oriented downwards the field direction. Given that chloroplasts have paramagnetic properties [59], the influence of the magnetic field on plants increases its inner-energy which is distributed among the atoms causing accelerated metabolism [60].

Conclusion

Magnetic treatment of culture medium shows a significant increase in the number of leaves, shoot length, shoot fresh weight, root length and root fresh weight for both strawberry and tomato plants. Mineral elements uptake (Mg, Ca, Fe, K, P et Na) and chlorophylls content show also a significant increase. It result that magnetic treatment allows a beneficial effect in plants development when cultivated in magnetically treated culture medium.

In Fe deficiency condition, magnetic treatment lead to a significant increase in the number of leaves, shoot length, shoot fresh weight, root length, root fresh weight and in the ratio shoot-to-root in strawberry and tomato plants. It also allow a better iron uptakes and a higher chlorophylls content. Moreover, the plants cultivated in magnetically treated culture medium under Fe deficiency show better growth than those cultivated in an untreated culture medium with a complete dose of iron.

In the agricultural production, The use of magnetic technology will enable intense and more quantitative and qualitative production. Moreover, It may be used for improving the efficiency of added fertilizers. On the other hand, The use of magnetic treatment as a response to Fe-deficiency stress obviously represents an interesting evolutionary solution to problems inherent in the context of calcareous soil. In sum, magnetic technology appear as a promising physical growth stimulation approach even under Fe deficiency conditions.

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Authors contributions:

Mrs. Taimourya performed the experiments, collected, analyzed, interpreted the data, and wrote the manuscript. Pr. Oussible and Pr. Smouni supervised this research and revised the manuscript. Pr. Baamal procured statistical expertise and contributed to data analysis. Pr. El Harif, Pr. Guedira and Pr. Zaid contributed to the revision of the manuscript. All authors contributed to conception and design of the research plan and discussed the results.

Figures:

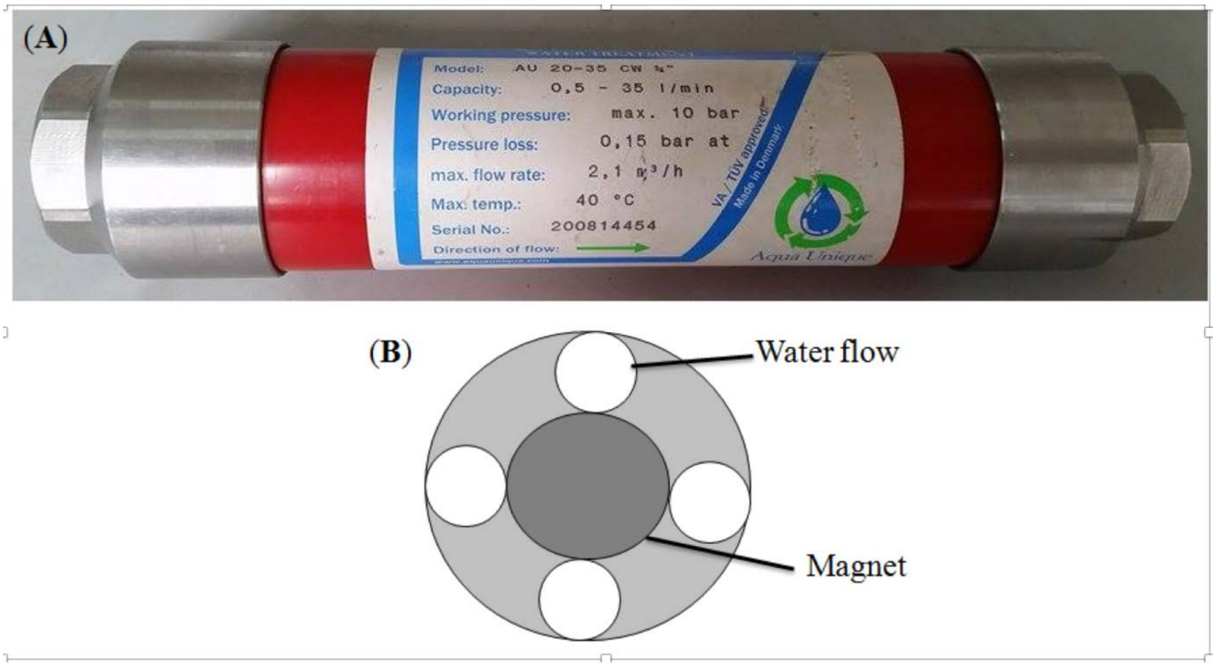

Fig. 1: (A) The magnetic treatment device and (B) Schematic representation of a cross section of the magnetic treatment device.

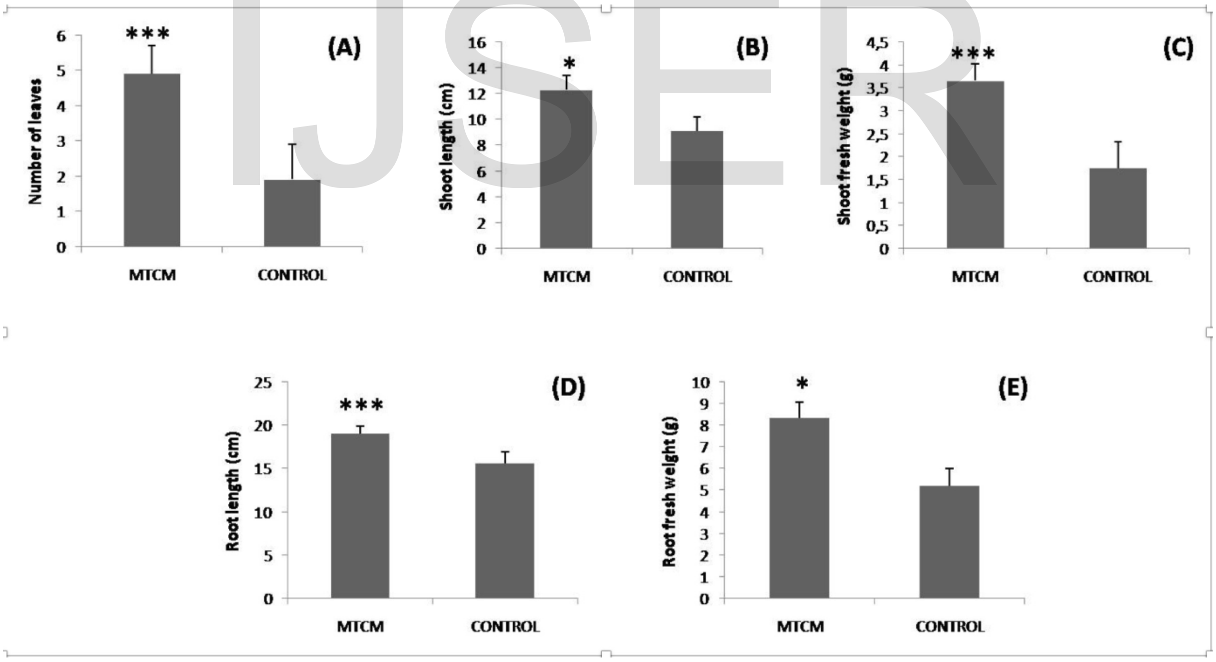

Fig. 2: Growth characters of strawberry plants cultivated in normal (control) and magnetically treated culture medium (MTCM): (A) Number of leaves, (B) Shoot length, (C) Shoot fresh weight, (D) Roots length and (E) Roots fresh weight. Values are mean ± SD of three biological and three technical replicates. *, ** , * showed that the difference is significant at the 0,05 ; 0,01 and 0,001 levels, respectively. Thin vertical bars represent average standard error of the mean.**

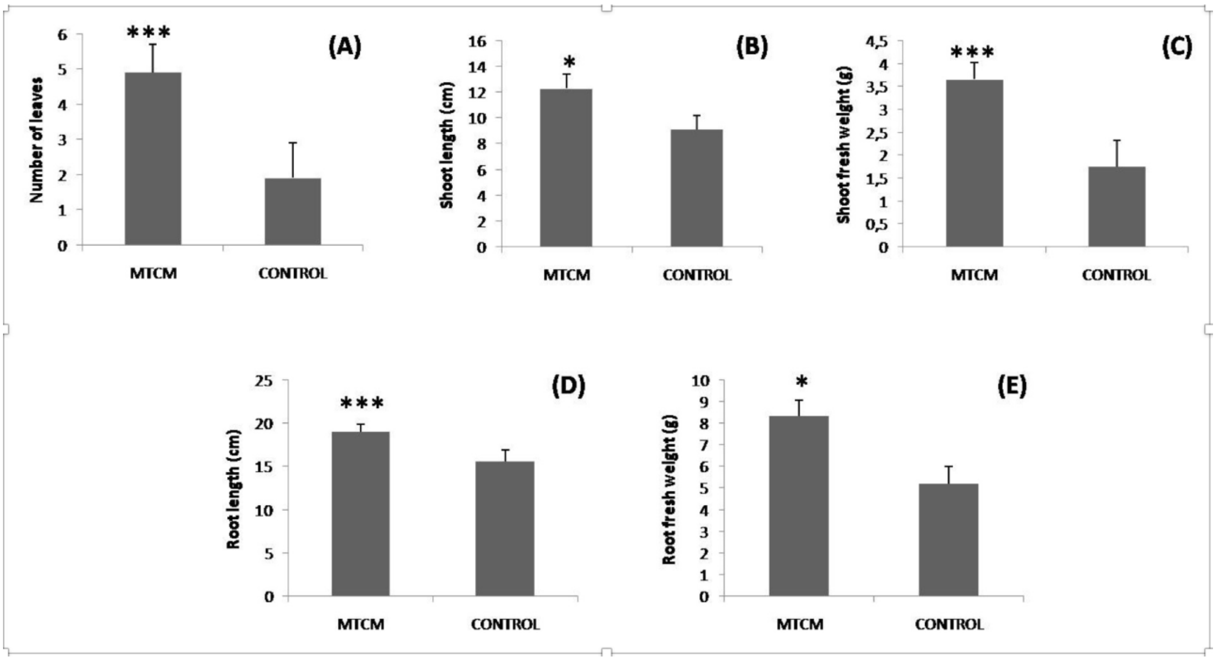

Fig. 3: Growth characters of tomato plants cultivated in normal (control) and magnetically treated culture medium (MTCM): (A) Number of leaves, (B) Shoot length, (C) Shoot fresh weight, (D) Roots length and (E) Roots fresh weight. Values are mean ± SD of three biological and three technical replicates. *, ** , * showed that the difference is significant at the 0,05 ; 0,01 and 0,001 levels, respectively. Thin vertical bars represent average standard error of the mean.**

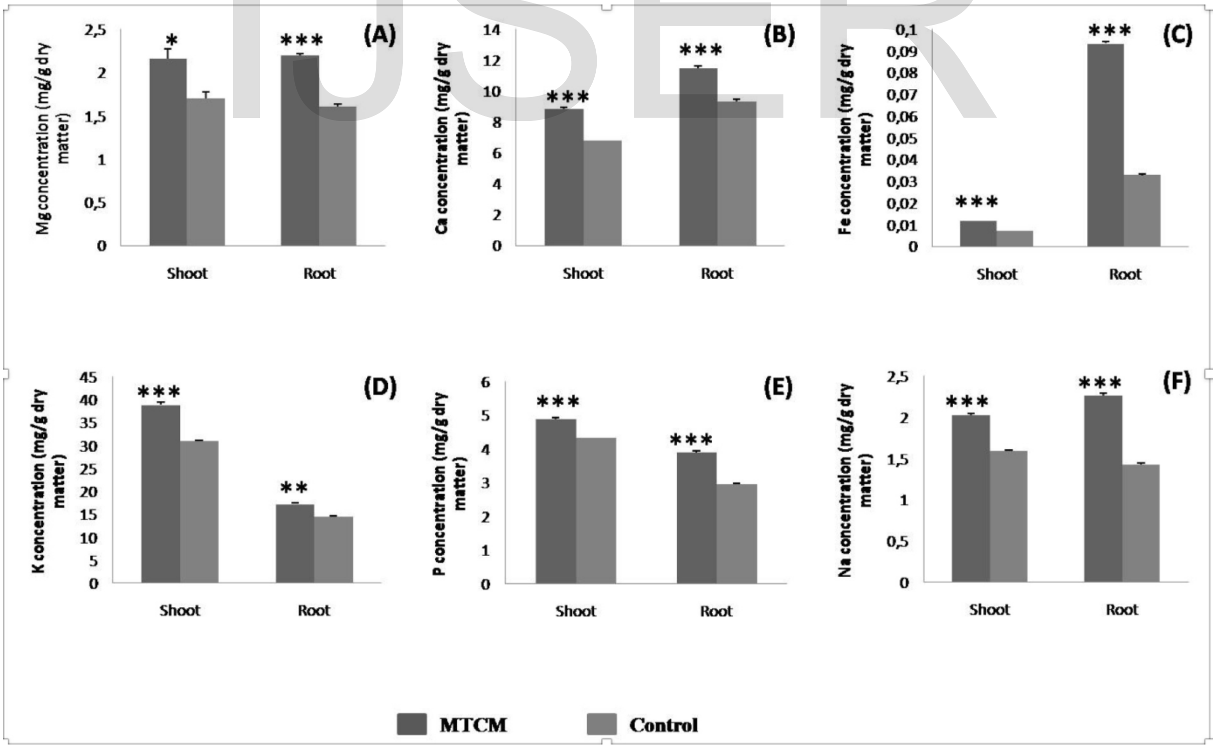

Fig. 4: Mineral elements concentration in shoot and root of strawberry plants cultivated in normal (control) and magnetically treated culture medium (MTCM): (A) Mg concentration, (B) Ca concentration, (C) Fe concentration, (D) K concentration, (E) P concentration and (F) Na concentration. Values are mean ± SD of three biological and three technical replicates. *, ** , * showed that the difference is significant at the 0,05 ; 0,01 and 0,001 levels, respectively. Thin vertical bars represent average standard error of the mean.**

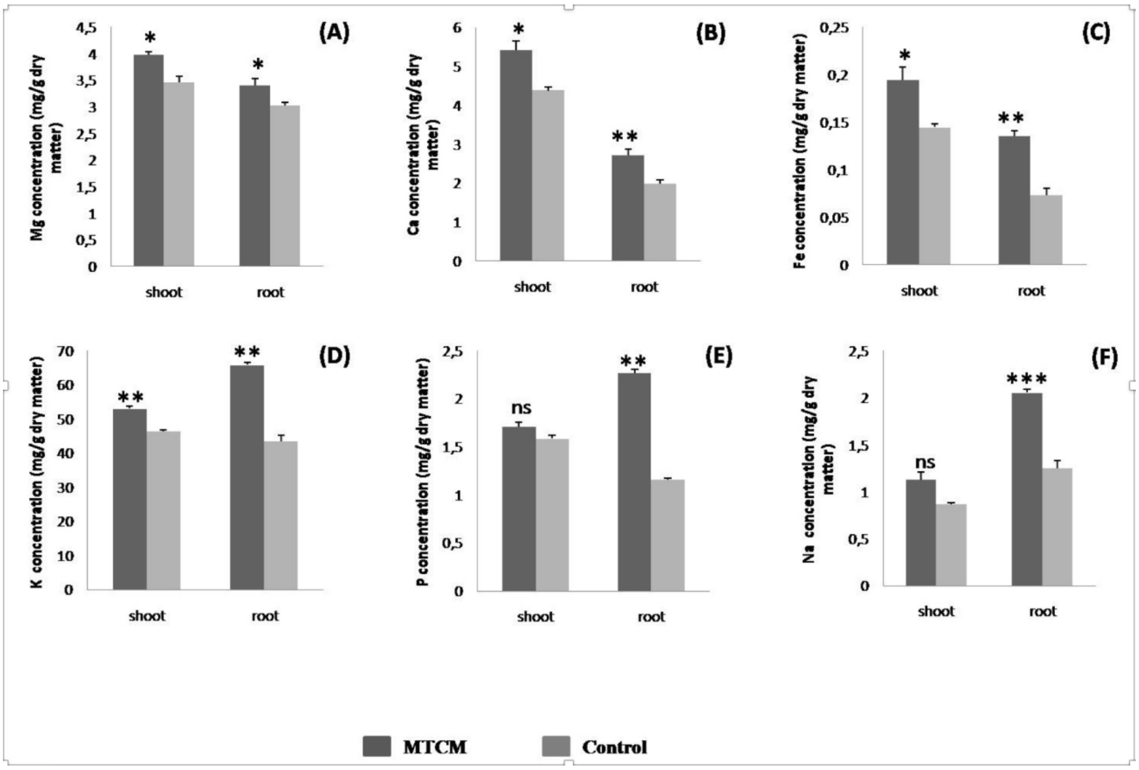

Fig. 5: Mineral elements concentration in shoot and root of tomato plants cultivated in normal (control) and magnetically treated culture medium (MTCM): (A) Mg concentration, (B) Ca concentration, (C) Fe concentration, (D) K concentration, (E) P concentration and (F) Na concentration. Values are mean ± SD of three biological and three technical replicates. *, ** , * showed that the difference is significant at the 0,05 ; 0,01 and 0,001 levels, respectively. Thin vertical bars represent average standard error of the mean.**

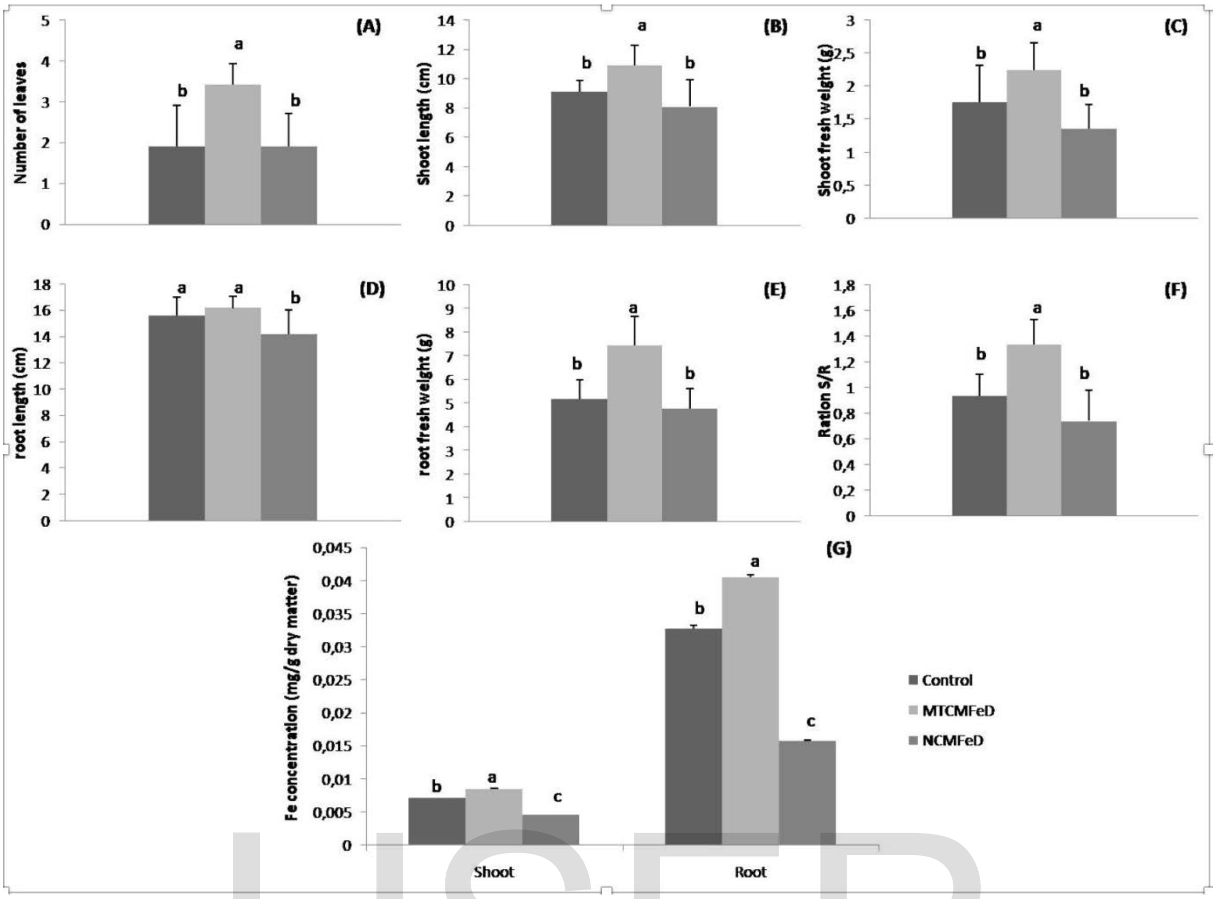

Fig. 6: Strawberry plants grown in a full nutrient solution (control) ; magnetically treated culture medium under Fe deficiency (MTCMFeD) or untreated culture medium under Fe deficiency (NCMFeD): (A) Number of leaves, (B) Shoot length, (C) Shoot fresh weight, (D) Roots length, (E) Roots fresh weight, (F) Shoot –to-root (dry weights) ratio and (G) Fe concentration. Values are mean ± SD of three biological and three technical replicates. Different letters in bars show significant differences ($p<0,05$) according to the Newmen-Keuls test. Thin vertical bars represent average standard error of the mean.

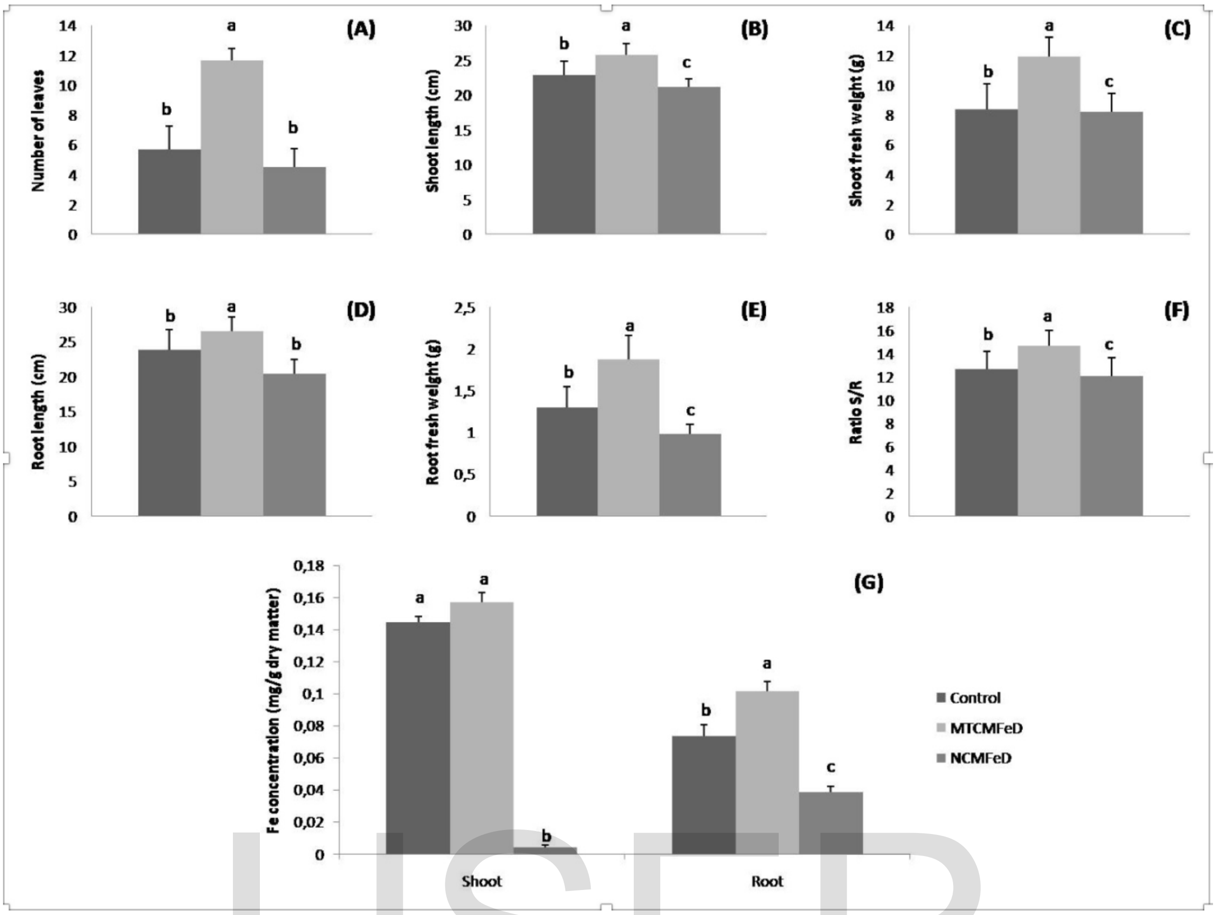

Fig. 7: Tomato plants grown in a full nutrient solution (control) ; magnetically treated culture medium under Fe deficiency (MTCMFeD) or untreated culture medium under Fe deficiency (NCMFeD): (A) Number of leaves, (B) Shoot length, (C) Shoot fresh weight,(D) Roots length, (E) Roots fresh weight, (F) Shoot –to-root (dry weights) ratio and (G) Fe concentration . Values are mean ± SD of three biological and three technical replicates. Different letters in bars show significant differences (p<0,05) according to the Newmen-Keuls test. Thin vertical bars represent average standard error of the mean.

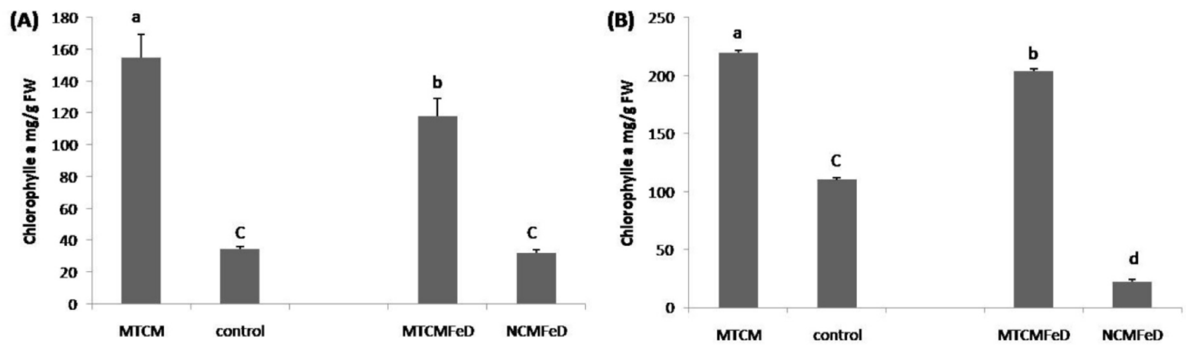

Fig. 8: Chlorophyll a of (A) Strawberry and (B) Tomato plants grown in magnetically treated full nutrient solution (MTCM), untreated full nutrient solution (control), magnetically treated culture medium under Fe deficiency (MTCMFeD) or untreated culture medium under Fe deficiency (NCMFeD). Values are mean ± SD of three biological and three technical replicates. Different letters in bars show significant differences (p<0,05) according to the Newmen-Keuls test. Thin vertical bars represent average standard error of the mean.

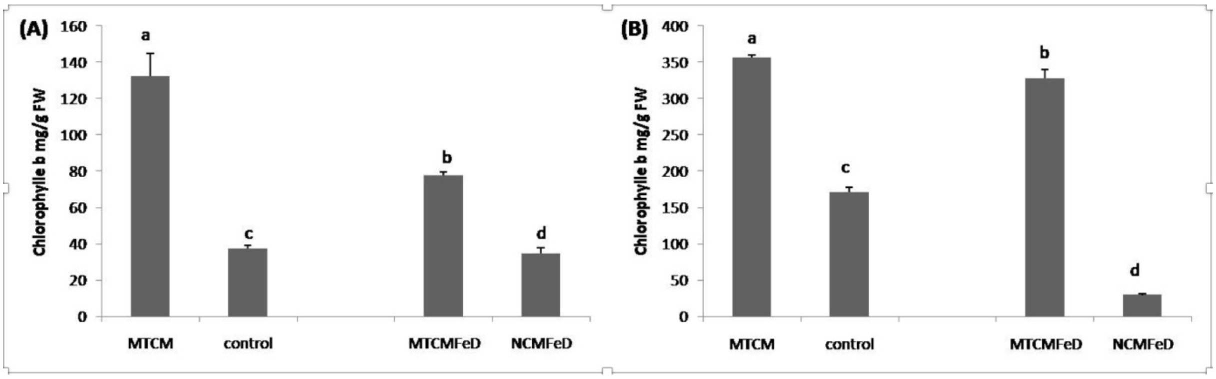

Fig. 9: Chlorophyll b of (A) Strawberry and (B) Tomato plants grown in magnetically treated full nutrient solution (MTCM), untreated full nutrient solution (control), magnetically treated culture medium under Fe deficiency (MTCMFeD) or untreated culture medium under Fe deficiency (NCMFeD). Values are mean ± SD of three biological and three technical replicates. Different letters in bars show significant differences (p<0,05) according to the Newmen-Keuls test. Thin vertical bars represent average standard error of the mean.