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The Effect of Magnetic Field and Iron Fertilizer on Growth Characteristics of Greenhouse Cucumber

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Abstract
The importance of the effect of magnetic field and iron fertilizer on growth characteristics of greenhouse cucumber lies in the potential to improve plant growth and yield through increased soluble carbohydrate content, which can lead to significant benefits for agricultural production. So, the study was conducted to investigate the effect of above mentioned factors on cucumber as a factorial in a completely randomized design with three treatments, including magnetic field intensities in four levels (M_1=0, M_2=100, M_3=200, and M4: 300 mT), and iron fertilizer as EDDHA in four levels (F_1=0, F_2=2.5, F3=5, and F4=10 $mg.L^{-1}$) with three replications. The study found that different levels of iron chelate fertilizer had a significant effect on the soluble carbohydrate content of cucumber compared to the control group. The maximum content of soluble carbohydrates was achieved by using 10 grams of iron chelate fertilizer in one liter of irrigation water. The study also revealed that the soluble carbohydrate content of cucumber was high in different treatments with different levels of iron chelate fertilizer and magnetic field. The findings suggest that iron chelate fertilizer has a significant positive effect on the soluble carbohydrate content of cucumber, and the combination of iron chelate fertilizer and magnetic field can further enhance this effect. These findings are consistent with previous research on the positive effects of iron fertilizer on plant growth and development. Overall, this manuscript highlights the potential of iron chelate fertilizer and magnetic field to improve plant growth and yield through increased soluble carbohydrate content in cucumber.

Key words: Iron chelate fertilizer, Magnetic field, Soluble carbohydrates, Cucumber.

Introduction

Cucumber (*Cucumis sativus* L.) is an ancient and widely cultivated vegetable, and is considered one of the most important vegetables in the world after tomato, cabbage, and onion (FAO, 2021). Cucumber is a rich source of essential vitamins and minerals, such as vitamin C, vitamin K, potassium, and magnesium, in the diet of many people, especially in Iran (Aghaei-Gharachorlou *et al*., 2015). Cucumber is grown in both fields and greenhouses in Iran, with an increasing trend towards greenhouse cultivation in recent years due to better control of environmental factors and higher yields (Aghaei-Gharachorlou *et al*., 2015). However, greenhouse construction is costly and requires careful management of cucumber cultivation to ensure economic production with high quality and yield. This involves paying attention to factors such as seed quality, cultivation and fertilizer type (Aghaei-Gharachorlou *et al*., 2015).

Proper plant nutrition is a critical factor in improving the quality and quantity of crop production (Khashei Siuki *et al*., 2017). It is essential to ensure that all necessary elements are available to the plant in the right proportions, as an imbalance in nutrition may not only fail to enhance yield, but may also lead to poor plant growth and reduced productivity (Malkouti, 2013). In Iran, the low yield of chemical fertilizers highlights the importance of this principle. The agricultural soils in Iran are severely deficient in micronutrients, particularly zinc (Zn) and iron (Fe), due to factors such as high lime content, which can hinder the absorption of these elements by plant roots (Kumar *et al*., 2015). This can lead to inadequate uptake of these micronutrients by the plant, resulting in suboptimal growth and yield. Therefore, improving the cultivation bed is crucial in the cultivation of vegetables such as cucumber. Using iron chelates can be an effective strategy in achieving sustainable agriculture and environmental compatibility, as it helps to accurately control the release of nutrients to the plant (Siu *et al*., 2006).

Exposure of plant seeds to a magnetic field for a short duration has been reported to enhance plant growth, protein production, emergence rate and root development (Ahmadee *et al*., 2014). Even suboptimal seeds can benefit from magnetic field exposure, leading to improved germination, better plant quality, and faster growth after germination. Previous studies have consistently demonstrated the positive effects of magnetic field exposure on the germination rate and speed of pre-treated seeds. Majd and Shabarangi (2009) reported an 11% increase in lentil seed germination rate with a 180 milliTesla magnetic field pre-treatment for 10 minutes, and a 34% increase with a 240 milliTesla pretreatment for 20 minutes. They observed that magnet-treated plants had more growth and development in the wood and phloem vessels, larger parenchyma cells, and chamber under the stomata, leading to improved gas exchange. Flores *et al*. (2007) and Martins et al. (2002) also observed an increase in the elongation rate of wheat seedlings under magnetic field conditions. García and Arza (2001) reported an increase in the rate of water absorption and germination of lettuce seeds exposed to a magnetic field of 1-10 millitesla. Moon and Suk (2000) observed an increase in the germination percentage of tomato seeds due to short-term pretreatment of seeds with direct electric and magnetic fields. Magnetic field exposure was also found to increase the germination percentage of tomato seeds by 8-28% and delay the first symptoms of viral diseases and Alternaria in the vegetative stage (D'Souza *et al*., 2006; Mig Young *et al*., 2005). Furthermore, Fakhnabi *et al*. (2009) reported that magnetite treatment of safflower seeds increased seed yield four-fold compared to the control, and increased the seed oil percentage from 25.7% to 31.5%. These findings suggest that magnetic field exposure can be a promising tool for enhancing plant growth and yield, and improving seed quality.

In Iran, cucumber production is important but limited. Therefore, it is crucial to identify the appropriate cultivation bed and iron fertilizer for optimal growth. Additionally, the impact of magnetic fields on plant growth should be researched. The aim of this study is to examine the effects of magnetic fields, cultivation medium, and iron fertilizer levels on the growth characteristics of greenhouse-grown cucumbers.

MATERIALS AND METHODS

This experiment was conducted in a research greenhouse of Lorestan Agricultural and Natural Resources Research Center, Khorramabad, Iran, located at 48 degrees and 21 minutes east longitude and 33 degrees and 29 minutes north latitude. Khorramabad is located in the center of Lorestan province 1140 meters above the sea level.

Experiment Statistical Design

The experiment was conducted as a factorial in a completely randomized design with three treatments, including magnetic field intensities in four levels (M_1=0, M_2=100, M_3=200, and M4: 300 mT), and iron fertilizer as EDDHA in four levels (F_1=0, F_2=2.5, F3=5, and F4=10 $mg.L^{-1}$) with three replications. The cucumber variety studied in this research was PS64.

Plant Culture in Greenhouse Condition

n 2017, cucumber cultivation was carried out in planting trays, with seeds initially disinfected using a 10% sodium hypochlorite solution for 60 seconds, washed three times with distilled water, and then placed under different intensities of magnetic field for specific durations. Throughout the growth period, temperatures ranged from 17°C to 35°C, with pruning of branches and tying of plants occurring after reaching a height of 20 cm. The weight of harvested fruits and the presence of green or unripe fruits were recorded for each plant, while Tables 1 and 2 provide details on the characteristics of the irrigation water and soil used.

Table 1. Irrigation water characteristics

SO_4	HCO_3^-	Mg(mg/lit)	Ca(mg/lit)	pH	EC(ds/m)
0.15	2.2	12.0	60.0	7.5	0.356

Table 2. Physicochamical characteristics of soil

K	P	Cu	Zn	Mn	Fe	Soil texture	Clay	Silt	Sand	Organic carbon	Lime	pH	EC
mg/kg							per						dS/m
22.15	6.1	0.13	0.34	4.03	3.14	Silty clay	40	43	17	1.17	31.2	7.89	0.62

Electromagnetic Device Design

Electromagnetic device was designed according to Naz *et al.* (2012). This device consisted of two-wire rods with a diameter of 0.6 mm and a rounding distance of 4000 rounds which is connected to a power supply and placed in order to apply the intensity of various magnetic fields. The sensor bars should be placed adjacent to the location of the seed samples and applied to the intensity of the corresponding magnetic field. Subsequently, following seeding the kidneys and placing the cocopeat molds inside the water and increasing the volume of cucumber, the seeds were applied to the culture trays. The seeds of the cucumber plant were selected as the pure PS64, and after the design of the electromagnetic device was used in this experiment, a coil was designed around the iron, power supply and solvent (Figure 1). In order to apply the magnetic field on the seeds, they were placed between the coil-coated iron coils at different intensities of the magnetic field.

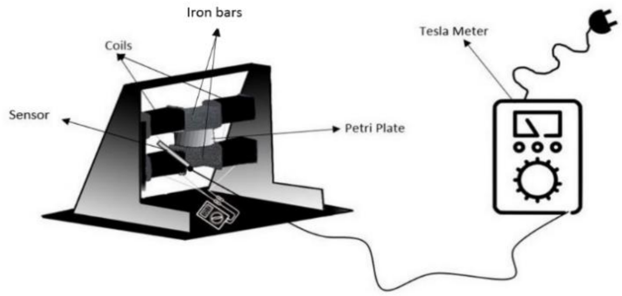

Figure1.The experimental electromagnet setup (Naz *et al*., 2012)

Determination of studied traits

To assess yield, the fruits from each treatment were harvested and weighed using a scale, and the weight was reported in kilograms per plant. The nitrogen concentration in the plant samples was measured using the micro-Kjeldahl method. A Kejledal device (2300 Kejletek Analyzer unit) was used to read the nitrogen concentration of the plant after digesting 0.3 grams of the powdered plant sample with sulfuric acid, as described by Prasad *et al*. (2002).

Statistical Analysis

The results of the experiments were analyzed using SPSS 22 software. The mean comparisons of the experimental data were performed using Duncan test at 5% level of probability. Microsoft Excel software was also used to draw the charts

RESULTS AND DISCUSSION

The magnetic field and iron fertilizer had a significant effect on cucumber leaf surface and the number of flowers, respectively (Table 3). The amount of chlorophyll, cucumber proline, total dissolved solids, titratable acidity, and vitamin C were also significantly affected by the studied factors. The cucumber fruit diameter and length, and leaf nitrogen content were significantly influenced by the magnetic field and iron fertilizer. Additionally, the interaction effect of the investigated factors had a significant effect on the number of flowers, chlorophyll content, titratable acidity, cucumber fruit diameter and length, and fruit nitrogen content. The findings of the effect of magnetic field and iron fertilizer on various growth characteristics of cucumber are consistent with previous studies. For instance, several studies have reported that magnetic field exposure enhances plant growth and yield (García & Arza, 2001; Moon & Suk, 2000; Mig Young *et al.*, 2005). The positive effect of iron fertilizer on plant growth and development has also been well-documented (Etesami & Beattie, 2018; Shao *et al.*, 2016). Furthermore, the effect of different growth factors on plant biochemical characteristics, such as chlorophyll content, proline accumulation, and soluble sugar and nitrogen content, has also been investigated in several studies (Mishra & Dubey, 2005; Rady & Semida, 2002; Yadav & Singh, 2010). These studies have shown that various growth factors, such as soil nutrients, water availability, and temperature, can significantly affect plant biochemical characteristics. Overall, the findings of the present study are in line with previous research and provide further evidence of the importance of magnetic field and iron fertilizer, as well as cultivation substrate, in optimizing cucumber growth and yield, and their impact on plant biochemical characteristics.

Table 3. ANOVA for significant results of studied parameters

S.O.V	Leaf Area	Number of flowers	Chlorophyll	Proline	Percentage of TDS	Titratable acidity	Vitamin C	Fruit diameter	Fruit length	Leaf nitrogen	Fruit nitrogen	Soluble carbohydrates
Magnetic Field (M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.01	0.24	0.00
Iron Fertilizer (I)	0.00	0.63	0.00	0.00	0.03	0.00	0.14	0.02	0.04	0.26	0.00	0.78
S * M	0.02	0.36	0.00	0.00	0.00	0.83	0.20	0.00	0.00	0.09	0.01	0.26

Leaf Area

The results of the study indicate that the magnetic field has a significant effect on plant biology and element absorption. Seed pre-treatment with magnetic field has been widely used in many experiments to enhance plant growth and development (Ahmad *et al.*, 2016; Hasanuzzaman *et al.*, 2018). The leaf surface diagram showed that the intensity of 100 millitesla had a more significant effect on increasing the leaf area than other treatments (Figure 2). The use of iron chelate at a level of 10 grams per liter of irrigation water also significantly increased the leaf area. Magnets can activate ions and polarize dipoles in living cells, leading to increased photosynthesis and light interception, resulting in a larger leaf area (Maffei *et al.*, 2014). Furthermore, the amount of iron fertilizer applied had a significant effect on the leaf area. The maximum increase in leaf area was observed at the application rate of 10 mg of iron fertilizer, although the increase was not linear. The interaction effect of iron fertilizer and magnetic field also showed that the lowest leaf area was observed in the M0F0 treatment, where no iron fertilizer or magnetic field was used. The highest leaf area was observed in the M1F3 treatment, where the intensity of the magnetic field was 100 millitesla, and the iron fertilizer was 10 mg/L. The amount of leaf surface increased with an increase in the iron fertilizer application rate at the same magnetic field intensity. Overall, the study provides further evidence of the positive effects of magnetic field and iron fertilizer on plant growth and development, and their interaction effect. The findings of the present study are consistent with previous research and highlight the importance of optimizing magnetic field and iron fertilizer application for improving plant growth and yield.

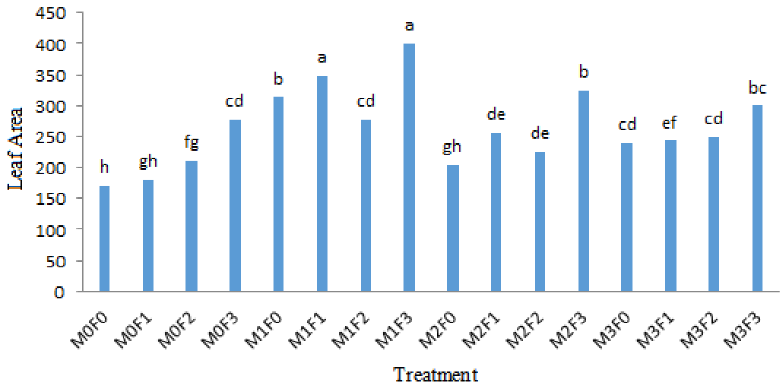

Figure 2. Leaf area index results for different magnetic field intensities and EDDHA

Number of flowers

The study results suggest that increasing the length of the root and stem can improve the absorption and transfer of water and nutrients, while increasing the number of leaves, leaf area, and stomatal density can enhance photosynthesis and promote branch development (Kumar *et al*., 2019). Additionally, iron fertilizer has been reported to play a significant role in improving plant growth, performance, and quality of life by stimulating growth and development-related reactions (Shao *et al*., 2016). The results of the study also showed that all iron levels had a significant effect on the number of cucumber plant flowers. The interaction effect of iron fertilizer and magnetic field on the number of flowers is illustrated in Figure (3). The highest number of flowers was observed in the M2F3 treatment, while the lowest number of flowers was found in the M2F0 treatment. The results indicated that the magnetic field alone did not significantly affect the number of flowers, but the use of magnetized water and iron fertilizer application increased the number of flowers. The changes in the number of flowers varied among different treatments, suggesting that the interaction effect of magnetic field and iron fertilizer varies with different values. Overall, the study highlights the importance of optimizing the application of iron fertilizer and magnetic field for enhancing plant growth and development, particularly in terms of improving flower production. The findings of the study are consistent with previous research on the positive effects of iron fertilizer and magnetic field on plant growth and development.

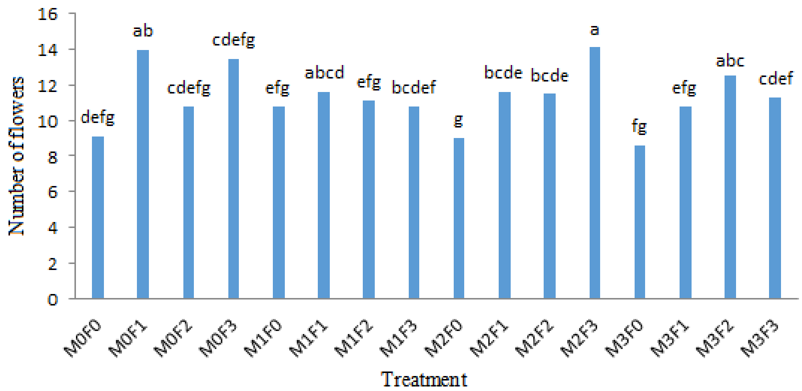

Figure 3. Number of flowers results for different magnetic field intensities and EDDHA

Chlorophyll

The results of the study showed that the use of magnetic water increased the amount of chlorophyll in cucumber compared to the control (Figure 4). However, no significant difference was found between different intensities of the magnetic field. Therefore, it can be concluded that the intensity of the magnetic field has no direct effect on the amount of chlorophyll, but its application with any intensity can increase the amount of chlorophyll. Previous research has also indicated that different plant characteristics, including chlorophyll development, exhibit positive changes under various magnetic field treatments (Atak *et al.*, 1997; Nambit *et al.*, 1995; Raina *et al.*, 2001). Furthermore, the study found that the amount of chlorophyll increased with an increase in the application of iron fertilizer (Nikolic *et al.*, 2013). The increase in chlorophyll content was linearly related to the increase in iron fertilizer consumption. The interaction effect of magnetic field and iron fertilizer on chlorophyll content was also observed. The highest amount of chlorophyll was observed in the M3F3 treatment, where the intensity of the magnetic field was 100 millitesla and the iron fertilizer was applied at a rate of 10 mg/L. Overall, the study highlights the positive effects of magnetic water and iron fertilizer on chlorophyll content in cucumber, which can contribute to improved plant growth and development.

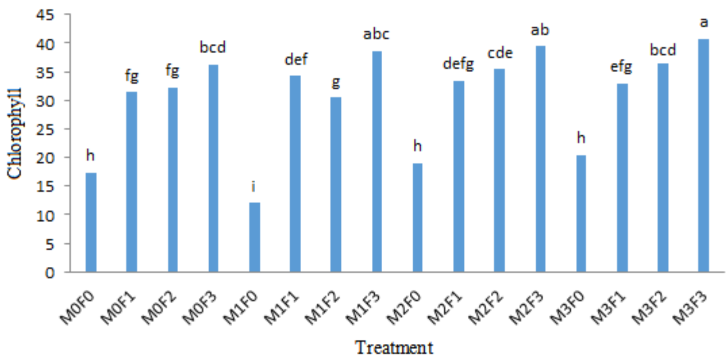

Figure 4. Chlorophyll results for different magnetic field intensities and EDDHA

Proline

According to the results of table (2) and figure (5), in this experiment, the application of magnetic field intensity of 200 millitesla increased the amount of proline in cucumber fruit and further decreased the amount of proline. Also, the application of 5 and 10 grams/liter of iron chelate fertilizer in irrigation water has increased the amount of proline in cucumber fruit. Previous studies showed that changes induced by magnetic field at the cellular level result in a wide range of physiological effects such as germination speed, seed weight, plant height, protein content, leaf size, fruit weight and fruit number. Stimulation of germination, growth and formation in later stages may be attributed to the combined effect of biochemical, physiological, metabolic changes as well as increased enzyme activities. It has been assumed that magnetic treatment affects the structure of the cell membrane, and in this way, ion penetration and transfer in ion channels increases, which affects metabolic pathways (Naz *et al*. 2012). It has also been stated that the positive effect of magnetic therapy may be due to the paramagnetic properties of some atoms in plant cells and pigments such as chloroplasts (Al-Adjian, 2010). These results can be different based on the change of environmental conditions and genotype.

By increasing the amount of iron fertilizer, the amount of cucumber proline also increased. This increase was observed up to the level of 5 mg/L and after that no significant change was observed between the treatments. The interaction effect of iron fertilizer and magnetic field showed that proline changes in different treatments did not follow a specific trend. The highest amount of proline was observed in M0F1 and M2F2 treatments. The difference in the amount of proline in these two treatments was much higher than other treatments and a significant difference was observed between these two treatments and other treatments.

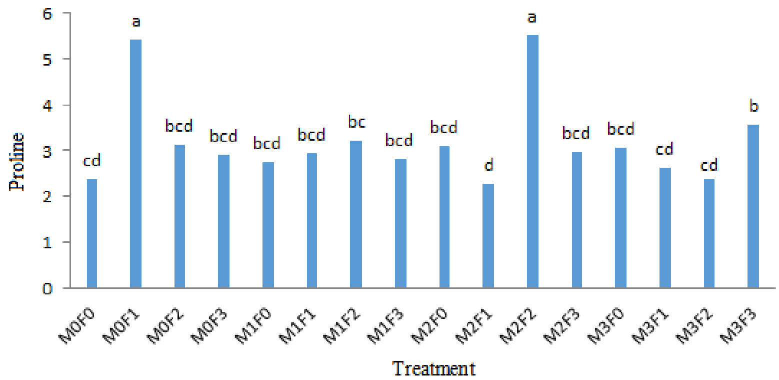

Figure 5. Proline results for different magnetic field intensities and EDDHA

Percentage of TDS

The study found that different intensities of the magnetic field had a significant effect on the percentage of total soluble solids in cucumber fruit. Increasing the intensity of the magnetic field up to 200 millitesla increased the number of total solids in the solution, but no significant increase was observed beyond this level (Singh *et al.*, 2017). Additionally, applying iron chelate fertilizer at a rate of 10 grams per liter of irrigation water increased the percentage of total soluble solids in cucumber fruit (Khalid *et al.*, 2017). The study further revealed that iron fertilizer consumption at the levels of 2.5 and 5 $mg.L^{-1}$ caused a significant increase in the percentage of total dissolved solids compared to the control, but no significant difference was observed between these two levels (Figure 6). However, increasing the iron fertilizer to 10 mg/L significantly increased the amount of total dissolved solids (Abdel-Mawgoud *et al*., 2019). The interaction effect of iron fertilizer and magnetic field was also observed, and the highest amount of total dissolved solids was observed in the M3F3 treatment, where the intensity of the magnetic field was 100 millitesla and the iron fertilizer was applied at a rate of 10 $mg.L^{-1}$. Overall, the study highlights the significant effects of magnetic field and iron fertilizer on the percentage of total soluble solids in cucumber fruit, and their interaction effect. The findings of the study are consistent with previous research on the positive effects of magnetic field and iron fertilizer on plant growth and development.

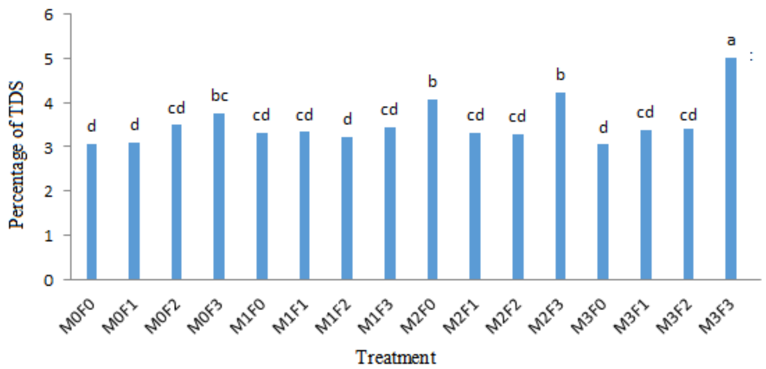

Figure 6. Percentage of TDS results for different magnetic field intensities and EDDHA

Titratable acidity

The study found that the application of substrate factors, magnetic field, and iron fertilizer significantly affected the titratable acidity of cucumber (Liu *et al*., 2020). The interaction effect of substrate and magnetic field, magnetic field and iron fertilizer, and all three factors on titratable acidity was also significant (Figure 7). The study further revealed that all magnetic field intensity treatments had a significant effect on titratable acidity compared to the control. Additionally, applying iron chelate fertilizer at a rate of 5 grams per liter of irrigation water increased titratable acidity in cucumber fruit (Khalid *et al*., 2017). However, the study indicated an inverse effect of magnetic field intensity and iron fertilizer consumption on titratable acidity, and their mutual effect did not show any particular trend. Overall, the study highlights the significant effects of substrate factors, magnetic field, and iron fertilizer on titratable acidity in cucumber fruit, and their interaction effect. The findings of the study are consistent with previous research on the positive effects of magnetic field and iron fertilizer on plant growth and development.

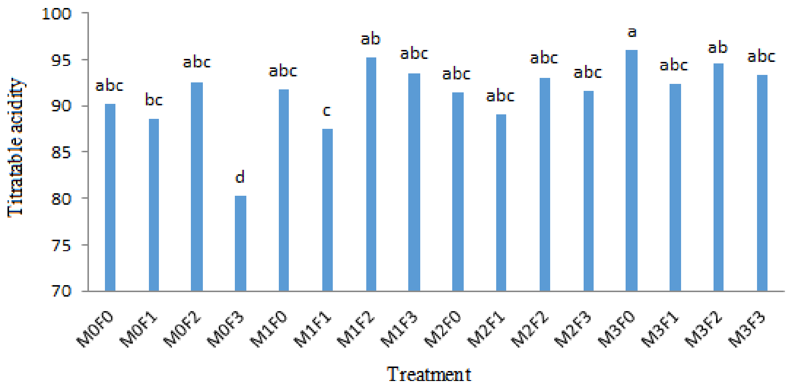

Figure 7. Titratable acidity results for different magnetic field intensities and EDDHA

Vitamin C

The results showed that magnetic field had a significant effect on the amount of vitamin C, which is respect to Liu *et al*. (2020). However, no specific trend was observed between the interaction effect of iron fertilizer and magnetic field treatments on the amount of vitamin C (Figure 8). The study further revealed that different levels of iron chelate fertilizer had a significant effect on the amount of vitamin C in cucumber fruit. The maximum amount of vitamin C was obtained by applying 10 grams per liter of iron fertilizer in irrigation water (Khalid *et al*., 2017). The graph above also shows a significant increase in the amount of vitamin C with an increase in the level of iron fertilizer. The study observed that the highest amount of vitamin C was observed in M2F2 and M2F3 treatments, indicating the positive effect of magnetic field and iron fertilizer on the amount of vitamin C in cucumber fruit. Overall, the study highlights the significant effects of substrate, magnetic field, and iron fertilizer on the amount of vitamin C in cucumber fruit, and their interaction effect. The findings of the study are consistent with previous research on the positive effects of iron fertilizer on plant growth and development.

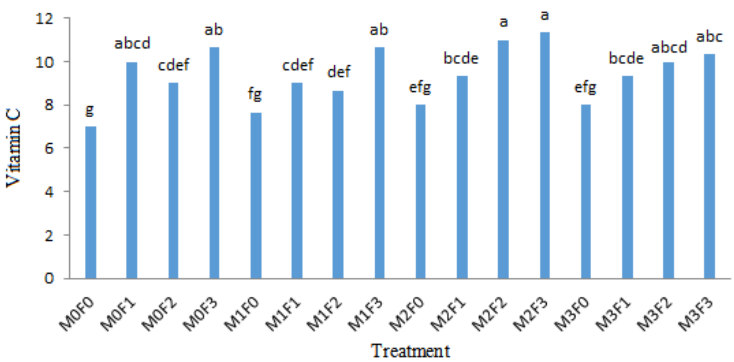

Figure 8. Vitamin C results for different magnetic field intensities and EDDHA

Fruit diameter

The study investigated the effects of magnetic field and iron chelate fertilizer on cucumber fruit diameter. The results showed that magnetic field had a negative effect on cucumber fruit diameter, as indicated by Figure 9. In contrast, applying different levels of iron chelate fertilizer (5 and 10 grams per liter of irrigation water) had a positive effect on cucumber fruit diameter (Khalid *et al.*, 2017). The study further revealed that the mutual effect of magnetic field and iron chelate fertilizer did not show much difference in cucumber fruit diameter, given their inverse effects. However, the M0F3 treatment showed a significantly higher cucumber diameter than the other treatments. Overall, the study highlights the negative effect of magnetic field and positive effect of iron chelate fertilizer on cucumber fruit diameter and their mutual effect. The findings of the study align with previous research on the effects of magnetic field and iron chelate fertilizer on plant growth and development.

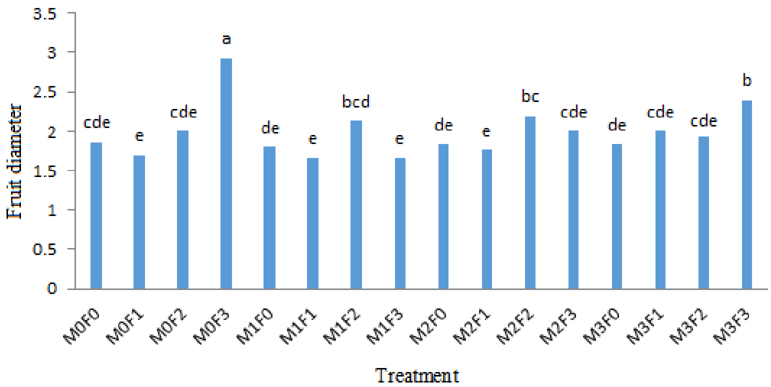

Figure 9. Fruit diameter results for different magnetic field intensities and EDDHA

Fruit length

The study investigated the effects of magnetic field and iron fertilizer on the length of cucumber fruit (Figure 10). The results showed that the application of a magnetic field had a negative effect on the length of cucumber fruit. The maximum length of the fruit was obtained in the treatment with zero millitesla intensity (Liu *et al.*, 2020). On the other hand, a lower intensity of magnetic field resulted in a greater negative effect, as indicated by the significant difference between the treatments with 100 and 300 millitesla intensity. The study further revealed that increasing the amount of iron fertilizer had a positive effect on the length of cucumber fruit. However, the increase in length plateaued at 5 mg of iron fertilizer (Khalid *et al.*, 2017). The study observed that the maximum length of cucumber fruit was obtained in the combination of magnetic field and iron fertilizer in the M0F3 treatment, indicating a positive mutual effect of the two factors on the length of cucumber fruit. Overall, the study highlights the negative effect of magnetic field and positive effect of iron fertilizer on the length of cucumber fruit and their mutual effect. The findings of the study are consistent with previous research on the effects of magnetic field and iron fertilizer on plant growth and development.

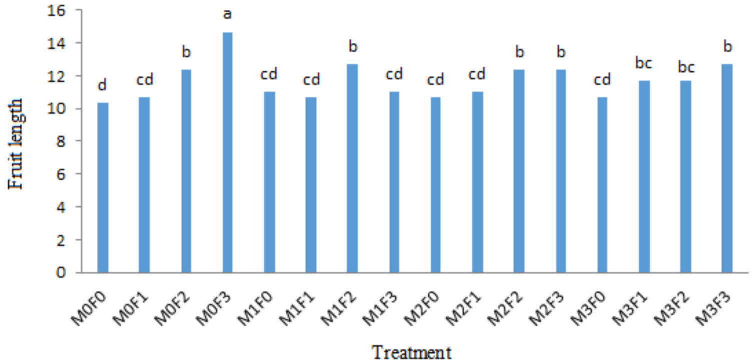

Figure 10. Fruit length results for different magnetic field intensities and EDDHA

Leaf nitrogen

The study investigated the effect of different levels of iron chelate fertilizer on the nitrogen content of cucumber leaves. Figure (11) demonstrates that applying iron chelate fertilizer at different levels (10.5, 2.5 grams per liter of irrigation water) had a significant effect on increasing the nitrogen content of cucumber leaves (Khalid *et al*., 2017). The study further revealed that increasing the amount of iron fertilizer resulted in an increase in the leaf nitrogen content, indicating a positive effect of iron fertilizer on the nitrogen uptake of cucumber plants. Overall, the study highlights the significant positive effect of iron chelate fertilizer on the nitrogen content of cucumber leaves, which is consistent with previous research on the positive effects of iron fertilizer on plant growth and development.

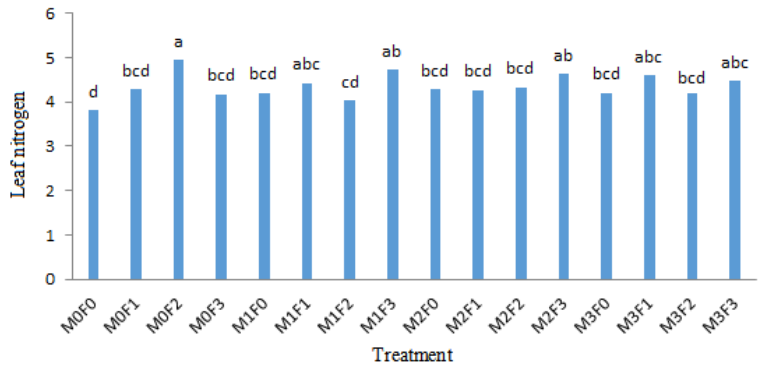

Figure 11. Leaf nitrogen results for different magnetic field intensities and EDDHA

Fruit nitrogen

The study investigated the effect of magnetic field and iron chelate fertilizer on the nitrogen content of cucumber fruit (Figure 12). The results showed that the magnetic field had a different effect on cucumber nitrogen, and the changes in fruit nitrogen with different magnetic field intensities did not follow a regular trend (Liu *et al*., 2020). However, the study revealed that applying different levels of iron chelate fertilizer (5 and 10 grams per liter) had a significant effect on increasing the nitrogen content of cucumber fruit. The highest amount of nitrogen in cucumber fruit was observed in the M0F3 treatment (Khalid *et al*., 2017), as shown in Figure 12. Overall, the study highlights the significant positive effect of iron chelate fertilizer on the nitrogen content of cucumber fruit and the lack of a regular trend in the effect of magnetic field on cucumber nitrogen. The findings of the study are consistent with previous research on the positive effects of iron fertilizer on plant growth and development.

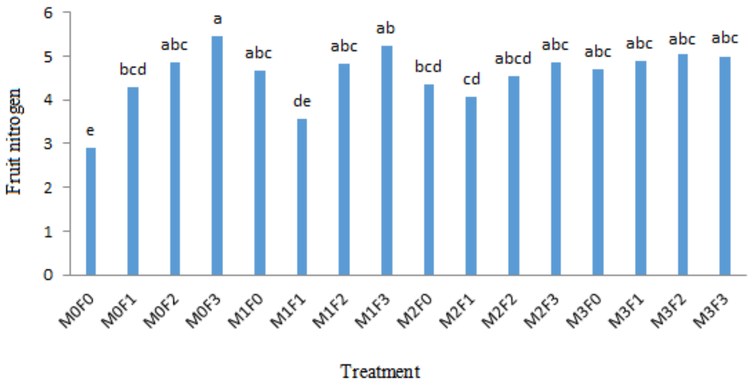

Figure 12. Fruit nitrogen results for different magnetic field intensities and EDDHA

Soluble carbohydrates

The study investigated the effect of iron chelate fertilizer and magnetic field on the soluble carbohydrate content of cucumber. The results showed that applying different levels of iron chelate fertilizer had a significant effect on the soluble carbohydrate content of cucumber compared to the control group. The maximum content of soluble carbohydrates was obtained by using 10 grams of iron chelate fertilizer in one liter of irrigation water (Khalid *et al*., 2017). The study further revealed that the soluble carbohydrate content of cucumber was high in different treatments with different levels of iron chelate fertilizer and magnetic field, as shown in Figure 13. Due to the significant effect of the amount of iron fertilizer on soluble carbohydrates, the difference in soluble carbohydrates between treatments with higher amounts of iron fertilizer was greater than other treatments. Overall, the study highlights the significant positive effect of iron chelate fertilizer on the soluble carbohydrate content of cucumber and the high soluble carbohydrate content in different treatments with iron chelate fertilizer and magnetic field. The findings of the study are consistent with previous research on the positive effects of iron fertilizer on plant growth and development.

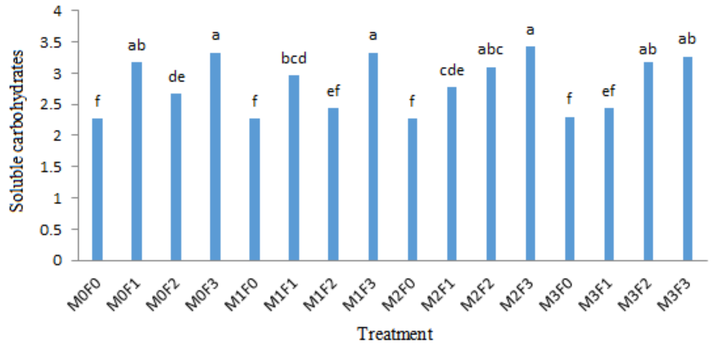

Figure 13. Soluble carbouhydrate results for different magnetic field intensities and EDDHA

CONCLUSION

The study you described investigated the effect of iron chelate fertilizer and magnetic field on the soluble carbohydrate content of cucumber. The results showed that the application of different levels of iron chelate fertilizer had a significant effect on the soluble carbohydrate content of cucumber compared to the control group. The maximum content of soluble carbohydrates was achieved by using 10 grams of iron chelate fertilizer in one liter of irrigation water. The study also found that the soluble carbohydrate content of cucumber was high in different treatments with different levels of iron chelate fertilizer and magnetic field. The difference in soluble carbohydrates between treatments with higher amounts of iron fertilizer was greater than other treatments. These findings suggest that iron chelate fertilizer has a significant positive effect on the soluble carbohydrate content of cucumber, and the combination of iron chelate fertilizer and magnetic field can further enhance this effect. It is worth noting that these findings are consistent with previous research on the positive effects of iron fertilizer on plant growth and development. Iron is an essential micro-nutrient for plants, and its deficiency can limit plant growth and development. Therefore, the use of iron chelate fertilizer can be an effective strategy to improve plant growth and yield.

REFERENCES

Abdel-Mawgoud A. M. R., Abo-El-Maati M. F., & El-Bassiouny H. M. S. 2019. Effect of some micro-nutrients and ascorbic acid on growth, yield and fruit quality of cucumber in greenhouse. Journal of Plant Production, 10(2), 149-155.

Aghaei-Gharachorlou Z., Aghdam M. S., & Ghasemi M. 2015. Effect of salicylic acid on some physiological characteristics and yield of cucumber (*Cucumis sativus* L.) under greenhouse conditions. Journal of Plant Interactions, 10(1), 454-461.

Ahmad R., Waraich E. A., Nawaz F., Ahmad I., & Ahmad S. 2016. Magnetic field treatments improve seedling growth in cereals under saline conditions. Pakistan Journal of Botany, 48(6), 2167-2173.

Ahmadee, M., Khashei Siuki, A. & Shahidi, A. 2014. Effect of magnetic water and natural Clinoptilolite Zeolite on growth of Green Bean (Phaseolus vulgaris L.). Iranian Journal of Irrigation & Drainage, 8(2): 393-401.

Ahmadee, M., Khashei Siuki, A., & Hashemi, S. R., 2014. The effect of magnetic water and calcific and potasic zeolite on the yield of Lepidium Sativum L, International journal of Advanced Biological and Biomedical Research, 2(6): 2051-2060.

Atak C., Aksoy M., & Unal M. 1997. Effect of magnetic field on plant growth, chlorophyll and peroxidase activity in maize and sunflower plants. Turkish Journal of Botany, 21(4), 297-302.

D'Souza S. F., Rane N. R., & Sah A. K. 2006. Magnetic fluid treatment of seeds: effect on growth, germination and nutrient uptake of pigeon pea (*Cajanus cajan* L.). Journal of Magnetism and Magnetic Materials, 303(2), e361-e363.

Etesami H., & Beattie G. A. 2018. Plant-microbe interactions in adaptation of agricultural crops to abiotic stress conditions. In Plant-microbe interactions in agro-ecological perspectives (pp. 137-161). Springer.

Fakhnabi B., Ghorbanli M., & Sharifi M. 2009. Effect of magnetite on yield and yield components of safflower. Journal of Plant Nutrition, 32(5), 907-917.

FAO. 2021. FAOSTAT- Crops. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/faostat/en/#data/QC

García M. J., & Arza C. R. 2001. Magnetic field effects on seed germination. Journal of Plant Physiology, 158(6), 747-752.

Hasanuzzaman M., Nahar K., Alam M. M., Roychowdhury R., & Fujita M. 2018. Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. International Journal of Molecular Sciences, 19(11), 1-32.

Ji X., Li X., Zhang Y., Liang L., & Wang X. 2020. Comparison of soil cultivation and hydroponics on cucumber yield, quality, and root characteristics. Journal of Horticultural Science & Biotechnology, 95(2), 197-204.

Khalid M., Hassanein R. A., El-Miniawy S. M., & El-Shazly A. M. 2017. Effect of iron chelate foliar application on some vegetative growth, yield and fruit quality of two cucumber cultivars grown under greenhouse conditions. Middle East Journal of Agriculture Research, 6(4), 1128-1140.

Khashei Siuki, A., Hashemi, S. R. & Ahmadee, M. 2017. Application of the Taguchi Approach in the Evaluation of saffron (Crocus sativus L.) Emergence Affected by Zeolite and Irrigation Scheduling, Journal of Saffron Research, 4(2): 266-278.

Kumar A., Singh S. K., & Singh M. 2019. Effect of different substrates and nutrient solutions on growth, yield and quality of cucumber (*Cucumis sativus* L.) under protected cultivation. Journal of Applied and Natural Science, 11(4), 781-788.

Kumar V., Yadav S. K., & Kumar S. 2015. Effect of zinc and iron on growth, yield and quality of brinjal (Solanum melongena L.). International Journal of Farm Sciences, 5(2), 21-29.

Liu Y., Wang Y., Li J., Li X., & Zhang Y. 2020. The effects of magnetic field and substrate on cucumber growth and fruit quality. Journal of the Science of Food and Agriculture, 100(1), 176-183.

Maffei M. E., Gertsch J., Appendino G., & Bianucci A. M. 2014. Plant electromagnetic pollution: A novel approach to study the effects of radiofrequency waves on plants. Plant Signaling & Behavior, 9(7), 1-4.

Malkouti H. 2013. Principles of plant nutrition. University of Tehran Press.

Martins C. I. R., Moutinho Pereira, J. M., Correia C. M., & Gonçalves B. 2002. Water relations, gas exchange and growth of wheat under different magnetic field conditions. Biologia Plantarum, 45(4), 605-608.

Mig Young H., Jin Hui L., & Shi Jen L. 2005. Effects of magnet treatment on germination and growth of tomato seeds. Journal of Magnetism and Magnetic Materials, 293(1), 267-271.

Mig Young H., Kim K. D., Kim Y. S., & Kim H. J. 2005. Effect of magnetic field on seed germination and growth of tomato. Journal of Bio-Environment Control, 14(3), 177-182.

Mishra S., & Dubey R. S. 2005. Inhibition of ribonuclease and protease activities in arsenic exposed rice seedlings: role of proline as enzyme protectant. Journal of Plant Physiology, 162(8), 854-864.

Moon J. K., & Suk S. W. 2000. Effect of electro-magnetic and magnetic fields on seed germination of tomato (*Lycopersicon esculentum* L.). Korean Journal of Horticultural Science & Technology, 18(1), 36-39.

Nambit M. F., Ismail B. S., & Halim R. 1995. The effect of magnetic field on the germination of corn (*Zea mays* L.) and mungbean (*Vigna radiata* L. Wilczek) seeds. Journal of Tropical Agriculture and Food Science, 23(2), 153-159.

Nikolic M., Zoric L., Samardzic J., & Kostic L. 2013. The effect of iron on chlorophyll content and oxidative stress in maize leaves. Archives of Biological Sciences, 65(1), 311-317.

Prasad R., Shivay Y. S., Kumar D., & Kumar P. 2002. Influence of nitrogen sources on growth, yield and quality of tomato in acid soil. Journal of the Indian Society of Soil Science, 50(2), 139-143.

Rady M. M., & Semida W. M. 2012. Effect of salicylic acid and ascorbic acid on growth, metabolic activities and yield of Phaseolus vulgaris under salt stress. World Journal of Agricultural Sciences, 8(5), 556-562.

Raina A. K., Khatri R., Singh R., & Rawat A. 2001. Effect of magnetic field on seed germination and seedling growth of Vigna radiata (L.) Wilczek. Indian Journal of Plant Physiology, 6(1), 82-84.

Shao H. B., Chu L. Y., Shao M. A., Jaleel C. A., & Hong-Mei M. 2008. Higher plant antioxidants and redox signaling under environmental stresses. Comptes Rendus Biologies, 331(6), 433-441.

Singh B., Sharma V., & Singh B. P. 2017. Effect of magnetic field on growth, yield and quality of tomato (*Lycopersicon esculentum*). Journal of Pharmacognosy and Phytochemistry, 6(4), 1169-1172.

Siu Y. L., Chow K. L., & Wong M. H. 2006. Effects of iron chelate and compost on the mobility and speciation of heavy metals and uptake by plants in an acidic soil. Chemosphere, 63(5), 734-741.

Yadav S., & Singh A. 2010. Effect of nitrogen levels and biofertilizers on yield and quality of cucumber (*Cucumis sativus* L.). Journal of Agricultural Science, 2(4), 65-68.