

# Investigation of the Effects of Radio Frequency Water Treatment on Some Characteristics of Growth in Pepper (*Capsicum annuum*) Plants

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## Abstract

The aim of the present study was to investigate the effect of electromagnetic radio frequency treatment of water on the growth of pepper (*Capsicum annuum*) plants. For this experiment, one hundred one-week old plants were divided into two groups. The first group of plants was watered with water subjected to radio frequency electromagnetic radiation from an internet router for one hour a day, while the other group was watered with tap water (control). The overall results showed changes of growth characters of plant watered with electromagnetic water. The length of pepper plants is significantly affected by the treated water, where the length of shoot was lower in plants grown under the effect of treated water ( $22.43 \pm 7.17$  cm) than those grown without treated water ( $28.11 \pm 8.57$  cm). The results revealed that the stem diameter of control plants ( $1.74 \pm 0.39$  cm) was significantly higher than that of the treated plants ( $1.66 \pm 0.35$  cm). In addition, the root length was lower in plants grown under the effect of treated water than those grown without treated water. Pepper plants watered with electromagnetic treated water exhibited marked decreases in health index, fresh and dry weight, relative water content, number of flowers and fruits/plant as well as number of seeds/fruit. In addition, the current experiment showed a significant decrease in the number of leaves, branch and flower per plant when watered with electromagnetic treated water. The results revealed that the first flowering time for plants in treated group was remarkably decelerated when compared to other plants in control group.

## Keywords

Electromagnetic Spectrum, Radiation, Electromagnetic Water Treatment, Growth Related Characteristics, Pepper (*Capsicum annuum*) Plants

## 1. Introduction

During the last decade, there has been a tremendous increase in use of wireless devices, including routers, which resulted in an increase of the exposure to electromagnetic radiations in our life [1]. Electromagnetic radiation consists of electromagnetic waves, which are synchronized oscillations of electric and magnetic fields that travel through a vacuum at the speed of light [2]. Electromagnetic waves are a form of radiation within the range from high energy cosmic rays and gamma rays to low energy microwave radiation and radio waves [3]. A router device is increasingly being used in telecommunication all over the world. It receives and sends information using radio waves, which are a type of electromagnetic radiation with wavelengths longer than infrared light. Radio waves have frequencies as high as 300 gigahertz (GHz) to as low as 30 hertz (Hz) [2].

All living creatures are surrounded by both artificial and natural electromagnetic radiation. Natural background radiations are mainly generated from three sources: 1) cosmic radiation, 2) terrestrial radiation and 3) internal radiation [4]. While man-made radiation sources are generated by radio communication, communication satellites, computer networks, broadcasting and radar [5]. The influence of electromagnetic radiation on living systems depends on the properties of exposed tissue, power level, exposure duration, frequency, and pulsed or continuous wave [6] [7] [8].

Electromagnetic radiation, particularly radiation emitted from routers, affects all living systems and influences cells, tissues and organs in several ways [9] [10] [11]. They affect, for example, mammals [12]-[17], fruit flies [18], ticks [19] amphibians [20] [21] [22], ants [23], birds [24], honey bees [25] [26] [27] and protozoa [28] [29].

In addition, electromagnetic radiations have been found to cause changes in plants at the cellular and molecular level [30] [31]. In general, electromagnetic radiations are known to stimulate physiological, cytological, ultrastructural and genetic modifications of the living cells [30]. The electromagnetic radiations act primarily on the cell membrane and influence the activation of ions and the polarization of dipoles in living cells [32].

Electromagnetic radiations are considered an effective stress factor on the development of plants [33]. Exposure to radiation influences plant development by affecting the metabolic activities, gene expression and growth related aspects [34] [35] and subsequently, the over growth of the exposed plants. In fact, these changes occur not only in the tissues directly subjected to radiations but also in adjacent tissues [36]. The responses elicited in different plant species depend on both the physical parameters of the radiation source and the status of the biological material such as vegetation stage, pretreatment and environmental conditions [37].

It has been reported that electromagnetic radiation affects essential physiological processes of exposed plants such as respiration [38], long-distance transport [39] [40] [41], photosynthetic pigments [42] [43], photosynthesis [44], the

functioning of the hormonal system [45] [46], antioxidant system of irradiated plants [47] [48] [49], mitotic division process [50] as well as genetic regulation of physiological processes [51] [52].

Though this radiation affects the functioning of living organisms, exact knowledge about this problem is still insufficient. Current years have brought a lot of reports relating the problem of the effect of electromagnetic radiation on living systems, seeking in them both positive and negative effects.

Though the effects of direct exposure of plants or seeds to radiation have been shown to alter plant development and growth, the effects of indirect exposure are not clear. Exposure of plants to electromagnetic radiation indirectly through water is of particular interest due to the importance of water to living systems, particularly plants which are sessile. Previous studies demonstrated that water has unique electromagnetic and biophysical properties [53] [54]. Water plays an important role in determining the response of biological objects to electromagnetic radiation. Indeed, water is considered the primary medium in which biochemical reactions occur [55]. So it is supposed that the exposure to electromagnetic radiation may alter cellular metabolism using body's water as a primary receptor of the electromagnetic radiation [56] [57]. Understanding the mechanisms underlying electromagnetic information storage, transduction, and amplification by water may help us in recognition of the processes operating in the water within living systems [58] [59] [60].

In recent years, many investigators have tested the effect of exposure to an electromagnetic radiation on the growth of plants. However, the effects related to the water treatment with radio frequency radiation on the growth of pepper plants are poorly discussed. Therefore, the aim of the present work was to investigate the influence of electromagnetic radio frequency treatment of water on the growth and morphological character of pepper (*Capsicum annuum*) plants.

## 2. Materials and Methods

The current study was conducted from February to July of 2019 for 200 days. Pepper seedlings were selected for study because of their economic importance for agriculture and food industry. Moreover, this species is considered of economic and cultural importance to the region (Gaza Strip, Palestine) [35].

### 2.1. Plant Treatment and Growth Condition

One hundred one-week old seedlings were purchased locally from the market and divided into two groups. The first group of plants was watered with water subjected to electromagnetic radiation from an internet router for one hour a day while the other group was watered with unexposed tap water. **Table 1** illustrates number and distribution of plants in each group.

At the beginning of the study, the plants were grown in a multi cell plug seed tray (Riverstone Hydroponic Floating Seeding Tray, 100 plants) for 2 months

(**Figure 1(A)** and **Figure 1(B)**). In this period, the industrial soil (peat moss, SUBSTRATE SUB3 50/50, Nord Agri) without any addition, free of heavy metals was used. Once the seedlings had grown to be about twice as tall as the height of the tray (nearly 5 cm), they were carefully removed from tray and transplanted into a bigger pots. A polypropylene plastic pots with a diameter of 10.5 cm and a height of 14 cm were used [Home mesh plastic clear pot] (**Figure 1(C)**). This period of time were previously determined depends on the observation of the researcher in the place of the study, when the seedlings were ready for transplanting (when the roots had grown sufficiently so that the seedlings could be easily pushed out of the trays with the entire root system intact).

Each pot was filled with 2 kg of air-dried soil that had been passed through 1 cm sieve. The soil was brought from an agricultural land. The plants were fertilized with 13-13-13NPK 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 guidelines of Haifa NutriNet™ company [61]. The nutrient content of NPK fertilizer is shown in **Table 2**.

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

To conduct this experiment, we took tap water and divided it into two parts, each group was given only one part. The first group was given water that had been exposed to radiation (irradiated water). The second group was given tap water that had not been exposed to radiation. Irradiation of water was performed using a Wi-Fi router (300 Mbps Wireless N Router TL-WR841N) (**Figure 1(D)**) that was plugged in 24 hours a day and it was not turned off. **Table 3** presented the full specification of the router used in this experiment.

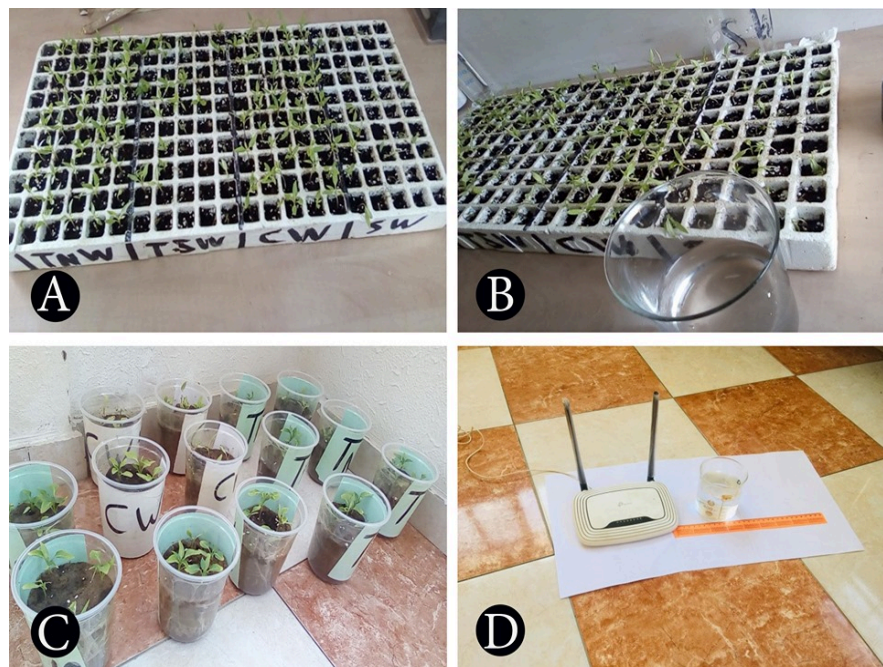
To prepare irradiated water, a glass flask containing water was placed adjacent the router at a distance of 5 cm (**Figure 1(D)**). The exposure time was 1 hour at a maximum power density of 170.22 Watts/m<sup>2</sup>. The power density was calculated using Equation (1).

**Table 1.** The distribution of pepper plants in the tested group.

Type of experimental group	Number of pepper in the experimental group
Water exposed to EMR	50
Water not exposed to EMR (Control)	50
Total	100

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

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



**Figure 1.** The experimental setup: (A) and (B) The seed tray that was used in the present experiment: non-irradiated CW (Control water), TNW (Treated normal water); (C) *Cap-sicum annum* seedlings were grown in 12 m<sup>3</sup> plastic containers to be grown with irradiated TNW and non-irradiated CW; (D) The process of exposing water sample to the electromagnetic radiation. The exposure duration is 1 hour.

$$P_D = \frac{P_{out} G_t x}{4 * \pi * D^2} \quad (1)$$

where

$P_D$  = power densit in watts/m<sup>2</sup>.

$P_{out}$  = output power from, the antenna in wats ( $W$ ).

$G_{tx}$  = gain of the antenna.

$D$  = distance from the antenna in meters ( $m$ ).

The transmission average power in the router is limited to a maximum of 30 dBm (1 watts). The frequency of the signal was range from 2.4 to 2.4835 GHz.

**Table 3.** Specification of the router used in the present experiment.

Item	Specification
Type	Cable router
Connectivity	Wireless
Max wireless transfer rate	300 Mbps
Max wired transfer rate	10/100 Mbps
Interface	4 10/100 Mbps LAN PORTS 1 10/100 Mbps WAN PORT
Max. output power	30 dBm (1 Watt)
Antennas	2 × 5dBi Fixed Omni Directional Antenna (RP-SMA)
External Power Supply	9 VDC/0.6 A
Dimensions (W × D × H)	7.6 × 5.3 × 1.3 in. (192 × 134 × 33 mm)
Wireless Standards	IEEE 802.11 n, IEEE 802.11 g, IEEE 802.11 b
Frequency	2.4 - 2.4835 GHz
Transmit power	CE: <20 dBm FCC: <30 dBm
Signal Rate	11 n: Up to 300 Mbps (dynamic) 11 g: Up to 54 Mbps (dynamic) 11 b: Up to 11 Mbps (dynamic)

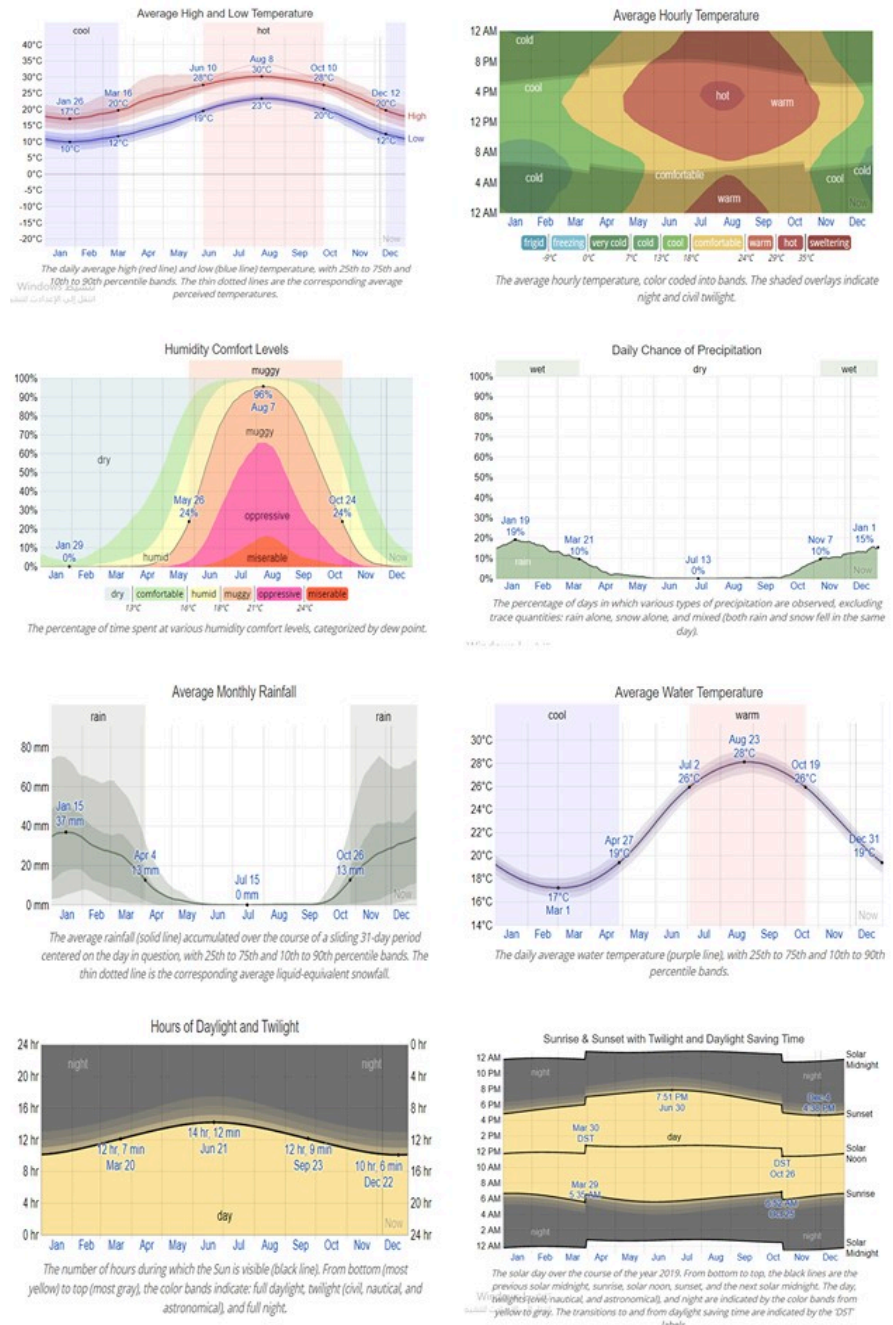
The control water was kept in fixed position in a similar flask in the same area at the same time, but was not irradiated. New exposed water samples were being prepared in the same way once a day during the experiment. In our experiment, both water samples (irradiated and control) were taken from the same container and the same glass flask was used. The seedlings were kept in a controlled environment and watered daily, in an orderly manner for a period of time identical in both groups. During the study, the seedlings in each group were subjected to the same temperature, humidity and atmospheric pressure. **Figure 2** summarizes the weather condition during carried out the present study [62].

## 2.2. Measuring Growth Related Characteristics

At the end of the experimental stage, each plant was harvested, and the following data was collected: leaf number, fruit number, stem length (from soil surface to the apical meristem), health index, and finally shoot fresh and dry weight. The small, medium and large leaves were counted and included in leaf number. A ruler and capillary were used to measure the shoot length and stem thickness of each seedling respectively.

For fresh and dry weight measurements, the whole plants (shoot and root) were separated from the soil and carefully washed off with tap water to remove any impurities. The plants were placed in separate aluminum foil and dried in an oven at 60°C for 3 days and weighed using an analytical balance (AB204-S;





**Figure 2.** The weather condition over the course of the current year.

Mettler Toledo, Columbus, OH). After this, the relative water content (*RWC*) for each plant was calculated using Equation (2). Also, the health index was determined using Equation (3).

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100 \quad (2)$$

$$\text{Health index} = \frac{\text{Stem diameter}}{\text{Stem height}} \times \text{Dry weight} \quad (3)$$

### 2.3. Statistical Analysis

Data were statistically analyzed using SPSS computer program version 22.0 for windows (Statistical Package for Social Sciences Inc, Chicago, Illinois). Graphs were plotted using Microsoft Excel program version 2010. In the case of normal distribution, a two-tailed Student's t-test was applied to determine statistical significance of the differences between experimental and control groups assuming equal variance. On the other hand, in the case of skewed distribution, a nonparametric test (Mann-Whitney Test) was applied to determine the statistical significance of the differences between each two groups. Differences were considered significant at  $p < 0.05$ .

## 3. Results

Possible effects of electromagnetic water treatment were investigated by growth characteristic of pepper plants. The first group of plants was watered with water exposed to electromagnetic radiation. The second group were watered with tap water and used as control. Results are based on 50 plants for each of two groups. During the course of the study, it has been observed that electromagnetic treated water could exert an influence on the growth of pepper plants. Also, stimulation and then inhibition of growth of exposed plants were observed. The results which are presented in **Figures 3-7** show the overall effect of electromagnetic water treatment on the growth of pepper plants.

### 3.1. Effect of Electromagnetic Water Treatment on Plant Length

Comparing the control plants to their exposed counterparts, from the first stage of the experiment, there was no significant difference that could be observed with naked eye. After two weeks of treatment, the treated group showed higher shoot length when compared to control group, and this difference continued to grow until the end of the second month. After two months of treatment, the plants length begins to slightly increase when compared with control group.

Shoot length of the plants in control group was slightly increased at the start of the study and then their length was extremely increased until their length was higher than those in treated group.

The length of pepper plants is significantly affected by the treated water, where the length of shoot was lower in plants grown under the effect of treated water ( $22.43 \pm 7.17$  cm) than those grown without treated water ( $28.11 \pm 8.57$  cm) (**Figure 4(A)**).

### 3.2. Effect of Electromagnetic Water Treatment on Stem Thickness

Stem thickness of pepper plants before and after the current study (**Figure 4(B)**). The results revealed that stem diameter decreased when watering plants with treated water as compared with those in control group. At the end of the study, the stem diameter of control plants ( $1.74 \pm 0.39$  cm) was significantly higher than that of the treated plants ( $1.66 \pm 0.35$  cm).





**Figure 3.** The effect of electromagnetic radiation on the growth of pepper plants at the end of the present study. (A)-(C) Watering with tap water; (D)-(F) Watering with water exposed to electromagnetic radiation. The exposure duration is 1 hour. It is the 200th day of the experiment.

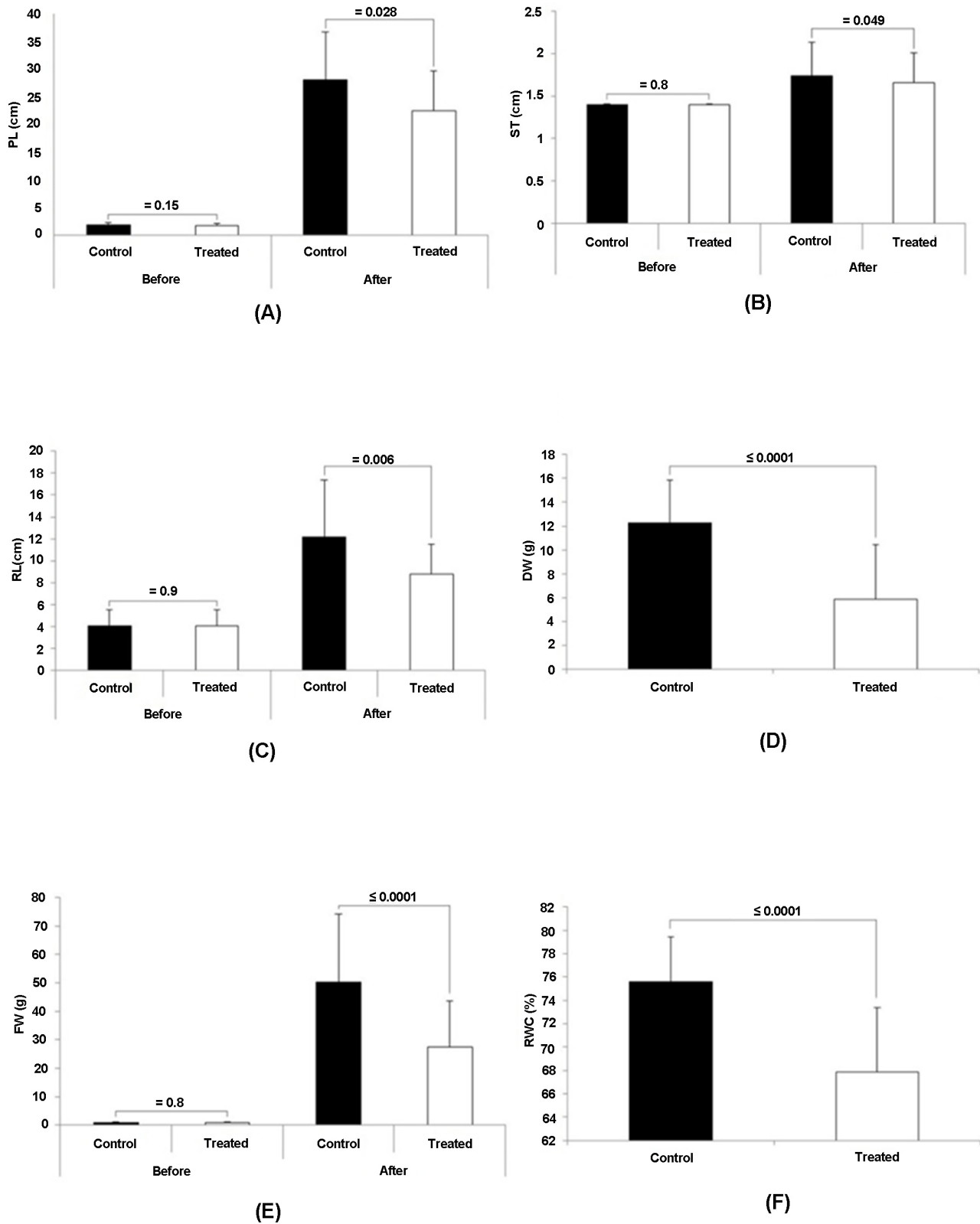
### 3.3. Effect of Electromagnetic Water Treatment on Root Length

The results of the study showed that root length of pepper plants is significantly affected by the treated water, where the root length was lower in plants grown under the effect of treated water than those grown without treated water (control). The average root length of pepper plants in each tested group at the end of experiment (**Figure 4(C)**). When pepper plants watered with water subjected to electromagnetic radiation show decrease in length of root as compared with the control.

### 3.4. Effect of Electromagnetic Water Treatment on FW, DW and RWC

The results which are presented in **Figure 4(D)** and **Figure 4(E)**, showed the impact of electromagnetic treated water on fresh weight (FW) for each tested plant. Electromagnetically treated water significantly decreased the FW and DW of exposed plants when compared with those in control group.

The treated water significantly decreased the RWC of exposed plants when compared with plants in control group (**Figure 4(F)**). The results showed that the RWC of pepper plant were reduced by about 10.21% in treated group compared to those in control group (unexposed plants).



**Figure 4.** The effect of electromagnetic radiation on growth related aspects of pepper plants: (A) Plant length; (B) Stem thickness; (C) Root length; (D) Dry weight; (E) Fresh weight; (F) Relative water content. Before (before the experiment), After (At the end of the present experiment). Data are presented as the mean  $\pm$  SD. The P values were considered statistically significant if P value was  $<0.05$ .

### **3.5. Effect of Electromagnetic Water Treatment on Number of Leaves**

The present study showed that the number of leaves is severely affected in pepper plants exposed to electromagnetic treated water. Comparing the control plants to their exposed counterparts, we observed that there was statistically significant difference in number of leaves between the two groups. The leaves of pepper plants watered with electromagnetic treated water ( $46.36 \pm 23.17$ ) were less in number compared to those which watered with tap water ( $80.50 \pm 36.76$ ) (**Figure 5(A)**).

### **3.6. Effect of Electromagnetic Water Treatment on Health Index**

Electromagnetic treatment of water had a significant effect on plant health index. Treatment water with electromagnetic radiation had an inferior plant health index ( $0.43 \pm 0.056$ ) compared to the control ( $0.76 \pm 0.059$ ) (**Figure 5(C)**).

### **3.7. Effect of Electromagnetic Water Treatment on Number of Plant Sub Branches**

Watering plants with electromagnetic treated water had a slight effect on the number of sub branches per plant at growth stage. The highest mean number of sub branch (2.75 branch/plant) obtained from control group and the least mean number of sub branch (2.58 branch/plant) obtained from treated group. Such, the difference observed between the two pepper groups was not significant.

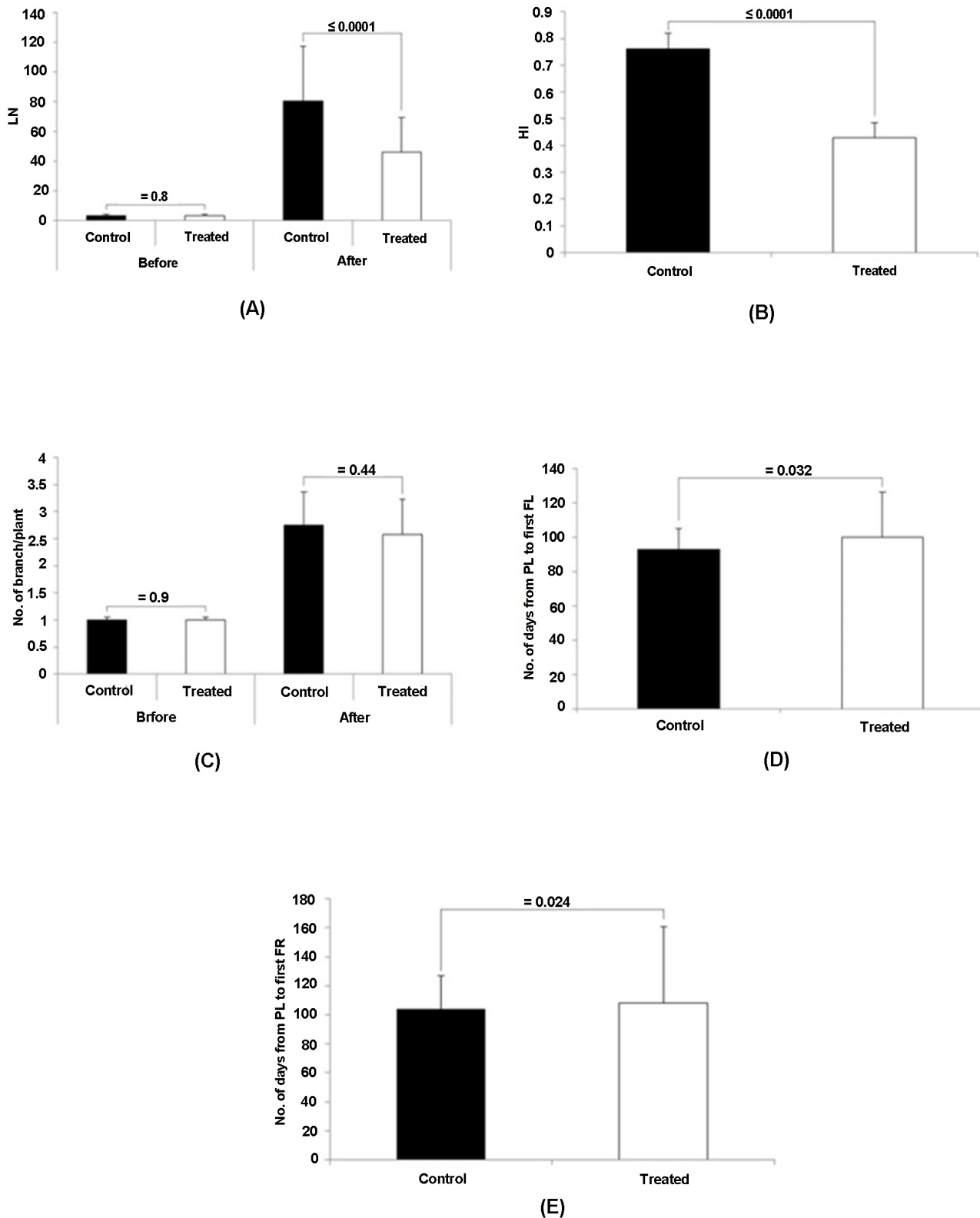
### **3.8. Effect of Electromagnetic Water Treatment on the Flowering and Fruiting Time**

Appearance of the first flower of pepper plants in control group is observed at a relatively early growing stage when compared to treated group. Number of days from the planting date to the first flowering is affected by irrigation water during that period. In the treated group, the period time from the planting to the first flowering is (100 days) significantly higher than those in the control group (93 days). In other words, the first flowering time for plants in treated group was remarkably decelerated when compared to other plants in control group. In addition, in the control group, the number of days required for the first fruiting (104 days) was shorter than the others in the treated group (108 days).

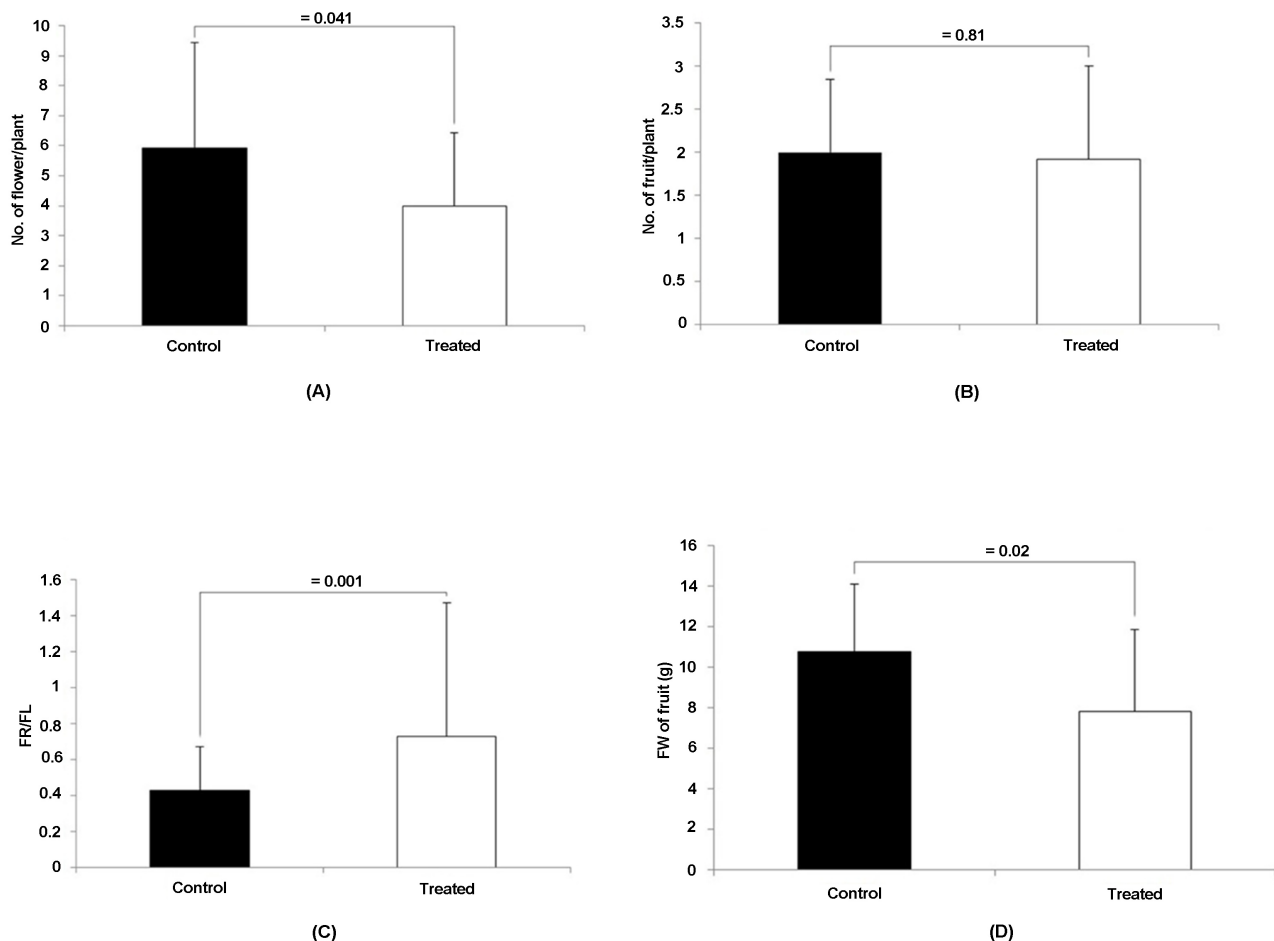
### **3.9. Effect of Electromagnetic Water Treatment on the Number of Flowers and Fruits/Plant**

The results showed that pepper fruits yield was affected by electromagnetic treated water. In treated group, the number of fruits decreased as compared to the control group. Analysis of these results revealed an average number of fruits of pepper in the treated group compared the control. Such difference observed between the two pepper groups was not significant (**Figure 6(B)**).

Regarding flower number, the results indicated that electromagnetic treated water decreased number of fruits ( $4.00 \pm 2.44$ ) compared to the control ( $5.92 \pm 3.53$ ) (**Figure 6(A)**).



**Figure 5.** The effect of electromagnetic radiation on growth related aspects of pepper plants: (A) Leaves number; (B) Health index; (C) No. of branch/ plant; (D) No. of days from planting to first flowering; (E) No. of days from planting to first fruiting. Before (before the experiment), After (At the end of the present experiment). Data are presented as the mean  $\pm$  SD. The P values were considered statistically significant if P value was  $<0.05$ .



**Figure 6.** The effect of electromagnetic radiation on growth related aspects of pepper plants: (A) No. of flower/plant; (B) No. of fruit/plant; (C) Fruiting to flowering ratio; (D) Fresh weight of fruit. Before (before the experiment), After (At the end of the present experiment). Data are presented as the mean  $\pm$  SD. The P values were considered statistically significant if P value was  $<0.05$ .

### 3.10. Effect of Electromagnetic Water Treatment on Fruiting-Flowering Ratios

The results reveal significant differences between two groups in terms fruiting-flowering ratios. Improved fruiting-flowering ratios ( $0.74 \pm 0.73$ ) were reported in pepper plants watered with treated water, which resulted in increased number of fruits being produced (Figure 6(C)).

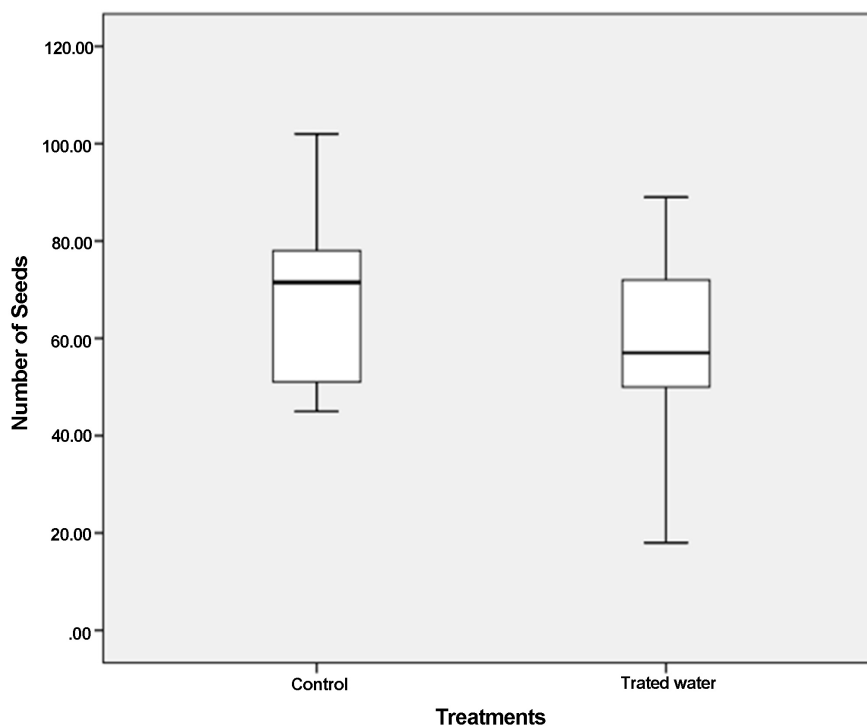
### 3.11. Effect of Electromagnetic Water Treatment on Fruit FW

The results showed that the treated water had a significant effect on the fresh weight of produced fruit (pepper horn). The average fruit weight in treated group was 7.79 g and 10.78 g in control group (Figure 6(D)). Between the two groups, the highest weight of fruit (20.92 g) was obtained from treated group.

### 3.12. Effect of Electromagnetic Water Treatment on the Number of Seeds

At the end of the study, each pepper fruit was opened to count the number of

seeds inside it. The results showed that the number of seeds per fruit was affected by treated water. The least number of seeds (18 seed/fruit) was obtained from treated group and the highest number (102 seed/fruit) obtained from control group. The mean number of seeds/fruit ( $59.00 \pm 16.98$  seed/fruit) in treated group was lower than the plants in control group ( $67.44 \pm 18.04$  seed/fruit) but the difference was not statistically significant (**Figure 7**).



**Figure 7.** The effect of electromagnetic treated water on the number of seeds/fruit. The P value was calculated by Mann-Whitney test and considered statistically significant if P value was  $<0.05$ .

#### 4. Discussion

Although other studies of the effect of electromagnetic radiation on the growth of plants have been published, this study is the first to quantify the effect of water that has been exposed to electromagnetic radiation emitting from home router. Special focus of the previous studies was paid within the following topics: 1) The effect of electromagnetic radiation on the growth of plants after exposure of their seeds to radiation. 2) The effect of magnetic water treatment on the growth and development of exposed plants. 3) The effect of microwave water treatment on seeds or plants. Despite these studies, there is a severe scarceness in the studies that investigate the effect of electromagnetic water treatment (Electromagnetic Radio Frequency Radiation emitting from router) on the growth of plants. Therefore, in this section, we focused on interpreting the results on variables related to previous studies that dealt with the effect of electromagnetic water treatment on the growth of plants.



The current study was conducted to explore the effect of water exposed to electromagnetic radiation emitting from router on the growth and development of pepper plants. Two samples of water, one of which was exposed to router electromagnetic radiation and the second one which was not exposed, were used for watering pepper plants. The level of development and growth of the pepper shoots were significantly better for the plants watering with tap water when compared to treated group. The study found out that the treated water causes changes in the morphology of pepper plants. Watering plants with electromagnetic treated water may significantly alter growth related aspects such as shoot and root length, stem diameter, dry and fresh weight, number of leaves and flowers.

Pepper plants grown under the effect of treated water recorded the lowest in both shoot length and stem thickness as compared to those of the control. The study revealed that pepper plants watered with treated water grew slower and had shoot length and stem thickness significantly smaller than the peppers not watered with treated water. These findings seem to coincide with that stated by Yamabhai *et al.* [63]. They studied the effects of water treated with an electromagnetic field (EMF) on the growth of soybean. Purified de-ionised water was treated by 1) boiling, 2) exposure to microwave radiation, and 3) low frequency electromagnetic oscillation molecular resonance effect technology (MRET). They found that the height of soybean plant watered with all three physically treated waters and the tap water were significantly shorter than those watered with non-treated purified water.

In addition, in the studies of Mikkelson [64], he showed that plants watered with microwave treated (a form of electromagnetic radiation) water fairly thriving. He concluded that microwaved water was harmful to plants. Also in the study of Saleem *et al.* [65], they mentioned that the treatment of plants with microwaved water resulted in significant inhibition of plant growth as compared with untreated control plants. In treated plants, a significant difference were observed in response to microwave radiations with respect to growth shoots. Similar results are reported by many workers [66] [67] with plants under stress.

Also, similar results were documented in the study of Alattar *et al.* [35], they carried out an experiment to study the impact of microwaved water on the growth of corn and pepper seedlings. They revealed that corn seedlings when watered with tap water grew faster and had shoot length significantly bigger than the corns which were watered with microwaved water.

On the other hand, these results differ from those obtained by Shalatonin [68], who carried out an experiment to study the biophysical properties of liquid water exposed to EM Radio Frequency radiation and its effect on the growth of wheat grains. In this study wheat grains were watered with water exposed to mobile phone electromagnetic radiation for 8 days. The exposure duration was 1.5 hour. He found out that wheat grains can alter significantly their germination and development when watering with water, exposed to mobile phone electromagnetic radiation. The study concluded that the level of development and

quantity of the appeared shoots were significantly better for the grains watered with the exposed water.

Also, in the study of Ozdemir *et al.* [69], they studied the effects of electromagnetic treatment of hard-alkaline well water on water quality and flower seed germination, rooting of cuttings and plant growth, compared with natural well water, rain water, distilled water and tap water. According to the germination test, water quality has not significantly affected shoots length of African violet and Coleus. In general, reductions in shoot elongation and thickness in response to stress factors (such as lighting, temperature, heavy metals, radiations, water deficits and quality) lead to reductions in tree size and length [70] [71] [72]. The stem thickness is considered one of the most indicator of water status of the plants and also the first physiological indicators of variations in tree water functioning compared with other parameters [73] [74], so stem thickness fluctuations in the current study may refer to the variation of water status of pepper plants after watering with treated water.

In the present study, electromagnetic treatment water significantly reduced the FW of pepper plants. Such a reduction in FW was documented by similar findings where plants were exposed to cell phone radiations in a direct method [75]. They reported that the mobile phone radiations significantly decreased the fresh weight of Pea (*Pisum sativum*) and Fenugreek (*Trigonella foenum-graecum*) after exposure of their seeds to mobile phone radiations. Furthermore, results of the present study were found parallel to those of Majd *et al.* [33] for *Satureja bachtiarica* L. They observed a significant decrease in fresh weight of treatment samples after exposing their seeds to low frequency EMR in comparison to control.

The results also revealed that electromagnetic treatment of water significantly decreased the dry weight of pepper plants. Similar results were also documented in the study of Majed *et al.* [33]. They found a significant decrease in dry weight after exposure of the seeds of *Satureja bachtiarica* L. to electromagnetic radiation at low frequency. Different results were documented in the study of Yamabhai *et al.* [63]. They found out that the dry weight of soybean plants watered with microwaved water were significantly higher than that of other types of water. There were no significant difference among MRET-treated water, stovetop boiled water and tap water.

In the present study, electromagnetic treatment water significantly reduced the root length of pepper plants. This result differs from those obtained by Yamabhai *et al.* [63]. They found that root length of soybean plants watered with both types of EMF, *i.e.*, microwave and MRET, were approximately three times longer than that of boiled, non-treated, and tap water. Therefore, it is likely that the treated water deactivated by an electromagnetic radiation could inhibit specific biological processes including plant signalling pathways that lead to inhibition growth and development of pepper root.

The electromagnetic water treatment seemed to decrease the RWC. The results showed that the RWC were better (highest) in pepper plants, that were wa-

tered with the normal tap water in comparison with those watered with exposed water. The same difference was observed in the study of Alattar *et al.* [34], when they directly exposed of corn, eggplant and basil plants to electromagnetic radiation. Also in the study of Sharma and Parihar [75], they studied the effect of mobile phone radiation on nodule formation in the leguminous plants. The radiation emitted from mobile phones show effect on the RWC of plants after exposure their seeds to this radiation. They revealed that the RWC decreases with increase in radiation exposure in exposed seeds.

The electromagnetic water treatment decreased the number of leaves per plant. These results are in accordance with those obtained by Alattar *et al.* [34], the results revealed that the leaves of basil exposed to Wi-Fi radiation were more in number compared to those that were not exposed. Also, Zuk-Golaszewska *et al.* [76], reported that *Avena fatua* and *Setaria viridis* plants which were directly treated by UV-B radiation produced the lowest significant values for number of leaves per plant. On the other hand, Ji *et al.* [77] conducted an experiment with tomato plants to investigate the effect of Far-Red radiation on the growth of tomato plants. They revealed that Far-Red radiation increased significantly the leaf number per plant.

The application of treated water had a significant effect on the health index of treated plants. The highest value of health index was noted in the plants watered with non exposed water. In our study electromagnetic treated water induced lower health index for pepper plants, indicating that treated water with electromagnetic radiation were not suitable for their growth [78]. The decline in pepper health watered with electromagnetic treated water was interpreted to a unfavorable effect coupled with water stress. As a result, plants have developed sophisticated mechanism to adapt their structure and physiology to the prevailing environmental conditions including treatment water with electromagnetic radiation.

Watering plants with electromagnetic treated water had little effect on the number of sub branches per plant. After analysis of the number of sub branches, the control plants and treated counterparts showed almost identical values. These findings seem to coincide with that stated by Kakani *et al.* [79], the conducted an experiment to study the effect of UV-B radiation on vegetative and reproductive morphology of cotton in sunlit, controlled environment chambers. They found no significant differences in branch number per plant were detected between UV-B treatments (0, 8 and 16 KJ). In the study of Amir *et al.* [80] they showed that the number of nodes and braches decreased in plants obtained from the seeds exposed to Gamma rays, but in the control the numbers of nodes were maximum.

The first flowering and fruiting of pepper plants was considerably affected by electromagnetic treated water. Watering pepper plants with electromagnetic treated water increased duration required to first flowering and then delayed fruiting. In the treated group, the period time from the planting to the first flowering is significantly higher than those in the control group. Similar results

were recorded with direct exposure of plants to radiation. For example, Wang *et al.* [81] found out that exposed to elevated UV-B doses delayed its onset of flowering by 1 day and shortened its flowering time by 5 days. In *Brassicainigra* and *Brassicarapa* grown in greenhouses, enhanced UV-B also delayed the start of flowering and decreased its duration compared to ambient UV-B [82]. Other studies, however, have reported advances in the onset of flowering under enhanced UV-B [83] [84], or have found no effect, e.g. in *Triticum aestivum* [85], *Lycopersicon esculentum* [86], or in the Mediterranean annual *Malcolmia maritima* [87].

From these results, it was concluded that the environmental condition including exposure to radiation, in direct or indirect method (water stress), affect promotion of floral bud differentiation, floral organ development, maturity of fruits and at the end affecting the growth, development, production and quality of fruit crops [88] [89] [90].

Further, in the study of Saleem *et al.* [65], they found that flowering in the microwaved water treated plants was also delayed. Plants under stress caused delay in flowering as flower formation is related to environmental conditions [91] [92]. Flower development involves a complex interaction of molecular, biochemical, and structural changes. However, little information is available on the physiology of early flower development, on the molecular aspects of fruit development in general, and on how flower development is coordinated with hormonal action. Plants under stress caused delay in flowering as flower formation as it is related to different environmental conditions [91]. Stress caused inhibition in flowering can be attributed to initiation of disruption in biological processes [67].

The number of fruits and flowers per plant was considerably affected under electromagnetic treated water. Electromagnetic water treatment influenced the average number of fruits and flowers for each plant by which treated group were more in number compared to control group. The results reveal significant differences between two groups in terms fruiting-flowering ratios. Improved fruiting-flowering ratios were reported in pepper plants watered with treated water when compared to control plants. Watering plants with electromagnetic treated water reduced flower number, fruit set and at the end decrease the production of fruits per plant. Similar results were mentioned when directly exposed to radiation. For example, in the study of Amir *et al.* [80] they revealed that number of fruits/plant in treated group (treated group: plants obtained from the seeds treated with gamma rays) was significantly decreased as compared to control.

Also Barbir *et al.* [93], UV-B radiation affect flower size and number. Also, in a detailed study by Van de Staaj *et al.* [94], it was shown that growth under UV-B doses ( $6 \text{ KJ}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ ) led to decrease in flower number. Different results were reported in the study of Petropoulou *et al.* [87], they did not find a significant effect of cover-ambient UV-B levels on the number of flowers of Mediterranean species *Mertensia maritima*. Over ambient-UV-B radiation markedly increased flowering of *Vaccinium myrtillus*, while it did not affect the number of

flower of *Vaccinium uliginosum*. In the study of Wang *et al.* [81] they found that exposure to elevated UV-B doses did not affect total flower and seeds number, seeds/fruit or fruit to flower ratio. Direct or indirect exposure to radiation cause plant stress and effect on vegetative tissue as well as plant morphology, including the structure and number of florescence and flowers [95] [96]. Recently, Kalaitzoglou *et al.* [97] reported that additional Far-Red radiation increased fruit number per plant of tomato plants in the vegetative growth stage.

The results showed that the treated water had a significant effect on the fresh weight of produced fruit (pepper horn). In control group, the FW of produced fruit was higher than those in treated group. Similar results were reported by Kumar *et al.* [98], they treated the papaya seeds of cv. Pusa Dwarf with different doses of gamma rays viz, 05, 10, 15 and 20 krad to observe the influence of treatment on fruit quality of papaya. The results revealed that the fruits obtained from the seeds treated with gamma rays had significantly minimum fresh weight as compared to control. The decrease of FW of fruit in treated plants may be due to decrease in seeds number, size and weight. On the other hand, increasing the weight of fruit in the control group because of fruits having enough time to mature and ripen due to did not delayed flowering and fruiting time and at the end resulted in increasing fruit size and weight [99].

The results showed that the number of seeds per fruit was affected by treated water. At the end of the current experiment, we found that the mean number of seeds/fruit in treated group was lower than the plants in control group. Similar results were reported in the study of Amir *et al.* [80], when they carried out an experiment to evaluate the effect of different doses of gamma rays on various morphological aspects of *Abelmoschuses culentus*. The results showed that number of seeds per fruit was maximum at control, fresh and dry weights of seeds were increased in control as compared to other doses. We hypothesize that a low seed yield per plant is due to small weight or quantity of fruits in treated plants.

The authors have interpreted the primary mechanisms of action of electromagnetic radiation on water and the mechanisms of biological activity of electromagnetic treated water on biological processes in plants based on the previous studies and the results of this study. The treatment of water by electromagnetic radiation caused changes in the chemical, physical, physicochemical and biophysical properties of water which lead to specific functions. As the water plays a major role in determining the response of plants to radiation and considered the primary medium of biochemical reactions, so it is supposed that the exposure to electromagnetic radiation may alter cellular metabolism using cell's water as a primary receptor of radiation. The electromagnetic radiation influence the activation of ions and polarization of water in exposed cells. In addition, they affect the permeability of cell membranes and activity of ions and related functions resulting in the upsetting the balance of ion concentration in the cell and changing the intracellular pH. Thus they affect mRNA quality, enzyme activities, gene expression, protein biosynthesis. As a result, phenotypic, genotypic, growth

characteristics and various functions of exposed plants will be changed such as germination of seeds, root and shoot growth, yield parameters, productivity, reproduction, chlorophyll contents, growth of the meristem cells.

## 5. Conclusion

Possible effects of electromagnetic water treatment were investigated by growth characteristic of pepper plants. The overall results showed changes of growth characters of plant watered with electromagnetic water. Pepper plants watered with electromagnetic treated water exhibited marked decreases in shoot and root length, stem thickness, health index, fresh and dry weight, relative water content, number of flowers and fruits/plant as well as number of seeds/fruit. In addition, the leaves of pepper plants watered with electromagnetic treated water were less in number compared to those which watered with tap water. The results revealed that the first flowering time for plants in treated group was remarkably decelerated when compared to other plants in control group. Also, the number of days required for the first fruiting was shorter than the others in the treated group. Improved fruiting-flowering ratios were reported in pepper plants watered with treated water.

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## Conflicts of Interest

We declare no conflict of interest.

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