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Effect of Magnetized Water on Imbibition, Germination, Macronutrient Content (N, P, K) and Yield of Zucchini (*Cucurbita pepo* L.)

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A B S T R A C T

Water scarcity and the deterioration of its quality represent the main obstacles to agricultural development in Libya, in addition to other challenges. This work was undertaken to investigate the effect of irrigation with magnetized water on the growth and productivity of zucchini plants (*Cucurbita pepo* L.). Three experiments were carried out: a laboratory experiment with three replicates per treatment, a plastic pot experiment with four replicates per treatment, and a field experiment with twelve replicates per treatment. Plants were watered with either magnetized or non-magnetized water, using a Completely Randomized Design (CRD). The research focused on seed imbibition and germination percentage, the plant's content of macronutrients (N, P, K), and total production. The outcomes found that irrigation with magnetized water had a significant effect on the mean ultimate yield of the harvest, 2.8692 kg compared to 1.279 kg for the non-magnetized. Regarding the average seed imbibition and germination percentage, as well as macronutrient content, the outcomes showed differences between the two treatments in favor of the magnetized treatment; however, these variances were not statistically significant. Based on these findings, it appears that this method has a promising role in improving certain plant growth traits, making it worthy of further investigation. Moreover, it may represent a new approach toward the optimal use of saline irrigation water in agricultural production.

1. Introduction

Libya covers an area of almost 1.8 million square kilometers and is located in North Africa, providing it with a temperate climate suitable for growing a variety of crops. However, low rainfall, scarce and poor-quality water resources, with increased soil salinity have led to a decline in the productivity of irrigated lands. (Algharíani et.al, 2020, Ehtaiwesh. 2022). Different strategies could be used to overcome water shortage and water salinity problems. Water treatment and desalination plants can be built to address water scarcity; however, these processes are expensive, time-consuming, energy-intensive, and environmentally

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detrimental (Hashim, 2005). Growing salt-tolerant crops is another strategy that could be used to overcome salinity and heat stress challenges (Ehtaiwesh, 2016, Ehtaiwesh, 2019). However, their application is limited to a small number of plant species, limiting the full use of the country's agricultural land (Al-Zoubi et.al, 2014). Along with above mentioned strategies, magnetized water (MW) has appeared as a hopeful, affordable, and labor-efficient strategy. it has significant effects on crop production, in addition to improving soil and water quality. Through passing water using magnetic pipes, its physical properties alternated and improving its effectiveness for agricultural practice (Al-Mosuli, 2019).

Seeds of different plants imbibe larger amounts of treated water in comparison to untreated water. However, there is a variation in the absorption rate of magnetized water among different plant species, which indicates that seed responses vary depending on their type. Consequently, the initial stage of water imbibition influences the germination percentage and germination rate (Posiadlo and Skorupa, 2017; Hassan and Ehtaiwesh, 2020). Also, Mahmood and Usman, (2014) reported in an experiment comparing magnetized and non-magnetized water that maize seeds showed an increase in germination percentage from 5.50% to 8.92%, while both the germination rate and speed increased from 10.06% to 12.48% in favor of magnetized water. They also found that the time required for germination was reduced by 17.90% when using magnetic treated wastewater comparison to non-magnetic treated water. Ahmed et al., (2013) found that sweet pepper seeds treated with magnetized water germinated one day earlier than that un-magnetic treated water seeds. Moreover, the germination ratio improved by 33.7–44.9% in the magnetized water likened to the un-treated plants. Numerous studies have indicated that using magnetized water has noteworthy effects on crop production, in addition to mitigating poor soil and water quality (Saju and Pillai, 2024). In addition, it was found that using magnetized water to irrigate plants has a noticeable effect on stimulating plant growth and vitality. Nour et al., (2016), reported that the germination period of green pea plants decreased from 3.72 to 2.92 days, and the germination capacity increased from 75% to 95% under magnetized water treatment related to un-treated water. The results of a research led by Liu et al., (2019) showed that the overall nitrogen content in the leaves and roots of American willow plants increased significantly in plants treated with magnetic treated water associated to those treated with non-magnetic treated water. Magnetic treated water improves the accessibility of minerals to plants, enhancing the use of organic and chemical fertilizers and increasing the solubility of major nutrients in the soil (nitrogen, potassium, and phosphorus). In a study by Faridvand et al., (2021) on sweet cumin plants using magnetized water with the addition of chemical and organic fertilizers, it was shown that the seeds nutrient content increased, reaching 39 mg/g of nitrogen, 28.5 mg/g of potassium, and 8.7 mg/g of phosphorus, leading to higher growth rates and greater productivity. The helpful effect of magnetic treated water on seed imbibition, germination, and minerals absorption appears to ultimately reflect on plant productivity. Irrigation with magnetic treated water also enhances the activity of antioxidants and enzymes, boosts plant metabolism, and builds plant pigments to withstand adverse environmental conditions (Saju and Pillai, 2024). In a study conducted on faba bean by Elsayed and Elsayed, (2014) reported that the seed weight of plants watered with ordinary water was 16.21g, whereas those moistened with magnetized water reached 22.11g. Moreover, the final seed production of the plants moistened with ordinary water was 10.82g, likened to 17.65g for those watered with magnetized water, with the difference being highly significant. The difference in the average total yield of watermelon under the magnetized water irrigation system and the non-magnetized water irrigation system was 7562 kg/h in favor of magnetized water, according to a study conducted by Ali et al., (2019a). In addition, Qazah et al., (2018) found in a study conducted on potato plants irrigated with water exposed to magnetic induction levels of 0.03, 0.06, and 0.09 Tesla that the changes in plant yield indicators showed increases of 4.34%, 15.84%, and 27.24%, respectively. In additional work directed by Ali et al., (2019b) on pumpkin (*Cucurbita* spp.), it was found that treatment with magnetized water improved fruit yield after 65 days of cultivation, with a total productivity increase of 18% compared to the control group. Furthermore, productivity increased by 45% when these groups were treated with magnetized water in combination with bio-chemical fertilizers compared to the non-magnetized water treatment. The results of the study conducted by Abdul Karim (2018) to measure the productivity of eggplant, broad bean and tomato plants also confirmed that treating these plants with magnetized water increased fruit yield by 1.97%, 3.01%, and 2.45% for the three plants, respectively, compared to the non-magnetized treatment.

Zucchini (*Cucurbita pepo* L.) is an annual vegetables crop belonging to the family Cucurbitaceae (Hassan, 1991). It is one of the main vegetables produced and consumed in Libya. However, salinity stress affects the production of zucchini plant, according to the Food and Agriculture Organization (FAO), the salinity tolerance threshold of zucchini is estimated at (4.9dS/m) (Francois, 1985). In this study, the magnetized water technique was applied to zucchini plants, which are considered one of the most imperative economic and commonly used crops in Libya, highlighting its effectiveness on the growth of local zucchini (*C. pepo* L.) and assessing the impact of magnetized water irrigation on the growth of this plant. Irrigation water poses a significant encounter to agriculture in Libya. However, is it possible to utilize saline groundwater from wells and apply the technique of magnetizing irrigation water to make it suitable for agricultural use? Therefore, the study objects is to explore the outcome of using magnetized water on zucchini plants compared to non-magnetized water, by assessing its impact on some traits.

Materials and methods:

The seeds used in the aforementioned experiment consisted of hybrid seeds of *Cucurbita pepo* L., belonging to the Cucurbitaceae family. The seeds were produced by the Sakata company and purchased from an agricultural store in Zawiya City.

1. 2.1. Laboratory experiments

1- Imbibition percentage:

This experiment was carried out in the laboratory according to a Completely Randomized Design (CRD), with three replicates, using plastic tubes with a capacity of 100 ml, as shown in Figure (1). The experimental procedure was as following:-

Two grams of seeds (equivalent to eight seeds) were weighed and placed in the tubes. Then, 30 ml of magnetic treated and non-magnetic treated water was added to the tubes according to the treatment. The seeds were allowed to absorb the added water and were then weighed after soaking for two hours. Before weighing, the seeds were drained of water, dried with paper towels, and placed on a sensitive balance to record their weight. The seeds were weighed again after 6, 12, 18, and 24 hours, following the same steps as above. The experiment was completed after 48 hours. The observations were then recorded to calculate the absorption rate according to the following equation of (Ehtaiwesh et.al, 2019):

$$\text{Imbibition (\%)} = \frac{Weight\ after\ soaking\ period - Initial\ weight}{Initial\ weight} \times 100$$

Figure1: Measurement of imbibition percentage.

2- Germination percentage and rate:

This experiment was conducted in the laboratory using a completely randomized design with three replicates. The experiment investigated the outcome of using magnetized water on the percentage and rate of seeds germination rate, compared to treatment with non-magnetized water. High-quality seeds were carefully chosen and surface sterilized with a 5% sodium hypochlorite mix for 3–5 minutes. The seeds were then thoroughly washed with water and allowed to air dry before use in the experiment (Ehtaiwesh and Abuiflayjah, 2020). A total of 60 seeds were used, with 10 seeds per treatment. The seeds were sown in Petri dishes lined with filter paper, with 5 ml of water added to each dish depending on the treatment. The dishes were placed in the dark at room temperature for 10 days. Throughout this time, the dishes were observed, water was added as needed, and germination data were recorded. The number of germinated seeds was taken daily to calculate both the germination percentage and the germination rate. The time required for germination was calculated according to the following equations by Ehtaiwesh et al., (2019):

$$\text{Germination Percentage} = \frac{Number\ of\ germinated\ seeds}{Total\ Number\ of\ seeds} \times 100$$

$$Germination\ Rate = \frac{number\ of\ seeds\ germinated\ on\ the\ first\ day}{Time} + \frac{number\ of\ seeds\ germinated\ on\ the\ second\ day}{Time} + \cdots etc$$

The time was measured in days.

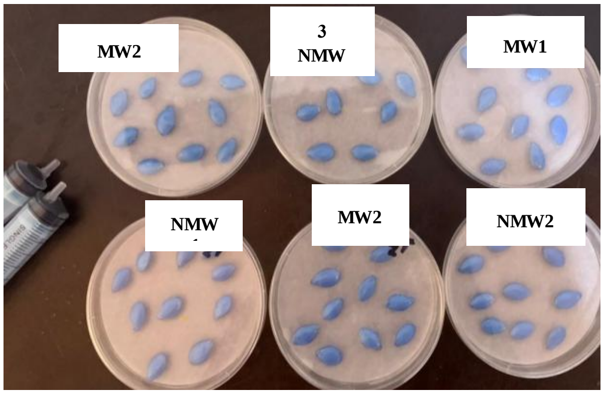

Figure 2: Randomized design of the germinated experiment where: (MW) magnetized water, (NMW) non-magnetized water.

3- **Plastic pots experiment:**

This trial was led according to a completely randomized design (CRD) using eight plastic pots with four replicates. Five seeds were sown per pot in 3 kg of soil mixed with 1% organic matter (30 g/pot). A layer of gravel was placed at the bottom of each pot to ensure good drainage. Pots were watered according to the treatments with 0.5 liters of water per pot. After germination, seedlings were reduced to one plant per pot to ensure the growth of complete roots. As shown in figure 1, the trial lasted for approximately three weeks and was terminated before the anthesis stage.

Fig. 3: The experiment conducted in plastic pots with four replicates per treatments.

4-Determination of macronutrient content in the plant (Nitrogen, Potassium, Phosphorus – NPK):

The plant samples were analyzed at Delta Technical Services Laboratory in Tripoli to determine the macronutrient (NPK) content in the leaves of zucchini plants under both treatments (magnetized and non-magnetized water). Specific instruments dedicated to each nutrient were used, and the following parameters were measured:

1- Nitrogen content in the plant

The nitrogen content was estimated using the Kjeldahl apparatus (Plaza et.al, 2013).

2- Potassium content in the plant

The potassium content was determined using a flame photometer (Thiex, 2016).

3- Phosphorus content in the plant

The phosphorus content was determined using a spectrophotometer (Thiex, 2016).

5- Field experiment and its design:

The field trial was led on a farm located in Zawiya City. Prior to the experiment, soil and water samples were sent to a laboratory in Tripoli to determine their chemical properties, as presented in Tables (1 and 2). The treatments were randomly distributed, and a Delta Water magnetization device with a magnetic strength of 14,800 Gauss (equivalent to 1.48 Tesla) was installed and connected to the drip irrigation system, which was designed accordingly to a Completely Randomized Design (CRD) of the experimental units. The trial was initiated on June 10, 2023, using water from a well with a salinity level of 938 mg/L at a depth of 100m in the Harsha Bin Youssef area, located 10 km west of Zawiya city. The experiment consisted of 24 experimental units, including 12 units irrigated with magnetized water and 12 units watered with non-magnetized water. The field was prepared through fertilization and irrigation according to each treatment. Organic matter was applied at a rate of 0.5 kg per unit and thoroughly mixed with the soil. After five days, specifically on June 15, 2023, zucchini seeds were sown. Irrigation was applied for 15 minutes per day, corresponding to 1.5 L daily per plant, based on an emitter flow rate of 6 L/h. The discharged water volume during 15 minutes was 1.5 L, which was then divided among four plants.

Both magnetized and non-magnetized water originated from the same well: magnetized water was passed through the Delta Water magnetization device, while non-magnetized water was supplied from a bypass before the device. Additionally, NPK fertilizer

(20:20:20) was applied in solid form by dissolving it in irrigation water at a concentration of 1 g/L on July 4, 2023. Experimental conditions (light, irrigation volume, irrigation frequency, and fertilization) were kept homogeneous across all units, ensuring that water treatment was the only independent variable affecting the measured dependent traits.

Table 1. The physical and chemical characteristics of the analyzed well-water sample

Analysis	Result
pH	7.54
Electrical Conductivity (EC)	1563 µS/cm
Total Dissolved Solids (TDS)	983 mg/L
Total Hardness (T.H.) as $CaCO_3$	494 mg/L
Calcium Hardness as $CaCO_3$	130 mg/L
Color	45 pt
Turbidity	16 NTU
Taste	Acceptable
Odor	Acceptable
Calcium (Ca^{2+})	68 mg/L
Magnesium (Mg^{2+})	77 mg/L
Sodium (Na^{+})	130 mg/L
Potassium (K^{+})	10 mg/L
Carbonates (CO_3^{2-})	0.0 mg/L
Bicarbonates (HCO_3^{-})	158 mg/L
Chloride (Cl^{-})	296 mg/L
Sulfate (SO_4^{2-})	191 mg/L
Nitrate (NO_3^{-})	20 mg/L

Table 2. Some chemical and physical properties of the soil in the study area

Analysis	Result
pH	8.02
Electrical Conductivity (EC)	2710 µS/cm
Sodium (Na)	368 mg/kg
Potassium (K)	50.76 mg/kg
Calcium (Ca)	580.76 mg/kg
Magnesium (Mg)	9.95 mg/kg
Phosphorus (P)	149 mg/kg
Nitrogen (N)	300 mg/kg
Organic Matter (OM)	0.17 mg/kg
Calcium Carbonate ($CaCO_3$)	11.5 Wt.%

Statistical analysis of experimental data:

The data were statistically analyzed using the SPSS software (version 26). A T-test was performed to determine the significant differences between the means of the two treatments (magnetized and non-magnetized) at a 5% significance level ($p \leq 0.05$).

3. Results

The probability value (P-value) for imbibition percentage, germination percentage germination rate, (N, P, K) content and average yield is shown in table (3).

Table 3: The probability value for the effect of magnetized water (MW) treatment on the studied traits.

Traits	(P-value)
Imbibitionpercentage	(0.42)
Germination percentage	(0.29)
Germination rate (seeds/day)	(0.44)
Nitrogen (mg/kg dry weight)	(0.56)
Potassium (mg/kg dry weigh)	(0.76)
Phosphorus (mg/kg dry weigh)	(0.55)
Average yield (kg)	(< 0.001)

1- Effect of magnetized water on imbibition

The results presented in Figure (4) indicate that there were differences between the two treatments (magnetized and non-magnetized water). The difference in the mean values was in favor of the magnetized treatment, and these differences became more pronounced after 36 hours of imbibition, where the mean percentage in the magnetized treatment was 77.5% compared to 65% in the non-magnetized treatment. However, these differences were not statistically significant at α=0.05, as shown in Table (3).

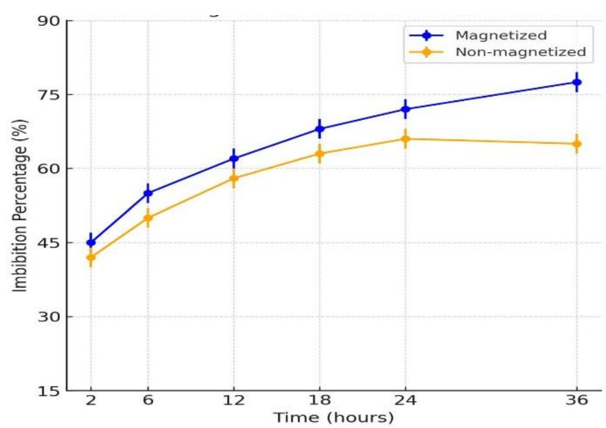

Figure 4: Effect of magnetized water on seeds imbibition over time (2,6,12,18,24 and 36 hours) with three replicates per treatment.

2- Effect of magnetized water on seed germination

The results obtained from our experiment to determine the germination percentage and rate showed differences between the two treatments (magnetized and non-magnetized water). The difference in the mean germination percentage between the two treatments was 10% in favor of the magnetized treatment, as shown in Figure (5). Meanwhile, the difference in germination rate was 2.07 germinated seeds/day)in the magnetized treatment compared to 1.85 germinated seeds/day in the non-magnetized treatment, as presented in Figure (6). However, these differences were not statistically significant at α=0.05, as indicated in Table (3).

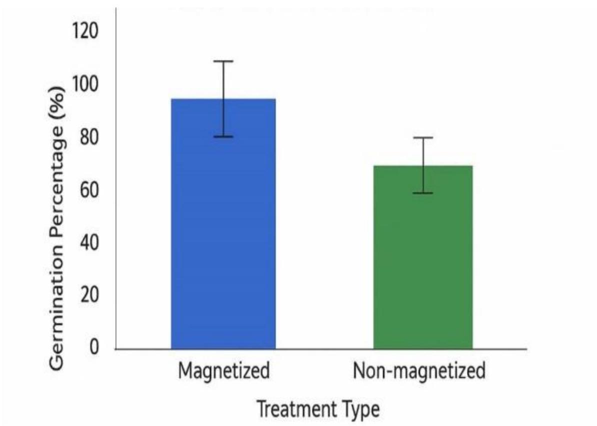

Figure 5: Mean germinated percentage of seeds in petri dishes between (the magnetized and non-magnetized treatments) after 10 days, with 3 replicates for each treatment.

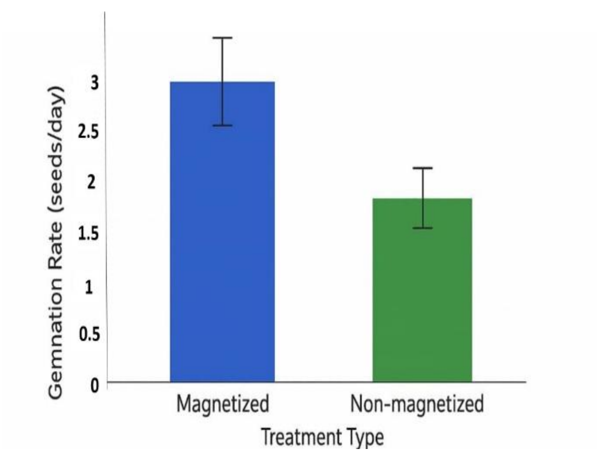

Figure 6: Mean germination rate of zucchini seeds in petri dishes between (the magnetized and non-magnetized treatments).

Even though the variances in germination percentage and rate were not statistically significant, it can be observed from Figure (7) that the seeds grown in the plates irrigated with non-magnetized water were still in the initial stage of germination, whereas the seeds in the plates treated with magnetized water had already reached more advanced stages of germination.

Figure 7: Comparison of seeds germination stages between (the m MW, and NMW after 10 days of germination.

3- Effect of magnetized water on plant macronutrient content (N, P, K)

The statistical results presented in Table (4) indicate that there were no significant variances in the plant content of nitrogen, potassium, and phosphorus between the magnetized and non-magnetized treatments, as shown in Table (4).

Table 4: Effect of magnetized water on plant macronutrient content (N, P, K).

Treatment	Nitrogen (mg/kg)	Potassium (mg/kg)	Phosphorus (mg/kg)
Magnetized	11.76±25.39	3.11±17.37	12.25±27.09
Non-Magnetized	32.83±0.96	15.37±3.08	22.78±43.83

4- Effect of magnetized water on crop yield

The results obtained from the field experiment revealed significant variances in the total crop yield when watered with magnetic treated water contrast to non-magnetic treated water. Statistical analysis showed that the mean total yield of the crop moistened with magnetized water was 2.8692 kg, whereas the mean yield under non-magnetized water treatment was 1.279 kg. The difference between the two treatments was 1.590 kg, as illustrated in Figure (8). These results indicate a highly significant difference ($p < 0.001$), as presented in Table (3).

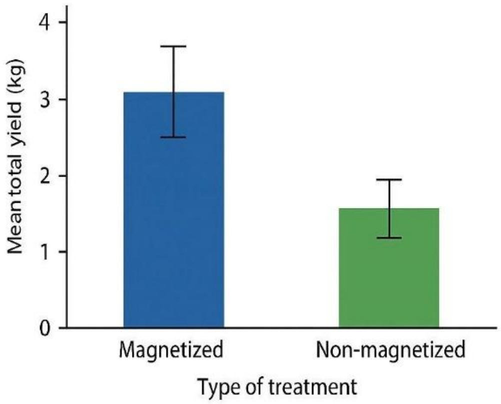

Figure 8: Mean yield of zucchini plant (kg) for 5 replicates of each treatment (magnetized and non-magnetized) after 50 days from the beginning of the experiment.

4. Discussion

The results illustrated in the figures (4, 5 and 6) demonstrate that magnetic treated water has positive effects on the imbibition and germination of zucchini seeds. The results showed a higher rate of water absorption in the first hours, and the effect was more pronounced after 36 hours of absorption in seeds treated with magnetic treated water contrast to those treated with non-magnetic treated water. These results were also reported in Hassan and Ehtaiwesh, (2020) study, which reported that the water absorption rate of wheat, barley, and lentil seeds treated with magnetic treated water was higher than that of seeds treated with non-magnetic treated water. From these results, it can be said that seeds treated with magnetic treated water absorb a larger amount of water from the medium at a faster rate than those treated with non-magnetic treated water.

Furthermore, in similar studies, it was found that the germination rate of seeds treated with magnetic treated water increased by approximately 2-3 days likened to seeds treated with non-magnetic treated water. (Al-Akhras et alk., 2024). This was confirmed by Salim, (2008), who reported that the germination rate of wheat seeds treated with magnetic treated and non-magnetic treated water reached 100% and 86%, respectively. This increase in germination rate and percentage is due to improved movement of water molecules when exposed to a magnetic field.

The results in Table (4) demonstrate no significant differences in the average ratios of nitrogen, potassium, and phosphorus between the treatment with magnetized water and the treatment with non-magnetized water. Conversely, a previous study conducted by Khater, (2019) on marjoram plants indicated a significant increase in the total percentages of nitrogen, potassium, and phosphorus when plants were treated with magnetized water in comparison to control treatments. The mean nitrogen content under magnetized water irrigation was 2.24%, whereas it was 1.54% under non-magnetized water. Similarly, the mean potassium percentage improved to 1.93% with magnetized water in comparison to 0.17% with non-magnetized water. A similar trend was observed for phosphorus, where the difference in means between the magnetized and non-magnetized treatments reached 1.76%. This rise may be attributed to the power of magnetized water in enhancing the solubility of salts in the soil, improving the efficiency of nutrient uptake and translocation from the soil to the roots, and accelerating their movement to the plant's vegetative tissues. This indicates that plants differ in their response to magnetic treated water depending on the species and cultivar. A new study by Chen, (2025) stated that irrigation with magnetic treated water improved soil nutrient availability, stimulate plant growth, and increase both grain yield and water-use efficiency.

From the above, it is evident that the positive and significant effect of magnetic treated water on the previously studied traits was ultimately reflected in the productivity of zucchini plants. This is clearly demonstrated by the results shown in the figure (8), where the total yield per plant also improved under magnetic treated water. The mean total yield per plant reached 2.8692 g with magnetic treated water compared to 1.279 g with non-magnetic treated water, indicating a highly significant variance ($P<0.001$). This improvement can be attributed to the fact that magnetizing water enhances plant growth traits by increasing the availability and intake of nutrients, allowing plants to absorb them more efficiently (Hegazy et al., 2025). These findings are in agreement with the results of Elsayed and Elsayed, (2014) on faba bean, where the difference in mean final seed yield between the treatments was also highly significant, amounting to 6.83 g.

5. Conclusions

From this study, it can be concluded that the use of magnetized water had a significant effect on the productivity of zucchini plants. The total yield of plants irrigated with magnetized water was noticeably higher from the second week of harvest until the end of the harvesting season, in comparison to those watered with non-magnetized water, indicating the potential for increased productivity. This effect may be attributed to the changes occurring in water particles when exposed to a magnetic field, enhancing water flow to the plant along with essential nutrients required for growth. According to previous studies, plants vary in their response to magnetized water, and consequently, their reactions may also differ depending on the species and cultivar.

Based on this study, we recommend that the state support scientific research by providing dedicated research centers and laboratories, with a focus on magnetized water technology. Affordable magnetic treatment devices with varying strengths should be made available. Given the positive effect of magnetized water on zucchini productivity observed in this study, it is recommended to apply this technique in greenhouses to further evaluate its impact on crop yield.

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Conflict of interest: The researchers declare that there are no conflicts of interest

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