



Research article

Effects of treated water with neodymium magnets (NdFeB) on growth characteristics of pepper (*Capsicum annuum*)

Etimad Alattar¹, Khitam Alwasife² and Eqbal Radwan^{1,*}

¹ Biology Department, Faculty of Science, Islamic University of Gaza, Gaza, Palestine

² Physics Department, Faculty of Science, Islamic University of Gaza, Gaza, Palestine

* **Correspondence:** Email: ernp2030@gmail.com; Tel: +972597364269.

Abstract: This study was conducted to investigate the effect of magnetic water treatment on growth characteristics of pepper (*Capsicum annuum*) plants. One week old pepper plants were selected and divided into four groups in a complete randomized design. In our study, we took normal tap water and divided it into four parts. The first group received given non-magnetically treated water (as a control), while the remaining groups received magnetized water at 3, 6, and 9 magnets, respectively. Four pipes and 18 permanent magnets with a flux density of 70 mT were used for this system. The results of the current study showed that magnetized water caused significant increases in all studied parameters, except plant length and dry weight, when compared to non-magnetized water. The results revealed that magnetizing water with 6 magnets was effective than others in increasing the number of fruits and leaves per plant, whereas magnetizing water with 9 magnets was effective than others in increasing the fresh weight of produces fruits. The impact of magnetic water treatment depends on the number of magnets used to magnetizing water. It appears that the utilization of magnetically treated water can lead to improving the quantity and quality of pepper fruits. Therefore, applying magnetized water could be one of the most promising ways to enhance agricultural production in an environmentally friendly way.

Keywords: magnetic water treatment; pepper (*capsicum annuum*) plants; neodymium magnets; growth characteristics

1. Introduction

In current decades, the interaction of magnetic fields with living beings has attracted the interest

of scientists from different disciplines including physics, medicine, biology, chemistry, biotechnology, biochemistry, and nanotechnologies. Extended progress in the experimental setup and the design of modern magnetic materials has resulted in the burgeoning development of new methods to reveal the functions of magnetic fields on the intracellular and molecular levels [1,2]. The use of magnetically treated water for watering crops in agriculture takes an important place in the list of environmentally clean methods. Magnetically treated water is water prepared by exposing normal water through the magnetic field of a certain intensity, flow rate and time [3,4,5].

Use of magnetic field can change the chemical, physical, physicochemical and biophysical properties of water which lead to specific functions [6–9]. Water plays a major role in determining the response of biological materials to magnetic fields. Indeed, water is considered the primary medium in which various biochemical reactions occur, so it is supposed that the exposure to magnetic fields may alter cellular metabolism using the body's water as a primary receptor of the magnetic fields. The differences between non-magnetically treated water (normal water) and magnetically treated water have been reported respecting to activation energy, viscosity, conductivity, hydrogen bond formation, surface tension, dissolved oxygen, water molecule size, evaporation, salt mobility as well as uniformity of its structure [10,11].

The biological effects of magnetic fields have gained increased attention of researchers from a wide spectrum of disciplines such as cell therapy, cell biology, targeted stem cell delivery, and nanomedicine. The response of biological material to magnetic fields have been studied extensively [12–15]. Magnetic fields affect all living systems, including plants, animals and humans, as well as influence cells, tissues, organs, and the whole organisms in different ways [16–20]. External magnetic fields influence both the activation of ions and polarization of dipoles in living cells [21]. Also, magnetic fields have been reported to affect the permeability of cell membranes and activity of ions and related functions, thus resulting in upsetting the balance of ion concentration in the cell and changing the intracellular pH [22]. Magnetic field was reported to affect phenotypic, genotypic, growth characteristics and different functions of the plants like root and shoot growth, germination of seeds, yield parameters, productivity, reproduction, growth of the meristem cells, mRNA quality, chlorophyll contents, enzyme activities, gene expression, protein biosynthesis [13,23–25].

Research on the responses of living beings to low, moderate and strong magnetic fields is prolific [26–29]. Although, there have been many reports on the biological effects of direct or indirect exposure to magnetic fields on living materials, the exact effect of magnetic fields is still under investigation [8]. Exposure of plants to magnetic fields indirectly through water is of particular interest due to the role of water to living systems, especially plants which are sessile. Previous papers indicated that the influence of exposure to magnetic fields is not identical. Some studies show an inhibitory effect by the magnetic fields, whereas, others show activation or no effects on the plants. For example, it was noticed that the magnetized water have a positive impact on germination percentages of seeds [22], shoot growth [4], root growth [30], emergence rate [31], essential element uptake [32], and seed yield [33]. On the other hand, Turker et al. [30] reported that weak magnetic field had negative effect on growth of roots during early growth.

In recent years, many investigators have tested the effect of exposure to a magnetic field on the growth of plants. However, the effects related to the treatment of water with magnetic fields on the growth and developments of pepper plants are poorly discussed. Therefore, the purpose of this study was to determine the impact of the magnetic treatment of water on the growth and morphological character of pepper (*Capsicum annuum*) plants.

2. Materials and methods

This study was conducted in March 2019 for 14 weeks in a field site in East Gaza, Gaza Strip, Palestine, to investigate the impact of magnetic water treatment on the growth and development of pepper plants. The practical part of the study consists of three stages: The first stage was designed for the magnetic system for the treatment of water. The second stage was the preparation of magnetically treated water by treating water samples with the magnetic field. Finally, the third stage was watering pepper plants with magnetically treated water.

2.1. Plant material and growth condition

Under controlled conditions at the field, one week old of pepper plants, without visible defect insect damage, were selected and divided into four groups in a complete randomized design. Pepper plants were chosen due to the lack of studies dealing with the response of peppers to magnetically treated water. Also, they growth during the study period and farmers extensively plant it in their fields. Furthermore, it is easy to transfer pepper plants from the field to the laboratory and conduct the required analysis. Table 1 illustrates the number and distribution of plants in each group.

Table 1. The distribution of pepper plants in experimental groups.

Treatments	Number of pepper plants in each experimental group
Normal tap water (control)	12
3 magnets	21
6 magnets	20
9 magnets	13
Total	66

Table 2. The nutrient content of NPK fertilizer used in our experiment.

Item	Nutrient	Quantity	Unit
Main components	Nitrogen(N)	13	%
	Phosphorus oxide(P ₂ O ₅)	13	%
	Potassium oxide(K ₂ O)	13	%
Trace element	Iron(Fe)	500	ppm
	Manganese(Mn)	250	ppm
	Zinc(Zn)	75	ppm
	Copper(Cu)	55	ppm
	Molybdenum(Mo)	35	ppm

All of the factors (e.g. light intensity, quantity and quality of water, time of watering plants, type and quantity of fertilizer, etc.) except the number of magnets were kept constant. Also, a constant watering time was maintained to reduce unexpected variables that affect the growth of tested plants, therefore the treatment and watering times were properly scheduled.

During the study, the tested plants were fertilized with 13-13-13 NPK fertilizer (Poly-Feed™, Haifa company, Occupied Palestinian territories). The NPK fertilizer used in this study was obtained locally from the farmers and added as recommended by the guidelines of Haifa NutriNet™ company [34]. The nutrient content of fertilizer is shown in Table 2.

Throughout the experiment, the plants were treated with Roger pesticides (Haifa company, Occupied Palestinian territories). All plants were treated at the same time and the same amount of fertilizer and pesticide. The tested pepper was grown until all the fruit yields were harvested.

2.2. Water treatment

Despite many devices that have been designed for the preparation of magnetically treated water, we preferred to build up our magnetic equipment in laboratory conditions. In our study, we took normal tap water and separated it into four parts. The first group was given non-magnetically treated tap water (normal tap water), while the remaining groups were given magnetically treated water. The block diagram of this study explains in the flow chart as shown in Figure 1.

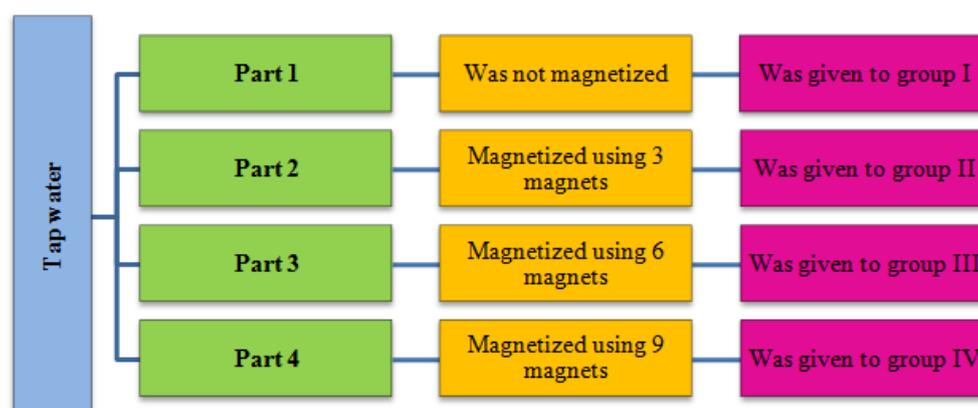


Figure 1. Block diagram of the experimental setup.

The system prepared for water treatment composed of pipelines that will hold the water and provide a surface that magnets can touch it. Four pipes and 18 Nickel-plated neodymium magnets were used for this system. We selected polyvinyl chloride (PVC) pipes with a diameter of 15 mm and a length of 270 mm. The magnets used in this study had an ellipse shape (30 mm length x 15 mm diameter) with a magnetic flux density of 70 mT. All magnets were identical and had the same size, shape, and strength. Neodymium magnets are preferable due to their remarkable strength and easy accessibility. For the first pipe, which corresponded to the control group of the experiment, no magnets are used. For all of the other groups that have magnets, the pipes with magnets were built up correctly. The second pipe was fitted with 3 magnets. The third and fourth pipes were fitted with 6 and 9 magnets respectively.

The magnets are stuck on the inner sides of the pipes. The preparation of Bi-Polar water was done by placing high powered magnets side-by-side at a distance of at least (5–10 mm) apart. The polarity of the magnets was taken into consideration, where the north and south poles of the magnets on the treatment pipe seat were alternated. This procedure is necessary to ensure that opposite poles

face each other and create the desired magnetic field between the two poles and thus, effectively treat water by the magnetic field [35]. The magnets were placed at the end which is nearest to the plant at the distance was 100 mm. The installation of the magnets inside the pipelines system was shown in Figure 2. After all, the pipes were ready, they were placed in the field with the same containers to watering the plants. The plants watered according to the guidelines of farmers and to the recommendation of the ministry of agriculture. The number of times of watering the plants was the same of number of times that our farmers watering their pepper plants in the fields (once a day).

2.3. Data recorded

At the end of the fourteenth week after transplanting, shoot length, fresh and dry weight, stem thickness, and leaves number were monitored and recorded. The length and thickness of the grown plants were carefully recorded using a ruler and capillary, respectively. These parameters were chosen because they indicate the status of growth and development of pepper plants under the tested growth condition. The investigated parameters are considered good criteria to explain the changes induced by magnetically treated water whether directly or indirectly. At 14 weeks from treatment date, plant fresh and oven-dry weight of plants were determined.

2.4. Statistical analysis

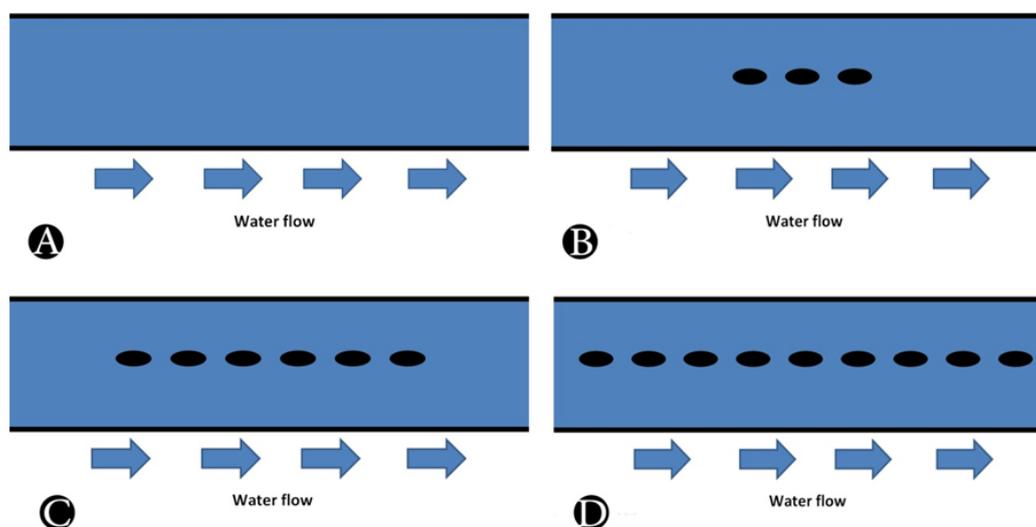


Figure 2. Construction of magnetic water treatment system: (A) non magnetized water, (B) Magnetized water with 3 magnets, (C) Magnetized water with 6 magnets, (D) Magnetized water with 9 magnets.

Data of all experiments were arranged and statistically analyzed using SPSS computer program version 22.0 for Windows (Statistical Package for Social Sciences Inc, Chicago, Illinois). The data were expressed as mean \pm standard deviation. The comparisons among the means of different treatments were made by one-way analysis of variance (ANOVA) followed by Tukey test for pairwise comparisons. For all the tests, a P-value of 0.05 or less was considered for statistical

significance.

3. Results and discussion

The influence of magnetized water were investigated by the growth characteristics of pepper plants. The results showed that magnetically treated water enhanced the growth of pepper plants over the course of the experiment.

3.1. Effect of magnetically treated water on plant length

Experimental results indicated that the patterns of plant length in the pepper plants watered with magnetically treated water were different than those observed in the plants watered with non-magnetically treated water (Figure 3). Mean shoot length of pepper plants was measured in each group every 7 days of treatment until the last day of the experiment (at day 105).

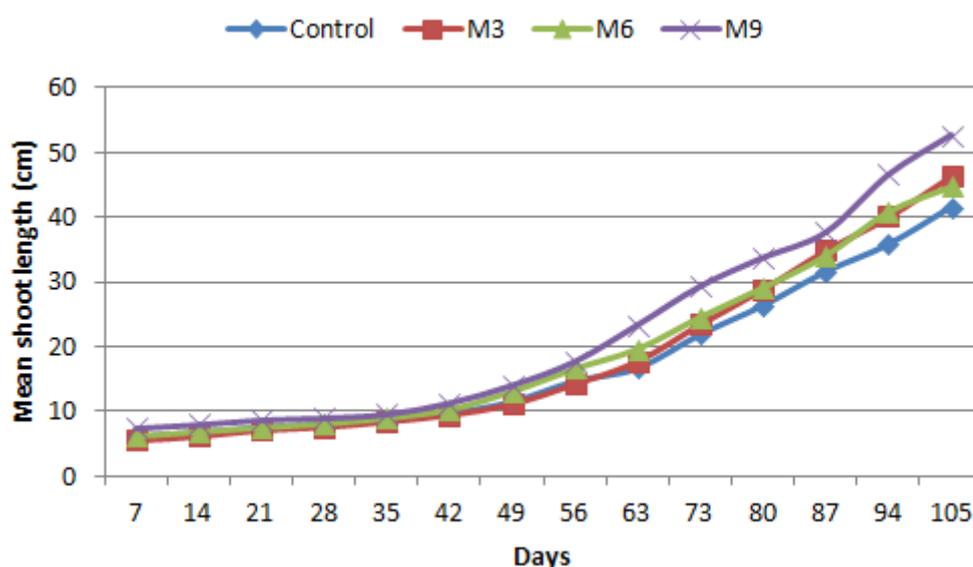


Figure 3. Mean shoot length of pepper plants during the current study.

On day 105, it was noticed that the magnetized water had a similar trend with regard to plant lengths. Plant length was measured after 105 days of growth. These values were taken as mean values of the length of each plant grown in the tested group. Although the growth of pepper plants was slightly affected when watering plants with magnetically treated water, the differences between the four treatments were not significant (Figure 4).

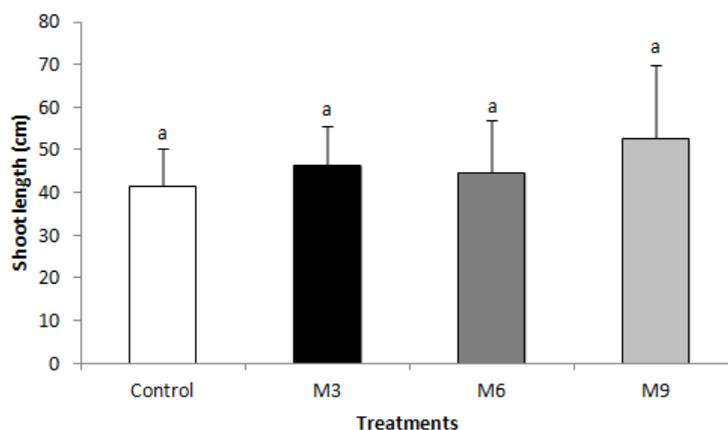


Figure 4. Mean shoot length of pepper plants at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

On the contrary, the present results disagree with that stated in the previous studies, which showed that magnetized water has either inhibition or a stimulatory effect on shoot length of treated plants. For example, in the study of Ahmad et al. [36]; they carried out a study to understand the effect of the magnetic field on seed germination, growth, yield, and fruit quality of sweet pepper (*Capsicum annuum*). Pepper seeds or irrigated water (separately or together) were passed through a magnetic funnel. They showed that the growth parameters were increased in the treated plants compared to the control. They concluded that the magnetic field is an effective method for the pre-sowing treatment of the seeds that enhance their growth. In addition, Similar enhancing effect of magnetically treated water on plants length was also reported on cucumber [37], corn [4], soybean [38,39], Tomato [40], cowpea and brinjal [23].

On the other hand, some studies revealed a negative impact of magnetized water on plant length such as Ijaz et al. [41], they conducted an experiment to study the impact of magnetized seed and magnetized water on wheat seeds. They observed that all values for plant length in treated groups (watered with magnetized water in different passing times) were less than control.

The stimulatory or inhibitory effect of magnetically treated water on the growth of pepper plants may be due to its effect on biochemical processes, protein formation and enzymatic activity. It was previously proposed that the specific intensity of magnetic field can accelerate or delay seedling growth and root development. These changes may be due to magnetic field interacts with ionic fluxes across the cell membrane that induces changes in the mechanism of water uptake, osmotic pressure and ionic concentrations [42,43]. The magnetic field could exert an influence on soil/water interface and may lead to destabilization of gas bubbles (air), thus disturbing the ionic balance between the shell of absorbed negative ions and counter ions [44].

3.2. Effect of magnetically treated water on stem thickness

The results revealed that stem diameter increased when watering plants with magnetically treated water when compared to the control (Figure 5). Among four treatments, watering with water

magnetized with 3 magnets significantly increased the stem thickness (Figure 6). At the end of the study, the magnetized water with 3 magnets gave the highest (2.59 ± 0.61 cm) increase in stem thickness as compared with other magnetic treatments. On the other hand, pepper plants watered with non-magnetized water was the lowest (1.84 ± 0.26 cm) among pepper plants in the other groups.

This result is in agreement with the result stated by Alattar et al. [4], they reported the positive effect of magnetic water treatment on the stem thickness of corn seedlings. Similar results were also obtained by Jogi et al. [45], they found that mustard plants watered with magnetically treated water exhibited significant increases in stem diameter when compared to those in the control group. In the study of Yusuf and Ogunlela [46], they showed that tomato plants watered with magnetically treated water had larger stem diameter than plants watered with non magnetically treated water. On the other hand, different results were mentioned in the study of Osman et al. [47]; they reported that stem diameter of pear seedlings was not significantly affected by magnetically treated water.

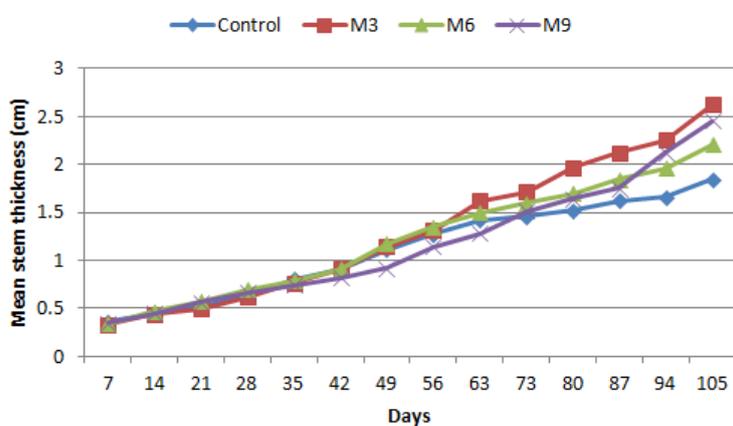


Figure 5. Mean stem thickness of pepper plants during the present study.

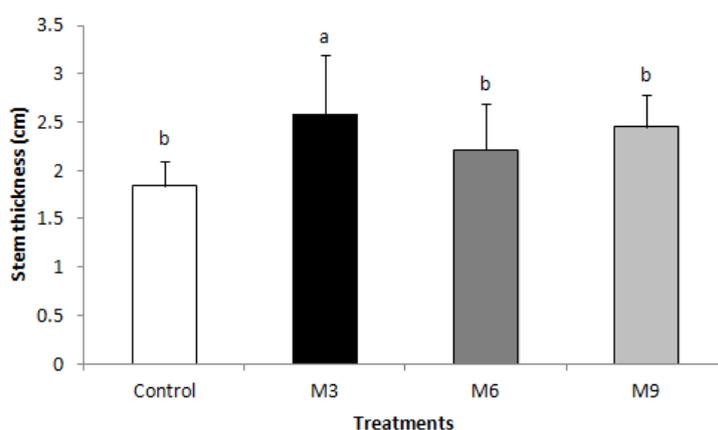


Figure 6. Mean stem thickness of pepper plants at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

The enhancement in vegetative parameters including plant length and stem thickness in plants watered with magnetically treated water may be due to an increase in photosynthetic pigments concentrations such as chlorophyll a and b and carotenoids as well as increased protein biosynthesis that provided a greater amount of assimilates available for vegetative growth. This resulted in a considerable increase in the vegetative growth of pepper plants indirectly treated by the magnetic field. It has been reported that the magnetic field caused changes in the transport properties of cellular plasmatic membranes, which play an important role in regulating the assimilation of the nutrients needed for its functioning [48].

3.3. Effect of magnetically treated water on the number of leaves

The present study showed that the number of leaves is severely affected in the pepper plants watered with magnetically treated water (Figure 7). The impact of different magnetic water treatments on the growth of pepper at the age of 105 days reveals that the number of leaves was significantly increased by applying magnetic treatments. Comparing the control plants to their exposed counterparts, we observed that there was a statistically significant difference in the number of leaves between the four groups. At the end of the experiment, the leaves of pepper plants watered with water treated with 6 magnets (84.75 ± 23.3) were the highest and pepper plants watered with water treated with 9 magnets were the lowest in number (47.45 ± 15.25) among four groups (Figure 8).

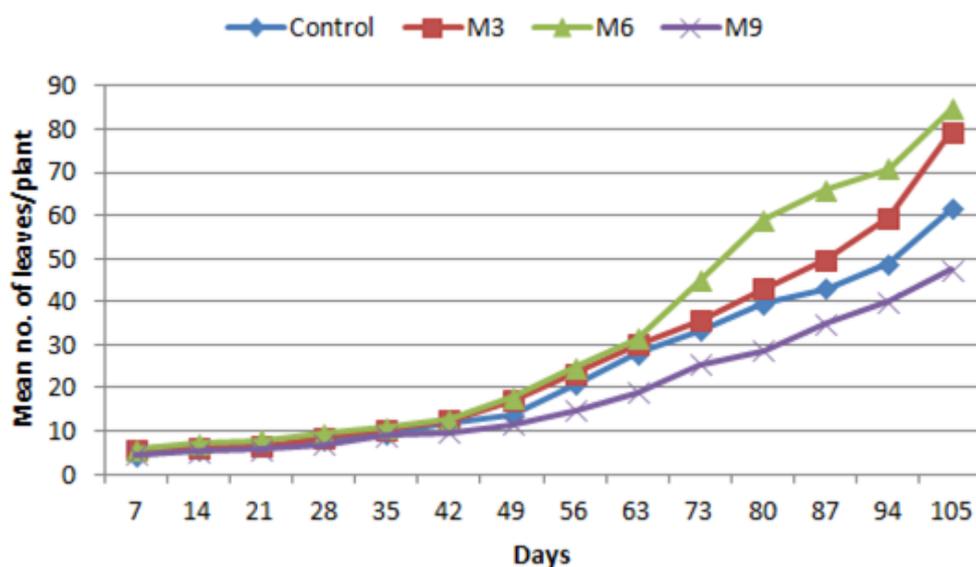


Figure 7. Mean number of leaves of pepper plants during the study.

These results are in agreement with those obtained by Osman et al. [47] and Alattar et al. [4], they showed that the number of leaves per plant was significantly increased by watering plants with magnetically treated water when compared to those in the control group. In the study of El-Gizawy et al. [49], they reported that the potato plants treated with a 30 mT magnetic field produced the highest significant values for the number of leaves per plant. The findings are also in agreement with those stated by Marks and Szcwowska [50] on potato and Ahamed et al. [36] on sweet pepper. They

pointed out that plants derived from magnetically exposed seeds produced a greater number of leaves compared to plants derived from non magnetically exposed seeds. Also, Eşitken [51] showed that the magnetic field had a positive effect on strawberry plants in terms of the number of leaves. In the studies of Surendran et al. [23], they showed that the magnetic treatment of irrigation water increased the number of leaves as compared to those in the control group.

The changes induced in the chemical and physical properties of magnetically treated water resulted in accentuated biological activity in plants and consequently influenced the growth of plants including the number of leaves per plant. Moreover, the magnetic field may be have resulted in faster activations of hormones and enzymes as well as improvement in the mobilization and transportation of nutrients during the growth process [23,32].

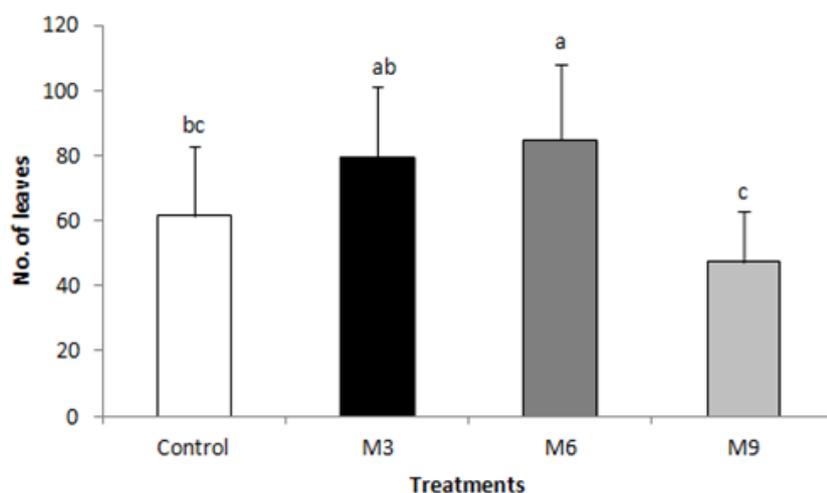


Figure 8. Mean number of leaves of pepper plants at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

3.4. Effect of magnetically treated water on fresh and dry weight

The results which are presented in Figure 9, showed the impact of magnetically treated water on fresh weight (FW) for each tested plant. Pepper plants were significantly influenced by watering with magnetically treated water. Magnetically treated water significantly increased the FW of exposed plants when compared with those in the control group. The pepper plants in the M9 group were the highest, whereas those in the control group were the lowest.

The positive effect of magnetic field on fresh weight was reported by many researcher [52,53]. The largest influences on fresh weight of plants were in group 4 (9 magnets) due to enhanced growth including increased plant biomass under the treatment with the magnetic water. The magnetized water would influence biochemical processes (transport of assimilates, free radicals formation, activity of proteins and enzyme, ions and water uptake and growth regulator,) which lead to change and regulate the overall pattern of plant growth and biomass [39,54].

The results of the present study showed that magnetic treatments did not lead to a significant (P

< 0.05) affect the dry weight of pepper plants (Figure 9). Similar results have been previously documented in the study of Maheshavari and Grewal [32], they showed that shoot dry weight of snow pea was not affected by magnetized water.

On the other hand, previous studies reported that magnetized water has either a negative or a positive effect on the dry weight of treated plants. For example, it was reported a stimulatory effect on the dry weight of snow pea and chickpea [55], soybean [38] some wheat cultivars [41,56] and cowpea [57] by treatments with magnetized water and its effect depending on the amount of water passed through the device. Whereas, Almaghrabi and Elbeshehy [56], revealed that magnetic water decreased the seedling dry weight of 21-day-old seedlings in 2 cultivars of wheat ('Sakha 93' and 'Masr 1').

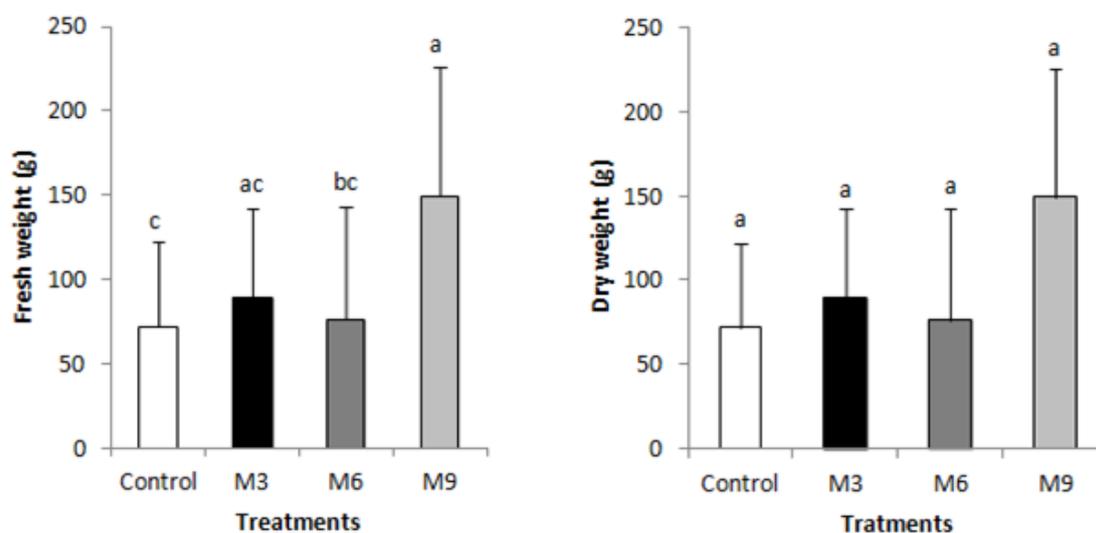


Figure 9. Mean FW and DW of pepper plants at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

3.5. Effect of magnetically treated water on FW of fruits

The results showed that the treated water had a significant effect on the fresh weight of produced fruit (pepper horn). Between the two groups, the highest average weight of fruit (20.92 g) was obtained from the M9 group while the lowest average weight was obtained from the M3 group (Figure 10).

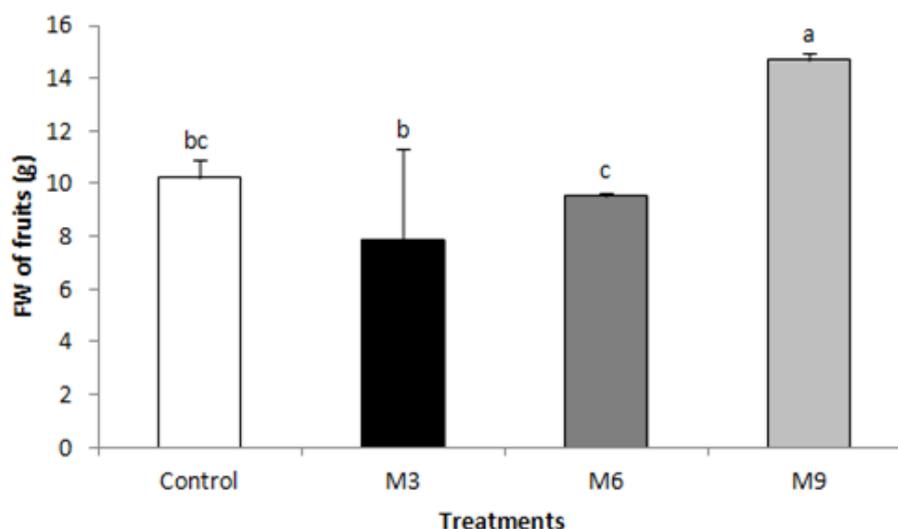


Figure 10. Mean FW of fruits of pepper plants at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

The results of the present study were consistent with the results of Ahmad et al. [36], they showed that fruit fresh weight was significantly increased in the pepper plants watered with magnetically treated water compared to the control. Similar results have been reported on tomato [58], mung bean [59], snow pea and chickpea [55], peas [60] and *Citrus reticulata* [61]. The enhancement in fruit yield and also the largest influences on fresh weight of fruits were found in group 4 plants (9 magnets) may be due to enhancing growth characteristics, which suggests there may be resonance-like phenomena that increase the internal energy of the plant that may induce higher fruit weight [62,63].

3.6. Effect of magnetically treated water on the number of fruits per plant

The results showed that pepper fruit yield was severely affected by magnetically treated water (Figure 11). The highest number of fruit/plant was obtained from plants in the M6 group, whereas the lowest number was obtained from plants in the control group.

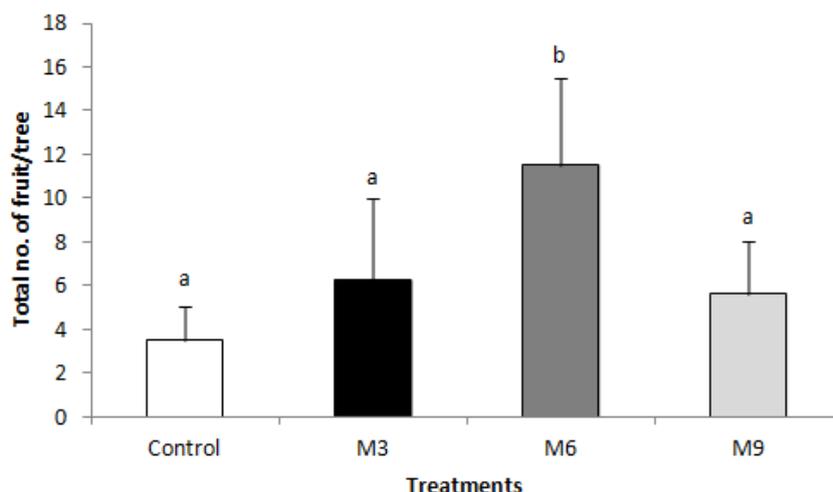


Figure 11. Mean number of fruits/tree of each treatment at day 105. Control: watered with normal water, M3: magnetized water with 3 magnets, M6: magnetized water with 6 magnets, M9: magnetized water with 9 magnets. Mean values followed by the same letter are not significant at $P \leq 0.05$ by Tukey's multiple range test.

Similar results were reported in the studies of Aladjadjiyan [42], Eşitken and Turan [64] and Ahmad et al. [36], they found out that magnetic water treatment increased yield and yield parameters of treated plants. The reasons standing behind increasing yields of the treated plant in the M6 group may be due to that the application of magnetic field with specific intensity (6 magnets) causes increased ions mobility and improves ions uptake which leads to biochemical changes or changed enzymatic activities, which results in better development of photosynthesis stimulation and thus increase the total number of fruits as well as improved their quality [65].

Conclusion

Results of the current study showed the positive effects of magnetically treated water on some growth aspects (e.g. stem thickness, plant fresh weight, fruit fresh weight, number of leaves, fruit yields) of treated plants compared to that of the control. On the other hand there are no effect on plant length and dry weight. The impact of magnetic water treatment depends on the number of magnets used to magnetizing water. These results suggest that, watering with magnetically treated water, a simple and safe method, can be used to improve plant growth and development. It appears that the utilization of magnetically treated water can lead to improved quantity of pepper fruits. Generally, using magnetic water treatment could be a promising technique for agricultural improvements but extensive research is required on different crops.

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Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

Author contributions

Eqbal Radwan wrote the manuscript and prepared figures, tables, and references. Etimad Alattar conceptualized the overall structure and edited the manuscript. Khitam Alwasife contributed critical comments to the draft and approved the manuscript. All the authors reviewed the draft.

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