

The Effect of Magnetically Treated Water Irrigation and Foliar Amino Acid Application on Onion Growth and Quality

Dina A. Ghazi¹, Mohamed A. Abdein^{2*}, Naglaa Khalafallah³, Mohamed A. Abd El-Aziz⁴, Mohamed A. El-Sherpiny⁴, Taghreed A.M.A. Badawi⁵, Nada S.M. Kamel⁵, Yasser A.M. Hafez⁶, Mohamed Abd Allah Azab⁷, Sadoun M.E. Sultan⁷, Asem M.A. Abdel-Gawad⁸, Amal A. Helmy¹

¹Soils Dept. Fac. Agric., Mansoura University, Mansoura, 35516, Egypt

²Seeds Development Department, El-Nada Misr Scientific Research and Development Projects, Turrell, Mansoura, 35511, Egypt

³Soil and Water Department, Faculty of Agriculture, Tanta University, 31527 Tanta, Egypt

⁴Soil & Water and Environment Research Institute, Agriculture Research Center, El-Gama St., Giza, 12619, Egypt

⁵Department of Plant Production, Faculty of Environmental Agricultural Science, Arish University, North Sinai 45516, Egypt

⁶Medicinal and Aromatic Plants Research Departments, Horticulture Research Institute, Agricultural Research Centre, Giza 12619, Egypt

⁷Vegetable Sciences, Horticulture Department, Faculty of Agriculture (Assiut branch), Al-Azhar University, Assiut 71524, Egypt

⁸Soils and Water Department, Faculty of Agriculture, Al-Azhar University (Assiut branch), Assiut 71524, Egypt

*Corresponding Author: Mohamed A. Abdein

Corresponding Author e-mail: abdeingene@yahoo.com

Abstract

Utilizing low-quality irrigation water in water-scarce regions is essential, but it demands careful management to mitigate adverse effects on soil and crop health. The adoption of suitable approaches and technologies, including methods involving magnetizing irrigation water, proves valuable in sustaining agriculture under these challenging conditions. So, a field experiment was conducted to evaluate the influence of two types of irrigation water (non-treated and magnetically treated water) as the primary factor. Additionally, the study included the external application of specific amino acids (proline, glycinebetaine, arginine and methionine) at a rate of 100 mg/L for each amino acid, along with a control group, as the secondary factor. The experiment aimed to assess their combined impact on the growth and development of onion plants over two consecutive seasons, namely 2023/2024 and 2024/2025. The findings revealed that onion plants subjected to magnetic water treatment exhibited superior growth, yield, and quality characteristics compared to those irrigated with untreated water. In terms of foliar application, the control treatment displayed the least favorable outcomes when compared to the other four amino acid treatments. Proline emerged as the most effective amino acid for achieving optimal performance under both water conditions, followed by glycinebetaine, arginine, and lastly, methionine. Given the notable benefits observed in onion plants irrigated with magnetically treated water, farmers in water-scarce regions should be encouraged to explore and adopt magnetic water treatment technologies. These approaches can contribute to sustaining agriculture by improving soil and crop health. Also, Farmers should consider incorporating specific amino acids, particularly proline, in their foliar application practices.

Keywords: Magnetizing, Proline, Glycinebetaine, Arginine, Methionine.

1 Introduction

In a world grappling with the severe challenges of water scarcity and diminishing water resources (Gad, 2017), agricultural operations often face the unavoidable necessity of utilizing low-quality water (Khairy et al. 2022). This strained water supply, laden with impurities and salts, poses a significant threat to the health and productivity of growing plants. The adverse effects of such water on soil structure and crop yields demand an

innovative approach to enhance its quality (Saffan et al. 2022). Recycling and reusing water, including drainage water, in agriculture is a practice known as water reuse or water recycling. While it can be a way to optimize water resources, there are some considerations and potential challenges associated with using low-quality water in agriculture (Al-Hazmi et al. 2023). One promising avenue involves the application of a magnetic field to water sources, a technique known as magnetized water (Dobránszki et al. 2023). This method seeks to mitigate the detrimental impact of low-quality irrigation water on plant growth. By subjecting water to a magnetic field, researchers aim to induce beneficial changes in its physical and chemical properties, ultimately promoting more favorable conditions for plant development (Khoshravesh and Pourgholam-Amiji, 2023; Shaban et al. 2023). Additionally, recognizing the pivotal role of amino acids in plant physiology adds another layer of complexity to the quest for sustainable agricultural practices. Amino acids, when sprayed on plants, can contribute to improved stress tolerance, including resistance to salinity (Abdelkader et al. 2023 and Alkharpotly et al. 2023a). Amino acids play a role in enhancing the plant's defense mechanisms, osmotic regulation, and overall stress response. While various amino acids may be used, certain types are often highlighted for their potential benefits in mitigating the effects of salinity stress (Seyedi et al. 2023) and drought stress (Amin et al. 2024). Some of these amino acids include proline which is known for its osmoprotectant properties. It accumulates in plant cells under stress conditions, such as salinity, and helps to maintain cell turgor and protect cellular structures (Yousif and Esho, 2023). Glycinebetaine, although not an amino acid itself, is often included in discussions about salinity tolerance. It is a quaternary ammonium compound derived from amino acids, and it helps plants to maintain cellular osmotic balance under saline conditions (Niu, et al. 2023). Arginine is involved in the synthesis of polyamines, which play a role in stress responses. Polyamines can help stabilize cell membranes and protect plants from the toxic effects of high salt concentrations (Mahdi, 2023). Methionine is an essential amino acid that participates in various metabolic processes. It is involved in the synthesis of ethylene, a plant hormone that regulates stress responses, including those to salinity (Khater et al. 2024). Onion (*Allium cepa* L) is a member of the Amaryllidaceae family and holds significance as a key vegetable crop in the world and Egypt (Ibrahim et al. 2022, Alkharpotly et al. 2023b and Azab et al. 2024). Renowned for their health benefits, onions contain antioxidants and compounds that combat inflammation, lower triglycerides and reduce cholesterol levels (Stoica et al. 2023).

In this context, the purpose of our study is to investigate the combined impact of magnetized water and exogenous application of specific amino acids i.e., proline, glycinebetaine, arginine and methionine on the growth and development of onion plants. The goal is to discern whether this integrated approach can contribute to mitigating the challenges posed by low-quality irrigation water, thereby providing valuable insights for sustainable agricultural practices in water-scarce regions.

2 Materials and Methods

A field trial was carried out over two successive seasons, namely 2023/2024 and 2024/2025, to assess the impact of irrigation with low-quality water, both before and after magnetization, as the primary factor. Furthermore, the study aimed to examine the external application of specific amino acids (proline, glycinebetaine, arginine and methionine) at a concentration of 100 mg L⁻¹ for each amino acid, along with a control group, as the secondary factor, on the growth and development of onion plants.

Experimental site

The present investigation was performed at a private farm situated at coordinates 31°4'54"N - 31°24'4"E in Met Antar Village, Talkha District, El-Dakahlia Governorate, Egypt.

Irrigation water source and magnetizing

The water source for this experiment was agricultural drainage water with a high electrical conductivity value (2.45 dS/m), sourced near the experimental site. To implement the magnetization process, the water was passed through a magnetic device acquired from Delta Water Company (Photo.1). The device, shown in the accompanying photograph, had a diameter of 2.0 inches and generated a magnetic field strength of 0.60 millitesla (mT).

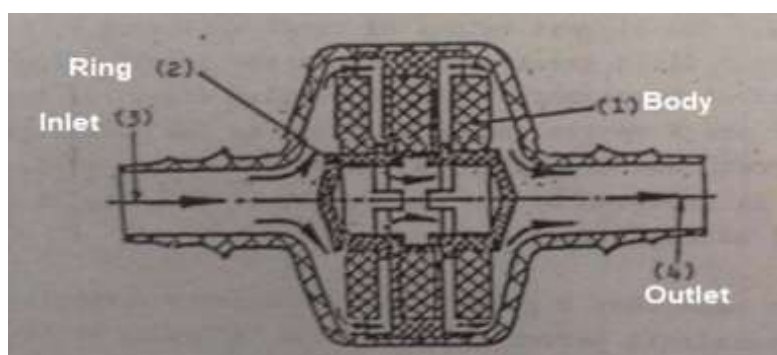


Photo.1. Used magnetic device

Soil and irrigation water analyses

Table 1 provides the characteristics of the initial soil (at a depth of 0-30 cm) at the experimental site, while Tables 2 outlines the analyses of irrigation water before and after undergoing magnetization. The assessments were conducted following the methods outlined by Dane and Topp (2020) and Sparks et al. (2020) for soil analyses and Nollet and De Gelder (2000) for water analyses.

Experimental set up

This study employed a split-plot design with three replicates to evaluate the effects of irrigation treatments and amino acid applications on onion plants (Cv. Giza Red). The experimental subplot area measured 12.8 m² (4.0 m × 3.2 m), with a 2.5 m separator between the main irrigation plots. Each subplot consisted of eight ridges, each 0.75 m wide and 3.0 m long. On November 29th, onion seedlings, 60 days old, were transplanted, arranged on both sides of the ridges with a spacing of 30 cm between plants. The experiment involved two irrigation treatments: half of the plot received non-magnetized water, while the other half was irrigated with magnetized water, as per the prescribed treatments. All studied amino acids were applied via foliar spray three times at three-week intervals, starting from the third irrigation event. Each amino acid application utilized a solution volume of 450 L per fed. The onion plants received a total nitrogen dosage of 288 kg N ha⁻¹, administered in two equal doses. The first dose was applied approximately one month after transplanting, followed by the second dose one month later. Additionally, calcium super-phosphate (15.5% P₂O₅) was added at a rate of 150 kg P₂O₅ ha⁻¹, two weeks before transplanting. Harvesting was performed manually 160 days after transplanting.

Measurement traits

At the 85-day mark post-transplanting, various growth and chemical attributes of onion plants were assessed. This included the measurement of growth parameters such as plant height (cm) and the determination of leaf fresh and dry weights (g plant⁻¹). Photosynthetic pigments, specifically chlorophyll (SPAD value) using SPAD-502 (Soil-

Plant Analysis Development, Minolta Camera, Osaka, Japan) as described by Castelli et al. (1996), and carotene (mg g^{-1} F.W) determined according to Şükran et al. (1998) via the spectrophotometric method, were also analyzed. The dry weight of foliage samples underwent digestion using a mixture of $\text{HClO}_4 + \text{H}_2\text{SO}_4$ following Peterburgski's method (1968). Nutrient content, namely Nitrogen, phosphorus, and potassium, presented as a percentage of dry weight (% DW), was determined through Micro-Kjeldahl, spectrophotometric, and flame photometer methods, respectively, in accordance with Walinga et al. (2013).

At the appropriate maturing stage of the bulbs (160 days from transplanting), harvesting was carried out, and various physical and quality characteristics were examined, including average bulb weight (g), diameter (cm), neck diameter (cm), total bulb yield (ton ha^{-1}), marketable bulb yield (ton ha^{-1}) as part of the physical characteristics. Quality characteristics of the bulbs were assessed through the determination of vitamin C (mg 100g^{-1}), total dissolved solid (TDS, %), total sugar (%), fiber (%) following AOAC (2007) methods. Dry matter (DM, %) content was calculated by oven-drying onion samples at 70°C until a constant weight was achieved. Anthocyanin pigment (mg 100g^{-1}) levels were determined as described by Crecente-Campo et al. (2012), pyruvic acid ($\mu\text{mol g}^{-1}$) content was assessed according to Anthon and Barrett (2003), Quercetin content was determined spectrophotometrically according to the method described by Chang et al. (2002). Fresh onion samples were extracted using 80% methanol, and the absorbance of the reaction mixture containing AlCl_3 was measured at 415 nm using a spectrophotometer. Quercetin standard was used for calibration, and results were expressed as mg quercetin per 100 g fresh weight (mg/100 g FW), Carbohydrates (%) and crude protein (%) levels were determined following AOAC (2007) protocols.

Statistical analysis

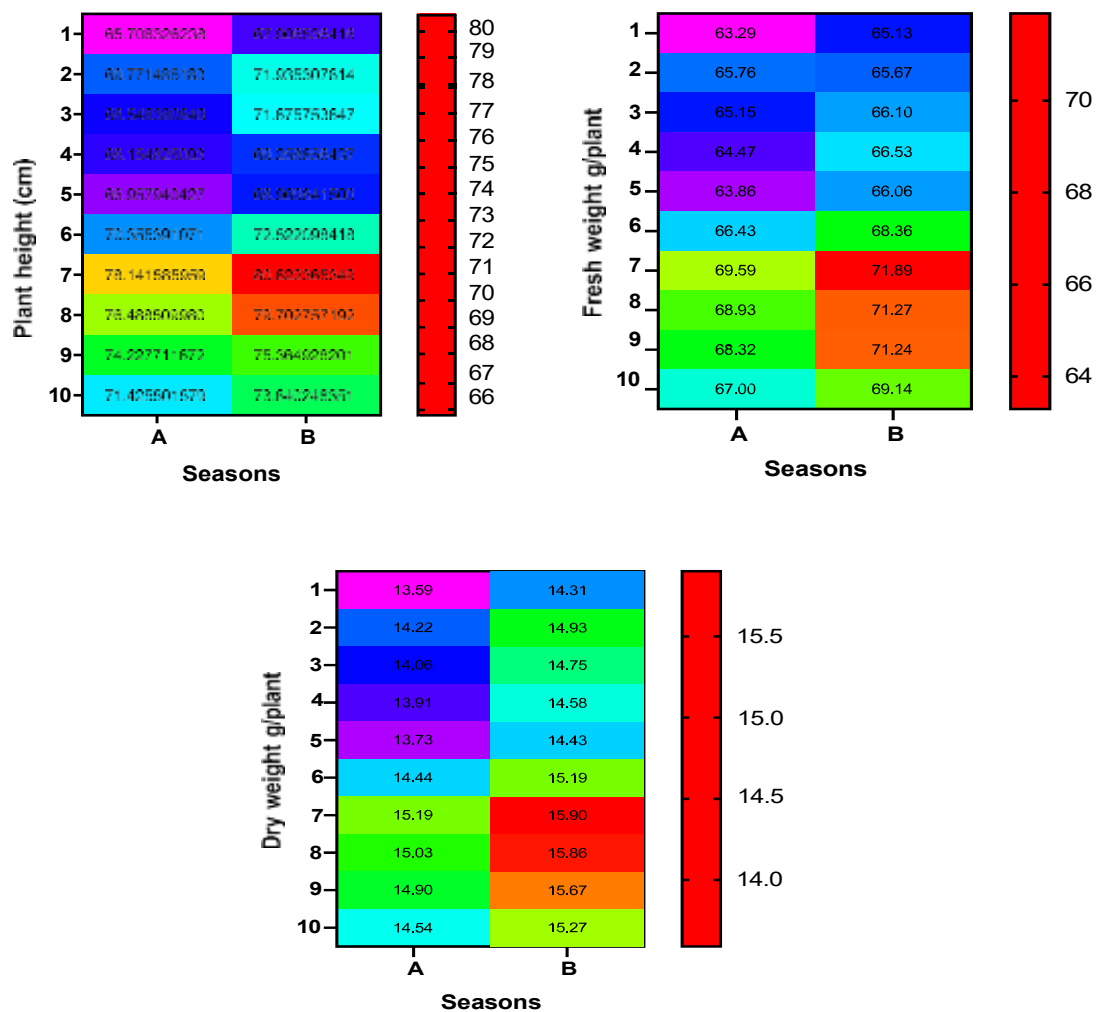
Data were analyzed using Co Stat software (Version 6.303, Co Hort, USA, 1998-2004). To assess the significance of the treatment effects, means were compared using Duncan's multiple range test at a 5% probability level (Waller and Duncan, 1969). This analysis allowed for the identification of significant differences among the various treatment groups in relation to the measured growth and yield parameters.

3 Results

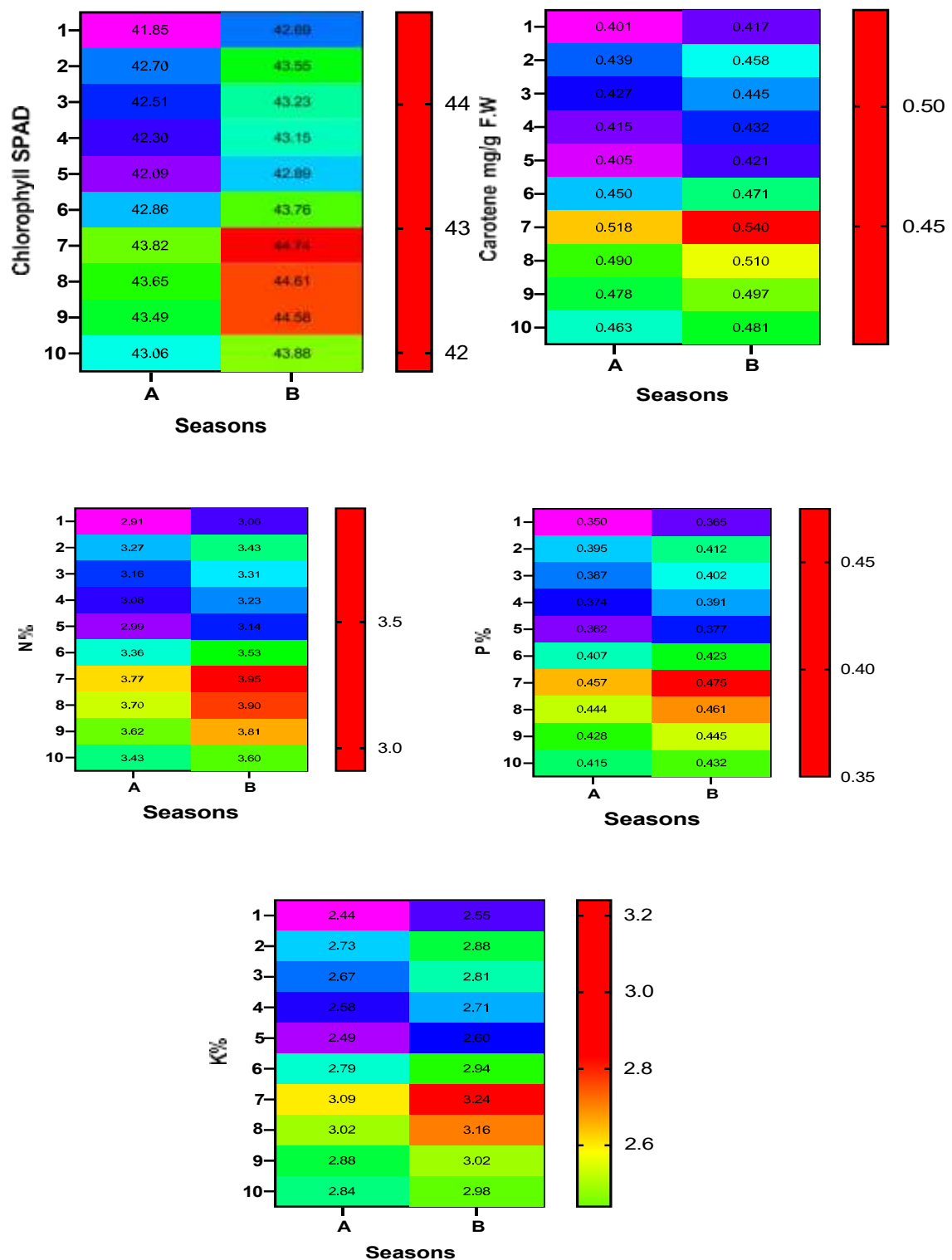
Onion performance after 85 days from sowing

After 85 days from sowing, all examined treatments had a significant impact on onion performance, as indicated by various growth parameters such as plant height (cm), leaf fresh and dry weights (g plant^{-1}), photosynthetic pigments including chlorophyll (SPAD value) and carotene (mg g^{-1} F.W) (Table 3) and leaf chemical constituents i.e., nitrogen, phosphorus and potassium (%) (Table 4). This trend was observed consistently across both studied seasons. The data show that the onion plants subjected to magnetic water treatment exhibited superior onion performance compared to those irrigated with untreated water. In terms of foliar application, the control treatment displayed the least favorable outcomes when compared to the other four amino acid treatments. Proline emerged as the most effective amino acid for achieving optimal performance under both water conditions, followed by glycinebetaine, arginine, and lastly, methionine. Overall, it is noteworthy that the highest values for plant height (cm), leaf fresh and dry weights (g plant^{-1}), chlorophyll (SPAD value), carotene (mg g^{-1} F.W), and leaf content of nitrogen, phosphorus, and potassium (%) were achieved when plants were irrigated with magnetic water and simultaneously sprayed with proline amino acid. The heat maps (1&2) provide a clear visual representation of these findings, highlighting the distribution of values across treatments. Warmer colors (e.g., red and orange) dominate the areas corresponding to magnetic water combined with proline, indicating the highest growth and quality metrics, such as plant height, leaf weights, chlorophyll content, carotene concentration, and nutrient uptake. Conversely, cooler colors (e.g.,

blue) are more prevalent in the control treatments, illustrating their comparatively lower performance. This visual analysis reinforces the synergistic effects of magnetically treated water and proline foliar application, which collectively optimize onion growth, yield, and quality under water-scarce conditions.



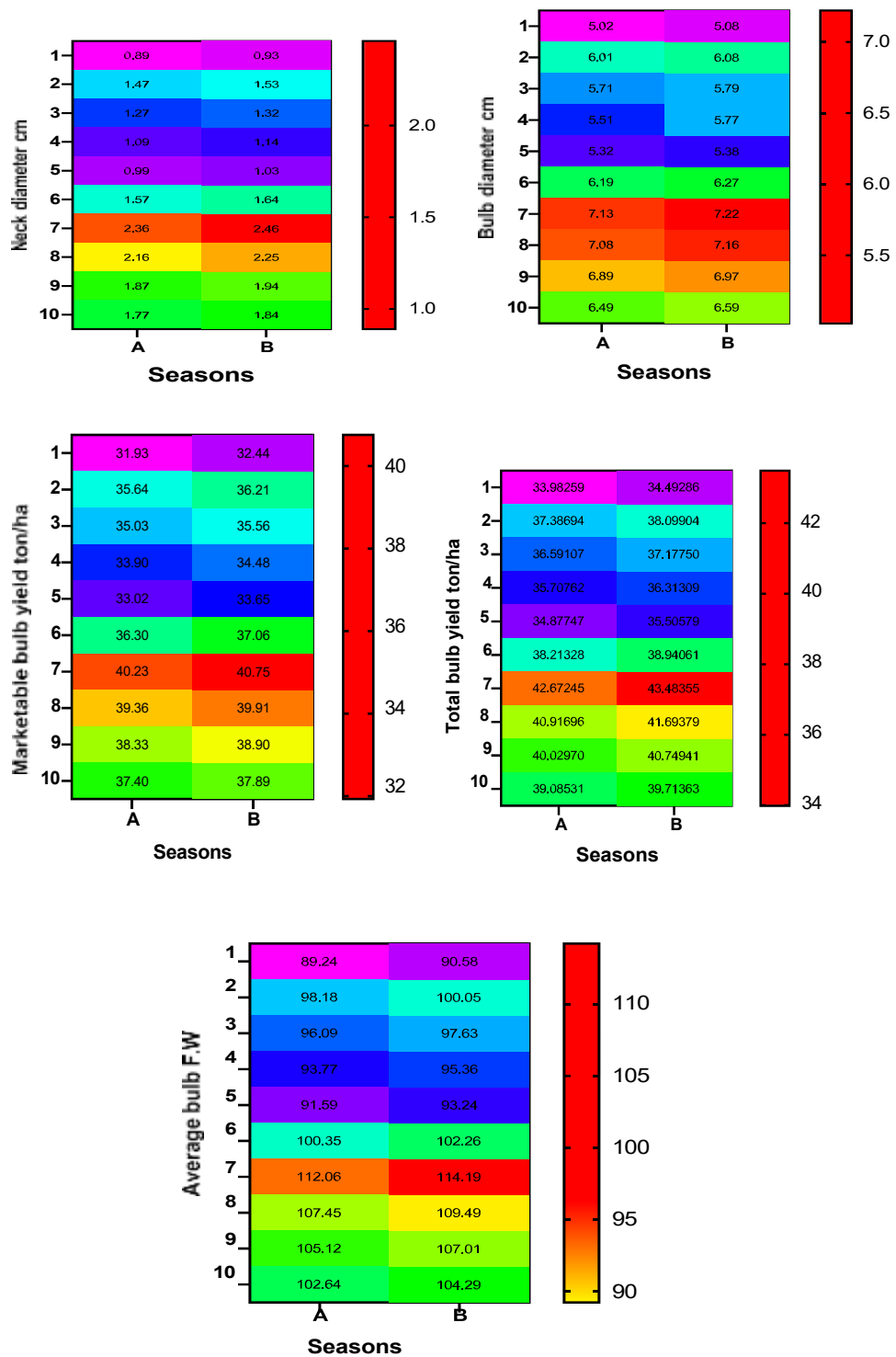
Heat map 1. Response of some growth criteria to the studied treatments



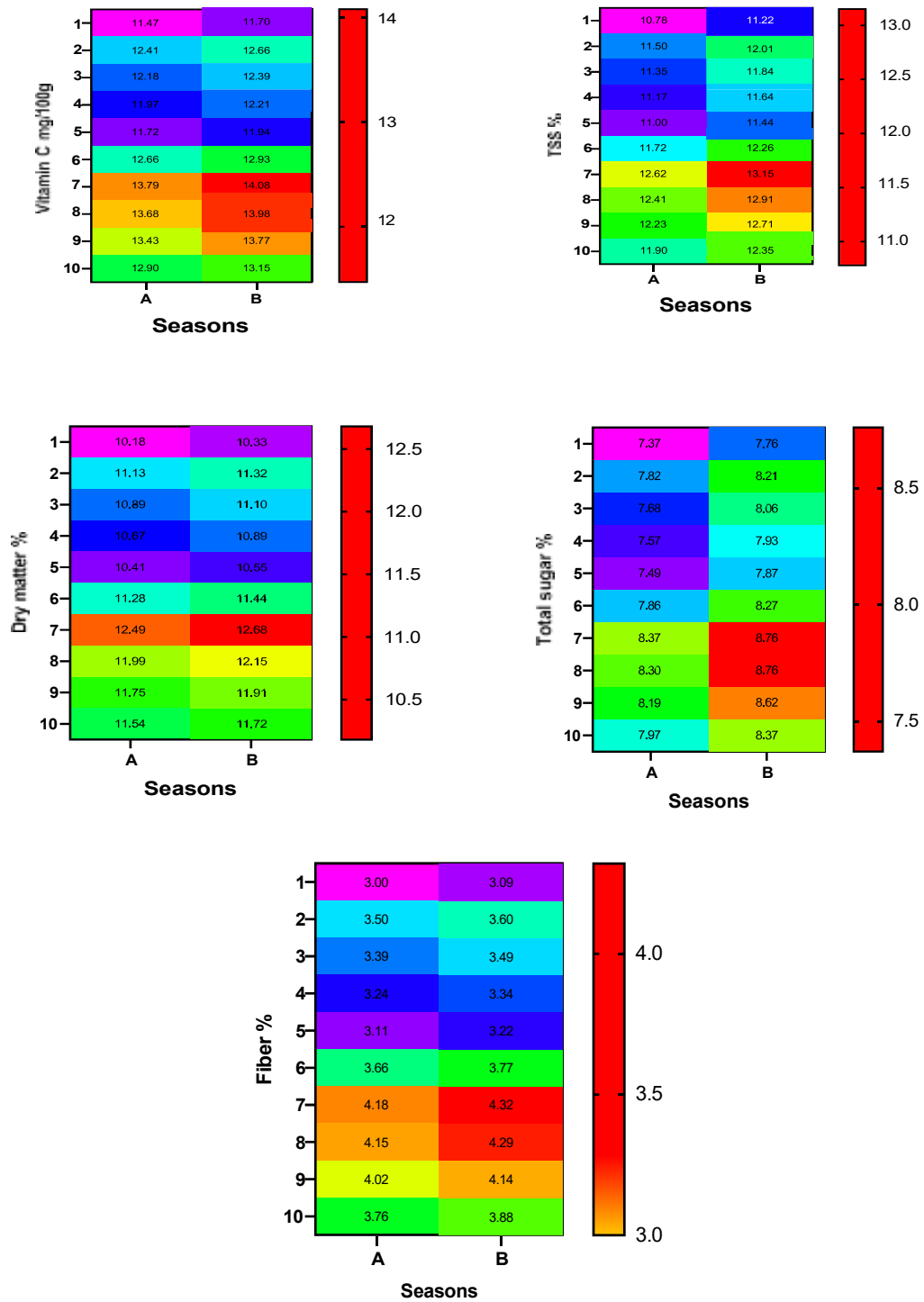
Heat map 2. Response of photosynthetic pigments and chemical content to the studied treatments

Bulb yield and quality at harvest stage

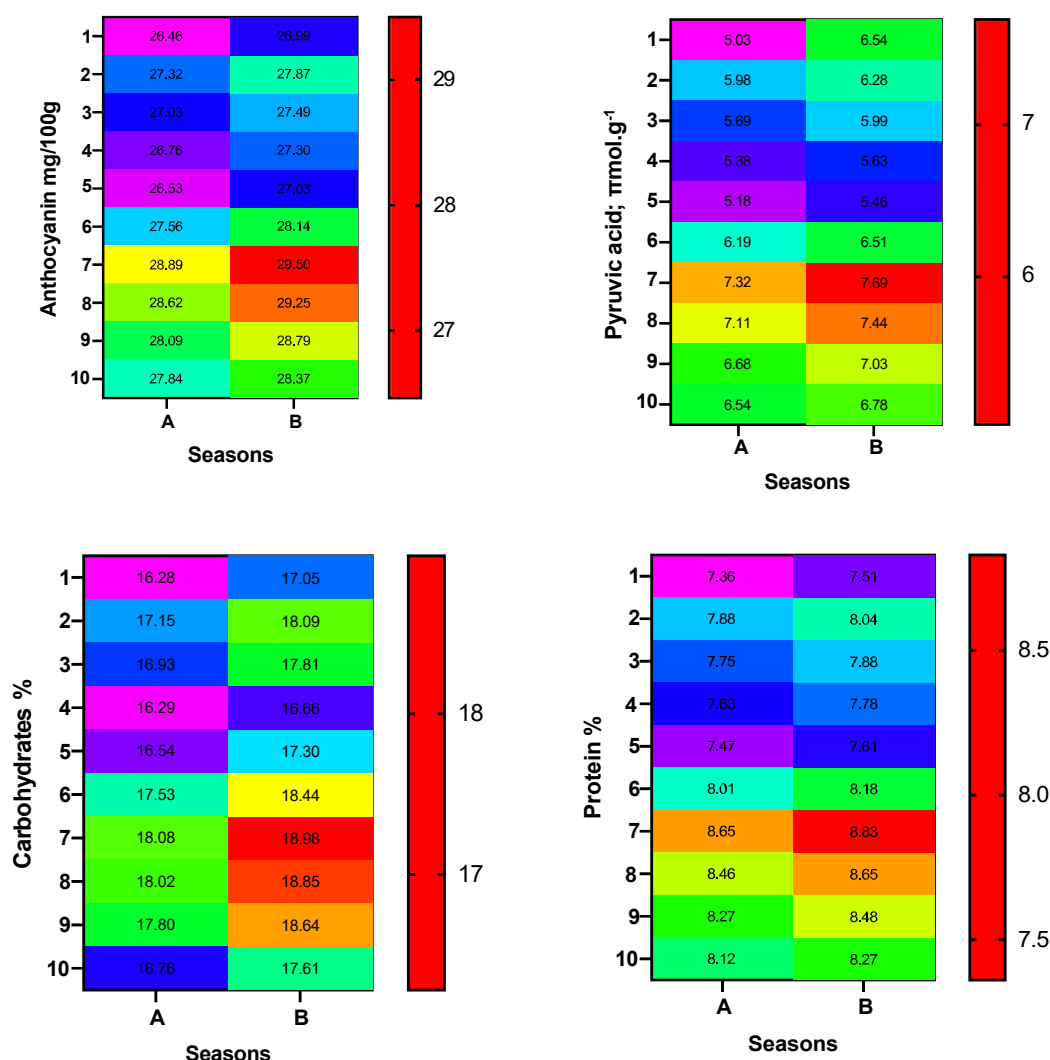
Data in Tables 5 and 6 depict the effect of two types of irrigation water (magnetic and nonmagnetic) and four amino acids (proline, glycinebetaine, arginine and methionine) on onion quantitative and qualitative during both studied seasons. The findings revealed that onion plants irrigated with magnetic water had the maximum values of average bulb weight (g), diameter(cm), neck diameter (cm), total bulb yield (ton ha⁻¹), marketable bulb yield (ton ha⁻¹, Fig1) (Table 5), vitamin C (mg 100g⁻¹), total dissolved solid (TDS,%), dry matter (DM,%), total sugar (%), fiber(%) (Table 6), anthocyanin (mg 100g⁻¹), pyruvic acid (μmol g⁻¹), carbohydrates (%), crude protein (%) (Table 7) and quercetin content (mg/100 g FW, Fig2) compared to those irrigated with non-magnetic water, which exhibited the lowest values across all examined quantitative and qualitative traits. Concerning foliar applications, proline treatment emerged as the most effective in achieving the highest values for all the mentioned quantitative and qualitative traits. Following proline, glycinebetaine treatment ranked second, succeeded by arginine treatment, methionine treatment, and lastly, the control treatment that did not receive any amino acid. Generally, onion plants subjected to magnetic water irrigation and simultaneously treated with proline amino acid exhibited the most favorable quantitative and qualitative traits. The heat maps (3&4_{a, b}) visually underscore these trends, with warmer colors (e.g., red and orange) dominating areas representing magnetic water combined with proline foliar application, which exhibited the most favorable results. Cooler colors (e.g., blue) are concentrated in the control and nonmagnetic water treatments, reflecting their comparatively lower performance. Among foliar applications, proline was the most effective, followed by glycine betaine, arginine, and methionine, while the control treatment consistently ranked lowest. Overall, the combination of magnetic water irrigation and proline foliar application proved to be the optimal strategy for enhancing both the quantitative and qualitative traits of onion plants, as vividly demonstrated by the heat maps.



Heat map 3. Response of bulb traits and yield to the studied treatments



Heat map 4a. Response of bulb quality to the studied treatments



Heat map 4b. Response of bulb quality to the studied treatments

4 Discussions

Onion performance after 85 days from sowing

The obtained results were due to the advantages of magnetic water on the onion performance expressed in plant height (cm), leaf fresh and dry weights (g plant⁻¹), photosynthetic pigments including chlorophyll (SPAD value) and carotene (mg g⁻¹ F.W) and leaf chemical constituents i.e., nitrogen , phosphorus and potassium (%). Magnetic water treatment may enhance nutrient uptake by the onion plants. The magnetic field could potentially alter the physical and chemical properties of water, making it more conducive for nutrient absorption by the roots. This could result in increased levels of essential nutrients, such as nitrogen, phosphorus, and potassium, in the plant tissues, contributing to overall growth. Also, magnetic fields might stimulate metabolic processes within the plant, leading to increased synthesis of chlorophyll, carotene, and other pigments. This stimulation can positively influence photosynthetic activity, thereby promoting greater plant height and increased fresh and dry weights. Magnetic water treatment may also contribute to the overall improvement of water quality, reducing the presence of harmful substances or impurities that could otherwise

negatively impact plant performance (Dobránszki et al. 2023; Khoshravesh and Pourgholam-Amiji, 2023).

In terms of foliar application, proline, glycinebetaine, arginine, and methionine are amino acids known to play crucial roles in plant metabolism. Proline, for instance, is involved in stress tolerance and osmotic regulation, which could contribute to improved performance under varying water conditions. This is probably why proline is superior. The amino acids applied foliar may enhance the onion plants' stress tolerance, especially under adverse growing conditions. This could explain why the control treatment, without amino acid application, exhibited less favorable outcomes. Amino acids are essential components in the synthesis of proteins and enzymes involved in photosynthesis. The application of amino acids could positively influence chlorophyll content and photosynthetic pigments, leading to increased plant height and improved weight parameters (Abdelkader et al. 2023; Seyedi et al. 2023; Yousif and Esho, 2023).

Overall, the observed peak in performance when plants were both irrigated with magnetic water and sprayed with proline suggests a potential synergistic effect. The magnetic water treatment may create an environment that enhances the uptake and utilization of proline, maximizing its positive impact on plant growth. The combination of magnetic water treatment and proline application may optimize nutrient absorption and utilization, leading to the highest values in plant height, weight parameters, chlorophyll content, carotene, and leaf nutrient concentrations. In summary, the obtained results can be attributed to a combination of factors, including improved nutrient availability, enhanced stress tolerance, and potential synergistic effects between magnetic water treatment and amino acid application, particularly proline. The results align with the studies conducted by El-Abagy et al. (2014); Ali et al. (2017).

Bulb yield and quality at harvest stage

The quantitative and qualitative traits of onion plants irrigated with magnetically treated water can be attributed to alterations in its properties, such as viscosity, hydrogen bonding, polarity, solubility of salts, conductivity, pH, and surface tension. These modifications are believed to be responsible for the observed improvements in onion plant performance. Magnetic water treatment may enhance the availability and uptake of essential nutrients by onion plants. This heightened nutrient accessibility could contribute to increased bulb weight, diameter, neck diameter, and overall bulb yield. Magnetic water treatment might improve water quality by altering its physical and chemical properties, leading to better nutrient transport to plant roots, subsequently influencing various biochemical processes and nutrient absorption, antioxidant activity, and secondary metabolite accumulation, which are closely related to flavonoid biosynthesis (Safwat and Abdel Salam, 2022; Khoshravesh & Pourgholam-Amiji, 2023; Shaban et al. 2023; Putti et al. (2023) and Alhaithloul et al. 2025). This improvement is reflected in the elevated levels of vitamin C, total dissolved solids, dry matter, total sugar, fiber, anthocyanin, pyruvic acid, quercetin content, carbohydrates, and crude protein.

Concerning foliar applications, proline, being an amino acid, is known for its role in stress tolerance. Its application may enhance the plant's ability to withstand adverse conditions, resulting in improved quantitative and qualitative traits, such as increased bulb weight, diameter, and biochemical content. Glycinebetaine, ranked second in effectiveness, is involved in osmoregulation and can contribute to the plant's ability to maintain water balance. This may influence bulb characteristics and biochemical composition. The positive impact of arginine and methionine can be attributed to their roles in protein synthesis and various metabolic pathways. While not as effective as proline and glycinebetaine, their application still contributes to improved plant performance (Khater et al. 2024; Mahdi, 2023; Niu, et al. 2023; Seyedi et al. 2023).

The most favorable results observed in onion plants subjected to both magnetic water irrigation and proline amino acid treatment suggest potential synergistic effects. The improved nutrient availability from magnetic water may complement the stress-tolerant properties of proline, resulting in enhanced quantitative and qualitative traits. Generally, the superior performance of onion plants irrigated with magnetic water and treated with proline amino acid can be attributed to a combination of factors, including improved nutrient availability, enhanced stress tolerance, and potential synergies between magnetic water treatment and the specific biochemical functions of proline. The findings are in harmony with those of El-Abagy et al. (2014); Ali et al. (2017).

Overall, our study's findings indicate that the use of magnetically treated water and amino acid applications significantly improved onion plant growth and productivity. To gain a deeper understanding of these effects, it is crucial to explore the biochemical and molecular mechanisms that may be responsible for these enhancements. Firstly: The Effect of Magnetically Treated Water on Nutrient Uptake and Ion Balance: When water is magnetically treated, its physical properties, such as surface tension and viscosity, can change, potentially enhancing the plant's ability to absorb nutrients. This change is believed to improve root nutrient uptake efficiency, leading to better overall plant nutrition and growth. Moreover, magnetically treated water may influence the ion balance within plant cells, supporting physiological processes associated with growth, such as ion exchange regulation and maintaining stable pH levels in plant tissues (Lin et al. 2024). Secondly: The Role of Amino Acids in Enhancing Osmotic Stress Tolerance and Growth Promotion: Amino acids like proline and glycinebetaine play a pivotal role in improving plant tolerance to various environmental stresses, particularly osmotic stress caused by the use of low-quality irrigation water. Proline, in particular, acts as a protective agent by stabilizing cell membranes and proteins and maintaining osmotic balance within plant cells. It can also function as a signaling molecule, activating biochemical pathways that trigger antioxidant production, thereby enhancing the plant's ability to cope with osmotic stress (Romanenko et al. 2024). The authors reported that flavonoid biosynthesis is closely related to amino acid metabolism, which acts as a precursor for phenolic compounds and flavonoids such as quercetin. They also indicated that stimulation of plant metabolism may enhance the accumulation of antioxidant secondary metabolites in plants. (Lemanowicz et al. 2025). Thirdly:

Applying magnetically treated water in conjunction with foliar amino acid applications may have a synergistic effect. Magnetized water could enhance the absorption of amino acids at the leaf level, increasing their concentration within plant tissues. This higher concentration may accelerate physiological processes that improve growth, such as stimulating enzyme production linked to photosynthesis and promoting the synthesis of organic compounds essential for cell development.

5. Conclusion

In water-scarce regions, the imperative use of low-quality irrigation water necessitates meticulous management to alleviate detrimental impacts on soil and crop well-being. This study explored the efficacy of magnetically treated irrigation water and external applications of specific amino acids in enhancing the growth and development of onion plants. The results indicated that magnetically treated water significantly outperformed non-treated water, showcasing superior growth, yield, and quality parameters. The foliar application of amino acids also played a pivotal role in influencing plant performance. Proline demonstrated exceptional effectiveness, proving to be the most favorable amino acid under both water conditions. Glycinebetaine, arginine, and methionine followed in descending order of impact.

Given the notable benefits observed in onion plants irrigated with magnetically treated water, farmers in water-scarce regions should be encouraged to explore and adopt magnetic water treatment technologies. These approaches can contribute to sustaining agriculture by improving soil and crop health. Also, Farmers should consider incorporating specific amino acids, particularly proline, in their foliar application practices. Proline has demonstrated consistent positive effects on plant growth and development, making it a valuable supplement for crops facing challenging water conditions. Further research is warranted to explore the long-term effects and potential variations in the performance of different crops under similar conditions. This will contribute to a more comprehensive understanding of the practical applications of magnetically treated water and amino acid foliar treatments in diverse agricultural settings.

Author Contributions:

Conceptualization: Mohamed Abdein, Mohamed Abd El-Aziz, Naglaa Khalafallah, Yasser Hafez and Dina Ghazi;

Data curation: Dina Ghazi, Mohamed El-Sherpiny, Mohamed Abd El-Aziz, Taghreed Badawi, Yasser Hafez, Nada Kamel, Sadoun Sultan, Asem Abdel-Gawad, Naglaa Khalafallah and Amal Helmy;

Formal analysis: Mohamed El-Sherpiny, Taghreed Badawi, Yasser Hafez, Mohamed Azab, Sadoun Sultan, Asem Abdel-Gawad Mohamed Abdein, Dina Ghazi, Nada Kamel, and Amal Helmy;

Funding acquisition: All authors;

Investigation: Mohamed Abd El-Aziz, Mohamed Azab, Sadoun Sultan, Nada Kamel, and Naglaa Khalafallah;

Methodology: Dina Ghazi, Mohamed El-Sherpiny, Mohamed Abd El-Aziz, Taghreed Badawi, Yasser Hafez, Mohamed Azab, Sadoun Sultan, Asem Abdel-Gawad and Amal Helmy;

Project administration: Yasser Hafez, Asem Abdel-Gawad, Mohamed Abdein and Taghreed Badawi; **Resources:** Dina Ghazi, Mohamed Abd El-Aziz, Taghreed Badawi, Yasser Hafez, Mohamed Azab, Sadoun Sultan, Mohamed Abdein and Amal Helmy;

Software: Naglaa Khalafallah, Mohamed Azab, Asem Abdel-Gawad, Nada Kamel, and Mohamed Abd El-Aziz;

Supervision: Mohamed El-Sherpiny and Mohamed Abdein;

Validation: Naglaa Khalafallah, Asem Abdel-Gawad, Nada Kamel, and Mohamed Abd El-Aziz;

Visualization: Mohamed El-Sherpiny, Naglaa Khalafallah, Taghreed Badawi, Mohamed Azab, Sadoun Sultan and Amal Helmy

Writing – original draft: Dina Ghazi, Mohamed El-Sherpiny, Mohamed Abdein, Nada Kamel, Mohamed Azab,, Naglaa Khalafallah and Amal Helmy;

Writing – review & editing: Dina Ghazi, Mohamed El-Sherpiny, Mohamed Abdein, Taghreed Badawi, Yasser Hafez, Nada Kamel, Sadoun Sultan, Asem Abdel-Gawad and Amal Helmy.

Acknowledgments:

The authors extend their appreciation to the Water and Environment Research Institute and Horticultural Research Institute, Agriculture Research Centre, Egypt.

Funding information

The authors financially support this research.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Declare no conflict of interest: The authors declare that they have no known competing financial interests or personal relationships.

References

1. Abdelkader, M., Voronina, L., Shelepova, O., Puchkov, M., Loktionova, E., Zhanbyrshina, N., ... & Ksenofontov, A. (2023). Monitoring role of exogenous amino acids on the proteinogenic and ionic responses of lettuce plants under salinity stress conditions. *Horticulturae*, 9(6), 626.
2. Alhaithloul, H.A.S., Soliman, K.G., Ibrahim, A.H., Abdulmajeed, A.M., Alsirhani, A.M., Abdein, M.A. Alqahtani, M.M., Albalwe, F.M., Tahir, M., Elshamy, M.M., Kedra, E.G.A., Zayed, G.A. & Al-Hamed, A.M.A. (2025). Evaluation of the Water Quality Index of some Drains Linked to the Bahr El-Baqar Drain and Study of Heavy Metals in Vegetables Grown Around Them and Their Potential Risks to the Health. *Water, Air, & Soil Pollution*, 236, 539 (2025). <https://doi.org/10.1007/s11270-025-08110-y>
3. Al-Hazmi, H. E., Mohammadi, A., Hejna, A., Majtacz, J., Esmaeili, A., Habibzadeh, S., ... & Mąkinia, J. (2023). Wastewater treatment for reuse in agriculture: Prospects and challenges. *Environmental Research*, 116711.
4. Ali, A.F., Salim, H.A., & Alsaady, M.H.M. (2017). Impact of Magnetic Water Irrigation for Improve Growth Parameters of Two Onion Cultivars *Allium cepa* L. *Journal of Natural Sciences Research*, 7(10), 75-77.
5. Alkharpotly, A., Soliman, M., El-Sherpiny, M., Baddour, A., Ghazi, D., Abdelgawad, Z., Abdein, M., Alzuaibr, F., Alasmari, A., Albogami, A., Alqahtani, M., Hussein, H., Elkady, F. and Abdelkader, M. (2023a). Evaluation of Cobalt Application Combined with Gypsum and Compost as a Regulator of Cabbage Plant Tolerance to Soil Salinity. *Open Journal of Ecology*, 13, 914-930. doi: 10.4236/oje.2023.1312056
6. Alkharpotly, A.A., El-Ghamry, A.M., Abd El-Hady, M.A.M., El-Sherpiny, M.A., Baddour, A.G. El-Bauome, H.A., Hussein, H.A., Elkady, F.M.A., Alqahtani, M.M., Alzuaibr, F.M., Alasmari, A., Albogami, A., Abdein, M.A., and Abdelkader, M.F.M. (2023b). Zeolite Amendment for Enhanced Onion Growth with Reduced Mineral Nitrogen Fertilization: A Promising Approach. *Ecology, Environment and Conservation*, Vol. 29 (4): 1479-1489, 2023, <http://doi.org/10.53550/EEC.2023.v29i04.003>
7. Amin, M.A., Shahhat, I. M.A.M., Ismail, M.A., Nowwar, A.I., Elsheikh, S.Y.S., El-Khawaga, H.A., Abdelwahab, A.T., Abdelfattah, M.A., Elsherbeny, S.A., Abdel-Mageed, A.M., Abdein, M.A., & Bedawy, I. M. (2024). Vicia faba overcomes drought stress by spraying with Xerophytic *Anabasis setifera* extract. *Edelweiss Applied Science and Technology*, 8(6), 8008-8022. <https://doi.org/10.55214/25768484.v8i6.3737>
8. Anthon, A. and D. Barrett (2003). Modified method for the determination of pyruvic acid with di-nitrophenyl hydrazine in the assessment of onion pungency. *J Sci. Food Agric.*, 83:1210-1213.
9. AOAC. (2007). "Official Methods of Analysis. 18th Ed". Association of Official Analytical Chemists", Inc., Gaithersburg, MD, Method 04.
10. Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture* (Vol. 29, p. 174). Rome: Food and Agriculture Organization of the United Nations.
11. Azab, M. A., Z.F. Fawzy, M.A. Abdein, H.A. Hussein, M.M. Alqahtani, F.M. Alzuaibr, E.S. Dessoky, M.F. M. Abdelkader, K.Z. Ghanem, S.M.E. Sultan, M.N. Shehata. (2024). Response of onion growth and seed yield to various phosphorus rates and foliar application of Nano-Boron, Nano-Chitosan and Naphthalene Acetic Acid. *Journal of Infrastructure, Policy and Development*. 8(8): 4679. <https://doi.org/10.24294/jipd.v8i8.4679>

12. Castelli, F., Contillo, R., & Miceli, F. (1996). Non-destructive Determination of Leaf Chlorophyll Content in Four Crop Species 1. Journal of Agronomy and Crop Science, 177(4): 275-283.
13. Chang, C.-C., Yang, M.-H., Wen, H.-M., & Chern, J.-C. (2002). Estimation of total flavonoid content in propolis by two complementary colorimetric methods. Journal of Food and Drug Analysis, 10(3), 178–182. <https://doi.org/10.38212/2224-6614.2748>
14. Crecente-Campo, J., Nunes-Damaceno, M., Romero-Rodríguez, M. A and Vázquez-Odériz, M. L. (2012). Color, anthocyanin pigment, ascorbic acid and total phenolic compound determination in organic versus conventional strawberries (*Fragaria× ananassa* Duch, cv Selva). Journal of Food Composition and Analysis, 28(1): 23-30.
15. Dane, J.H. and Topp, C.G. (Eds.) (2020). "Methods of soil analysis", Part 4: Physical methods (Vol. 20). John Wiley & Sons.
16. Dobránszki, J. (2023). From mystery to reality: Magnetized water to tackle the challenges of climate change and for cleaner agricultural production. Journal of Cleaner Production, 139077.
17. El-Abagy, H.M., El-Tohamy, W.A., Abdel-Mawgoud, A.M.R., & Abou-Hussein, S.D. (2014). Effect of different amino acid sources and application rates on yield and quality of onion in the newly reclaimed lands. Middle East J. Agric. Res, 3(1), 81-88.
18. Gad, W. A. (2017). Water scarcity in Egypt: causes and consequences. IIOAB J, 8(4), 40-47.
19. Ibrahim, H.H., Abdalla, A.A., & Salem, W.S. (2022). Efficacy of irrigation intervals and chemical weed control on optimizing bulb yield and quality of onion (*Allium cepa* L.). Bragantia, 81, 1722.
20. Khairy, S., Shaban, M., Negm, A. M., Eldeen, O.W., & Ramadan, E.M. (2022). Drainage water reuse strategies: case of El-bats drain, Fayoum governorate, Egypt. Ain Shams Engineering Journal, 13(5), 101681.
21. Khater, M.A., Zaki, F., Dawood, M., El-Awadi, M.E., & Elsayed, E. (2024). Comparing Physiological Role of L-Methionine and its Encapsulated NanoForm on Growth and Crop Productivity of Onion (*Allium Cepa* L.). Egyptian Journal of Chemistry, 67(4), 291-307. doi: 10.21608/ejchem.2023.238455.8675.
22. Khoshraves, M., & Pourgholam-Amiji, M. (2023). Effect of water stress on strawberry yield and yield components using magnetized water. Journal of Water Research in Agriculture, 36(4), 441-453.
23. Lemanowicz, J., Gawlińska, K., Jaskulska, I., Jaskulski, D., & Sar, M. (2025). Flavonoids in plants and human health: From biosynthesis to neurodevelopmental and neurodegenerative disorders. Molecules, 31(1), 66. <https://doi.org/10.3390/molecules31010066>.
24. Lin, S., Wang, Q., Deng, M., Wei, K., Sun, Y., & Tao, W. (2024). The mechanism of using magnetized-ionized water in combination with organic fertilizer to enhance soil health and cotton yield. Science of The Total Environment, 173781.
25. Mahdi, S.F. (2023). The effect of foliar spraying with the amino acid arginine on some vegetative and yield for cowpea plant *Vigna unguiculatal* L. exposed to salt stress. Journal of Survey in Fisheries Sciences, 10(3), 2796-2808.
26. Niu, T., Zhang, J., Li, J., Gao, X., Ma, H., Gao, Y., ... & Xie, J. (2023). Effects of exogenous glycine betaine and cycloleucine on photosynthetic capacity, amino acid composition, and hormone metabolism in *Solanum melongena* L. Scientific Reports, 13(1), 7626.
27. Nollet, L. M., & De Gelder, L. S. (Eds.). (2000). Handbook of water analysis. CRC press.

28. Peterburgski, A. V. (1968). "Hand Book of Agronomic Chemistry". Kolas Publishing House Moscow, (in Russian).
29. Putti, F. F., Gabriel Filho, L. R. A., Klar, A. E., Cremasco, C. P., & Ludwig, R. (2023). Effect of magnetic water treatment on the growth, nutritional status, and yield of lettuce plants under irrigation. *Horticulturae*, 9(4), 504. <https://doi.org/10.3390/horticulturae9040504>.
30. Romanenko, K. O., Babenko, L. M., & Kosakivska, I. V. (2024). Amino acids in regulation of abiotic stress tolerance in cereal crops: a review. *Cereal Research Communications*, 52(2), 333-356.
31. Saffan, M. M., Koriem, M. A., El-Henawy, A., El-Mahdy, S., El-Ramady, H., Elbehiry, F., & Prokisch, J. (2022). Sustainable production of tomato plants (*Solanum lycopersicum* L.) under low-quality irrigation water as affected by bio-nanofertilizers of selenium and copper. *Sustainability*, 14(6), 3236.
32. Safwat, G. A., & Abdel Salam, H. H. (2022). The effect of exogenous proline and glycine betaine on biochemical responses of salt-stressed basil plants. *Egyptian Journal of Botany*, 62(2), 531-545. <https://doi.org/10.21608/ejbo.2022.117935.1840>.
33. Seyed, A., Fathi, S., & Movloddzadeh, R. (2023). The effect of bio stimulants based on free amino acids on some growth and physiological parameters of *Dracocephalum moldavica* L. under salinity Stress. *Journal of Medicinal plants and By-product*.
34. Shaban, K. A., Ahmed, M. A., & El-Sayed, H. A. (2023). Effect of magnetic irrigation saline water and pre-sowing of grains treated with magnetic field on saline soil fertility and wheat productivity and quality. *Asian Journal of Advances in Agricultural Research*, 23(1), 41-58.
35. Sparks, D. L., Page, A. L., Helmke, P. A. & Loeppert, R. H. (Eds.). (2020). "Methods of soil analysis", part 3: Chemical methods (Vol. 14). John Wiley & Sons.
36. Stoica, F., Rațu, R. N., Veleşcu, I. D., Stănciuc, N., & Râpeanu, G. (2023). A comprehensive review on bioactive compounds, health benefits, and potential food applications of onion (*Allium cepa* L.) skin waste. *Trends in Food Science & Technology*, 104173.
37. Şükran, D. E. R. E., GÜNEŞ, T. & Sivaci, R. (1998). Spectrophotometric determination of chlorophyll-A, B and total carotenoid contents of some algae species using different solvents. *Turkish Journal of Botany*, 22(1):13-18.
38. Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W., & Novozamsky, I. (2013). *Plant analysis manual*. Springer Science & Business Media.
39. Waller, R. A., & Duncan, D. B. (1969). A Bayes rule for the symmetric multiple comparisons problem. *Journal of the American Statistical Association*, 64(328), 1484-1503.
40. Yousif, F. K., & Esho, K. B. (2023). Estimating the genetic parameters for vegetative and flower growth in muskmelon (*Cucumis melo* L.) and spraying with the amino acid of the proline and boron cultivated in dry area in the Al-Qosh region. *Journal of Pharmaceutical Negative Results*, 2157-2175.

List of tables

Table 1. Characteristics of the initial soil

Table 2. Chemical Composition of Irrigation Water Pre- and Post-Magnetization

Table 3. Growth performance of onion plants influenced by varied irrigation water and amino acid treatments over an 85-day period, seasons 2023/2024 and 2024/2025

Table 4. Leaf chemical constituents of onion plants influenced by varied irrigation water and amino acid treatments over an 85-day period, seasons 2023/2024 and 2024/2025

Table 5. Physical characteristics of bulbs and total yield of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Table 6. Bulb quality characteristics (V.C, TDS, DM, TS, fiber) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Table 7. Bulb quality characteristics (anthocyanin, pyruvic acid, carbohydrates, protein) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Table 1. Characteristics of the initial soil

Attributes	Values
Particle size distribution, %	
Sand	17.32
Silt	33.28
Clay	48.40
Texture class is clayey	
Chemical traits	
Organic matter, %	1.25
EC, dSm ⁻¹	5.65
pH (1:2.5 soil suspension)	7.88
Available nutrients, mg kg⁻¹	
Nitrogen (N)	55.5
Phosphorus (P)	11.22
Potassium (K)	250

Table 2. Chemical Composition of Irrigation Water Pre- and Post-Magnetization

Parameter	Irrigation water pre-magnetization	Irrigation water post-magnetization
pH	7.400	7.150
EC (dSm ⁻¹)	2.45	2.00
Soluble cations, meq L⁻¹		
Ca ⁺²	2.95	1.8
Mg ⁺²	3.36	2.9
Na ⁺	18.29	15.4
K ⁺	0.006	0.005
Soluble anions, meq L⁻¹		
CO ₃ ⁻²	ND	ND
HCO ₃ ⁻	3.80	3.43
Cl ⁻	18.6	14.8
SO ₄ ⁻²	2.22	1.90
*Water class	C3	C2

* According to **Ayers and Westcot (1985)**, as C1 - Low salinity water: EC less than 0.75 dSm⁻¹, C2 - Medium salinity water: EC between 0.75 to 2.25 dSm⁻¹, C3 - High salinity water: EC between 2.25 to 4 dSm⁻¹, C4 - Very high salinity water: EC greater than 4 dSm⁻¹

Table 3. Growth performance of onion plants influenced by varied irrigation water and amino acid treatments over an 85-day period, seasons 2023/2024 and 2024/2025

Treatments		Growth criteria						Photosynthetic pigments			
		Plant height, cm		Fresh weight, g plant ⁻¹		Dry weight, g plant ⁻¹		Chlorophyll, SPAD value		Carotene, mg g ⁻¹ F.W	
		1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Main factor: Water irrigation types											
Non-treated water		67.83b	69.95b	64.45b	65.93b	13.90b	14.59b	42.39b	43.08b	0.417b	0.434b
Magnetically		74.13a	76.37a	67.99a	70.35a	14.84a	15.57a	43.32	44.29a	0.479a	0.500a
LSD at 5%		0.96	0.44	2.03	1.45	0.18	0.02	0.63	0.68	0.013	0.015
Sub main factor: Amino acid types											
Without amino acids (control)		68.04d	70.22c	64.78b	66.67c	14.01b	14.73b	42.35a	43.22c	0.425e	0.444d
Proline		73.96a	76.28a	67.64a	68.95a	14.73a	15.41a	43.25a	44.12a	0.478a	0.499a
Glycinebetaine		72.52b	75.69a	67.01ab	68.63ab	14.56ab	15.29ab	43.08a	43.88ab	0.458b	0.477b
Arginine		71.20c	72.32b	66.28ab	68.87a	14.41ab	15.12ab	43.02a	43.88ab	0.446c	0.464c
Methionine		69.20d	71.31bc	65.40ab	67.57bc	14.15b	14.84b	42.58a	43.34bc	0.434d	0.451d
LSD at 5%		1.26	1.22	2.55	1.09	0.60	0.56	*N.S	0.62	0.007	0.008
Interaction											
Non-treated water	Control	65.71	67.91	63.18	65.04	13.58	14.30	41.97	42.71	0.401	0.417
	Proline	69.78	71.94	65.76	65.98	14.27	14.91	42.72	43.50	0.439	0.458
	Glycinebetaine	68.55	71.68	65.10	66.07	14.00	14.72	42.50	43.19	0.427	0.445
	Arginine	68.16	69.26	64.36	66.56	13.90	14.58	42.55	43.17	0.415	0.432
	Methionine	66.96	68.97	63.86	65.98	13.77	14.42	42.24	42.84	0.405	0.421
Magnetically	Control	70.36	72.53	66.38	68.30	14.45	15.16	42.73	43.72	0.450	0.471
	Proline	78.15	80.63	69.53	71.92	15.18	15.90	43.79	44.75	0.518	0.540
	Glycinebetaine	76.49	79.70	68.92	71.19	15.12	15.85	43.67	44.57	0.490	0.510
	Arginine	74.23	75.37	68.21	71.18	14.91	15.66	43.49	44.58	0.478	0.497
	Methionine	71.43	73.64	66.93	69.15	14.54	15.26	42.92	43.84	0.462	0.481
LSD at 5%		1.78	1.73	3.61	1.54	1.28	0.80	*N.S	0.89	0.010	0.012

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 4. Leaf chemical constituents of onion plants influenced by varied irrigation water and amino acid treatments over an 85-day period, seasons 2023/2024 and 2024/2025

Treatments		Nitrogen, %		Phosphorus, %		Potassium, %	
		1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Main factor: Water irrigation types							
Non-treated water		3.04b	3.23b	0.373b	0.389b	2.58b	2.71b
Magnetically treated		3.57a	3.75a	0.430a	0.447a	2.92a	3.07a
LSD at 5%		0.16	0.04	0.006	0.02	0.09	0.09
Sub main factor: Amino acid types							
Without amino acids		3.04d	3.30e	0.378e	0.394e	2.61c	2.74c
Proline		3.52a	3.69a	0.426a	0.443a	2.91a	3.06a
Glycinebetaine		3.43ab	3.60b	0.415b	0.431b	2.85a	2.99ab
Arginine		3.35bc	3.52c	0.401c	0.418c	2.73b	2.86bc
Methionine		3.21c	3.37d	0.388d	0.404d	2.66bc	2.79c
LSD at 5%		0.16	0.06	0.007	0.004	0.10	0.15
Interaction							
Non-treated water	Control	2.71	3.06	0.350	0.365	2.44	2.54
	Proline	3.27	3.43	0.395	0.412	2.73	2.86
	Glycinebetai	3.16	3.31	0.386	0.402	2.67	2.81
	Arginine	3.08	3.23	0.374	0.391	2.57	2.72
	Methionine	2.99	3.13	0.362	0.376	2.49	2.60
Magnetically treated water	Control	3.36	3.53	0.407	0.423	2.79	2.94
	Proline	3.77	3.94	0.457	0.475	3.09	3.26
	Glycinebetai	3.70	3.90	0.444	0.461	3.02	3.17
	Arginine	3.62	3.80	0.428	0.445	2.88	3.01
	Methionine	3.43	3.60	0.414	0.432	2.84	2.98
LSD at 5%		0.23	0.10	0.009	0.006	0.15	0.21

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 5. Physical characteristics of bulbs and total yield of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Treatments		Average bulb weight, g (F.W)		Bulb diameter, cm		Neck diameter, cm		Total bulb yield, ton ha ⁻¹		Marketable bulb yield, ton ha ⁻¹	
		1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Main factor: Water irrigation types											
Non-treated		93.7	95.33	5.51	5.59	1.14	1.19	35.6	36.3	33.88	34.
Magnetically		105.	107.4	6.75	6.84	1.95	2.03	40.1	40.9	38.28	38.
LSD at 5%		1.68	1.72	0.17	0.08	0.21	0.07	0.64	0.65	1.06	0.0
Sub main factor: Amino acid types											
Without amino		94.7	96.40	5.60	5.67	1.23	1.28	36.0	36.7	34.10	34.
Proline		105.	107.0	6.57	6.6a	1.91	2.00	40.0	40.7	37.92	38.
Glycinebetaine		101.	103.4	6.38	6.4a	1.72	1.79	38.7	39.4	37.13	37.
Arginine		99.4	101.2	6.20	6.31	1.48	1.54	37.8	38.5	36.09	36.
Methionine		97.0	98.66	5.90	5.98	1.38	1.44	36.9	37.5	35.16	35.
LSD at 5%		1.40	1.41	0.23	0.24	0.09	0.08	0.53	0.54	1.33	0.6
Interaction											
Non-treated water	Control	89.2	90.62	5.02	5.08	0.89	0.93	34.0	34.5	31.93	32.
	Proline	98.0	99.94	6.01	6.07	1.47	1.52	37.3	38.0	35.61	36.
	Glycinebeta	96.0	97.55	5.70	5.78	1.27	1.32	36.5	37.1	34.97	35.
	Arginine	93.8	95.41	5.51	5.66	1.09	1.14	35.7	36.3	33.90	34.
	Methionine	91.4	93.13	5.31	5.38	0.99	1.03	34.8	35.4	32.99	33.
Magnetically treated water	Control	100.	102.1	6.18	6.26	1.58	1.64	38.1	38.9	36.27	37.
	Proline	112.	114.2	7.13	7.22	2.35	2.48	42.6	43.4	40.23	40.
	Glycinebeta	107.	109.4	7.07	7.15	2.16	2.26	40.8	41.6	39.30	39.
	Arginine	105.	107.0	6.88	6.97	1.87	1.94	40.0	40.7	38.29	38.
	Methionine	102.	104.1	6.48	6.59	1.77	1.84	39.0	39.6	37.33	37.
LSD at 5%		1.96	2.00	0.32	0.33	0.13	0.12	0.75	0.76	1.87	0.94

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 6. Bulb quality characteristics (V.C, TDS, DM, TS, fiber) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Treatments		Vitamin C, mg 100g ⁻¹		TDS, %		Dry matter, %		Total sugar, %		Fiber, %	
		1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Main factor: Water irrigation types											
Non-treated		11.95b	12.17b	11.16b	11.63b	10.65b	10.82b	7.58b	7.96b	3.25b	3.36b
Magnetically		13.29a	13.58a	12.17a	12.67a	11.80a	11.99a	8.13a	8.55a	3.95a	4.08a
LSD at 5%		0.10	0.22	0.02	0.02	0.15	0.36	0.31	0.25	0.11	0.04
Sub main factor: Amino acid types											
Without amino		12.06d	12.31d	11.25c	11.75c	10.72e	10.86c	7.61c	8.01c	3.32c	3.43d
Proline		13.10a	13.37a	12.05a	12.57a	11.80a	12.00a	8.09a	8.48a	3.84a	3.96a
Glycinebetaine		12.92a	13.17b	11.88ab	12.37ab	11.43b	11.64ab	7.98ab	8.41ab	3.77a	3.89ab
Arginine		12.69b	12.99b	11.70b	12.17b	11.20c	11.40bc	7.87b	8.26abc	3.63b	3.75bc
Methionine		12.31c	12.53c	11.44c	11.88c	10.96d	11.13bc	7.73c	8.12bc	3.43c	3.55cd
LSD at 5%		0.22	0.18	0.21	0.22	0.21	0.57	0.13	0.32	0.13	0.21
Interaction											
Non-treated water	Control	11.47	11.71	10.78	11.23	10.16	10.29	7.37	7.75	3.00	3.10
	Proline	12.40	12.65	11.49	12.00	11.12	11.24	7.82	8.21	3.50	3.60
	Glycinebetaine	12.17	12.38	11.34	11.83	10.90	11.09	7.67	8.05	3.39	3.49
	Arginine	11.96	12.21	11.18	11.65	10.65	10.92	7.57	7.92	3.24	3.36
	Methionine	11.72	11.93	10.99	11.43	10.40	10.55	7.49	7.87	3.11	3.23
Magnetically treated water	Control	12.65	12.92	11.72	12.26	11.28	11.44	7.85	8.26	3.65	3.76
	Proline	13.79	14.08	12.61	13.14	12.48	12.75	8.36	8.75	4.18	4.32
	Glycinebetaine	13.67	13.97	12.42	12.92	11.97	12.19	8.30	8.76	4.15	4.29
	Arginine	13.42	13.77	12.21	12.70	11.75	11.87	8.18	8.61	4.01	4.14
	Methionine	12.90	13.14	11.89	12.34	11.52	11.71	7.96	8.36	3.75	3.87
LSD at 5%		0.30	0.26	0.30	0.31	0.30	0.82	0.18	0.45	0.19	0.29

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 7. Bulb quality characteristics (anthocyanin, pyruvic acid, carbohydrates, protein) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025

Treatments		Anthocyanin mg 100g ⁻¹		Pyruvic acid, μmol g ⁻¹		Carbohydrate s, %		Protein, %	
		1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Main factor: Water irrigation types									
Non-treated water		26.80	27.31	5.45b	5.72b	16.68	17.36	7.61b	7.76b
Magnetically treated		28.17a	28.78a	6.77a	7.09a	17.62	18.49	8.30a	8.47a
LSD at 5%		0.89	0.43	0.06	0.06	0.31	0.24	0.13	0.26
Sub main factor: Amino acid types									
Without amino acids		27.00	27.54c	5.61e	5.88d	16.90a	17.73	7.68d	7.84b
Proline		28.09a	28.65a	6.65a	6.99a	17.61a	18.52	8.26a	8.43a
Glycinebetaine		27.78a	28.34a	6.40b	6.71b	17.45a	18.31	8.10b	8.26a
Arginine		27.41a	28.02	6.02c	6.33c	17.17a	17.63	7.95c	8.12a
Methionine		27.15a	27.67c	5.88d	6.12c	16.63	17.43	7.79d	7.94b
LSD at 5%		1.01	0.49	0.13	0.24	0.74	0.31	0.11	0.31
Interaction									
Non-treated water	Control	26.46	26.97	5.03	5.27	16.28	17.03	7.36	7.50
	Proline	27.30	27.85	5.98	6.27	17.14	18.08	7.87	8.04
	Glycinebetai	26.98	27.45	5.69	5.98	16.90	17.79	7.74	7.87
	Arginine	26.76	27.28	5.37	5.63	16.55	16.64	7.63	7.77
	Methionine	26.51	27.00	5.17	5.46	16.53	17.27	7.46	7.61
Magnetically treated water	Control	27.54	28.10	6.19	6.50	17.52	18.43	8.00	8.17
	Proline	28.89	29.45	7.31	7.70	18.08	18.97	8.65	8.82
	Glycinebetai	28.57	29.23	7.10	7.43	17.99	18.83	8.45	8.65
	Arginine	28.06	28.77	6.67	7.02	17.78	18.61	8.27	8.47
	Methionine	27.79	28.34	6.59	6.78	16.73	17.60	8.11	8.26
LSD at 5%		1.42	0.69	0.18	0.34	1.05	0.44	0.16	0.44

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

List of figures

Fig 1. Marketable bulb yield (ton ha⁻¹) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025.

Fig 2. Quercetin content (mg/100 g FW) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025.

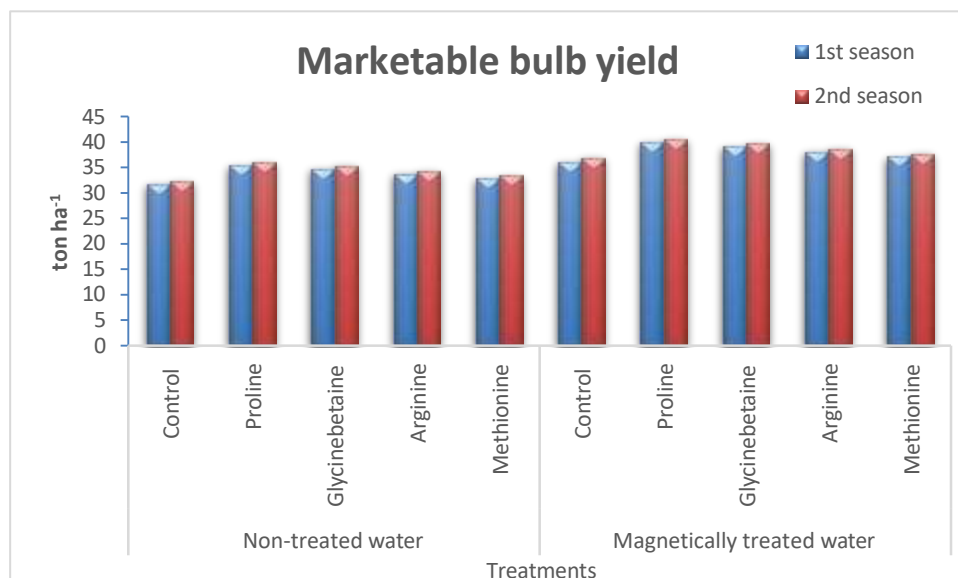


Fig 1. Marketable bulb yield (ton ha⁻¹) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage,

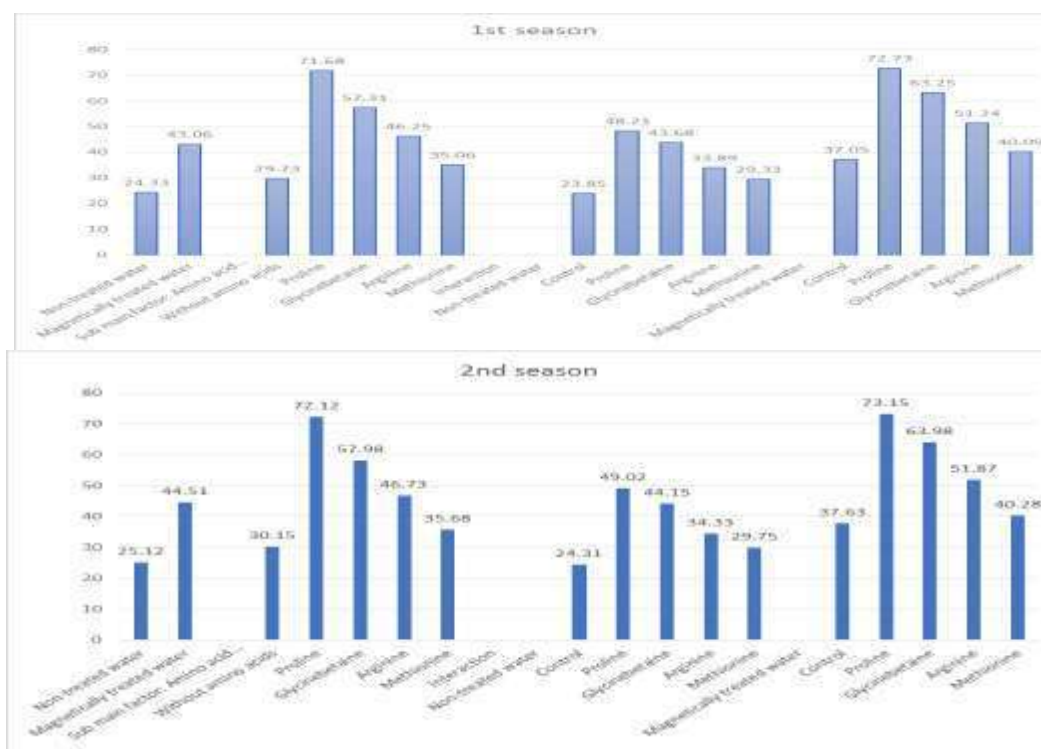


Fig 2. Quercetin content (mg/100 g FW) of onion plants influenced by varied irrigation water and amino acid treatments at harvest stage, seasons 2023/2024 and 2024/2025.