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ORIGINAL RESEARCH ARTICLE

Effect of Al-Nibras and Kinglife nutrient solutions on yield, agronomic traits, and soil nutrient availability in two eggplant cultivars (Barcelona and Jawaher)

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Abstract: Foliar nutrition is considered an effective approach to enhance crop productivity and quality. In a field experiment conducted at the College of Agriculture, University of Baghdad, during the 2023 – 2024 agricultural season, the effects of two foliar nutrient solutions (Al-Nibras and Kinglife) on eggplant yield, its traits, and soil nutrient availability were evaluated for two cultivars: Barcelona and Jawaher. The main plot was assigned to cultivar type, the subplot to foliar fertilizer type, and the sub-subplot to spray concentration (0, 3, 6, and 9 g/L). It was found that the Jawaher cultivar outperformed the Barcelona cultivar in terms of plant height, number of branches, number of fruits per plant, and the contents of the soil molybdenum, iron, and zinc. In addition, the foliar fertilizer Kinglife was consistently better than the Al-Nibras in all traits. All characteristics were markedly affected by spraying concentration; particularly, the highest averages of plant height (100.39 cm), the number of branches (7.68 branches/plant), the number of fruits (50.7 fruits/plant), and nutrients in the soil availability: Mo (0.113 mg/kg), Fe (5.04 mg/kg), and Zn (1.68 mg/kg) were achieved using 9 g/L Al-Nibras/Kinglife. The interaction between the Jawaher cultivar and Kinglife fertilizer had the most pronounced superiority in all studied features, recording the highest values of 96.57 cm (plant height), 7.78 branches/plant, 50.6 fruits/plant, 0.169 mg/kg for molybdenum, 6.45 mg/kg for iron, and 2.73 mg/kg for zinc. These findings indicate that the choices of cultivar, fertilizer, and spray concentration are important in increasing the yield of eggplant and enriching soil nutrients.

Keywords: Cultivars; Foliar nutrients; Eggplant; Element availability; Fertilizer type

1. Introduction

Modern agricultural-based food is one of the most significant contributors to attaining food security, particularly due to the environmental pressure of an increasing population and limited agricultural produce. Eggplant (*Solanum melongena* L.) is a promising plant for vegetable production due to its nutritional quality, contributions to food systems, and its importance among cultivated plants. Efficient tools and methods (e.g., integrated nutrition application, nutritional solutions) have been applied to enhance plant physiological function, vegetative and flower growth, and brinjal productivity and quality. The majority of countries in the world, including those with severe climatic conditions, are facing huge problems in a common sector—agriculture—with most of them have less or limited crops for sale to international markets, leading to economic adversaries. These challenges include poor fertility of the soil, insufficient fertilization, and limited balanced nutrient solution usage. With the increasing costs of traditional fertilizers and the declining efficiency in their usage, it is essential to search for more effective and durable alternatives.[2]

In the agricultural sector, one of the significant challenges is increasing crop productivity and quality, especially in light of the decline in soil fertility and the limited use of nutritional solutions. The use of fertilizers, such as Al-Nibra and Kinglife, is an effective remedy to improve the development of brinjals and increase the availability of nutrients. Promoting these agricultural practices helps to increase the efficiency of agricultural investments, ensuring better financial returns through higher-quality crops.[3]

Optimized fertilizer applications, such as the use of 9 g/L Kinglife, significantly contributes to environmental sustainability by increasing the efficiency of nutrients and reducing the loss of nutrients through evaporation or leaching. This targeted nutrient distribution system provides plants with essential micronutrients in easily accessible forms, reducing environmental footprint associated with excessive or poor fertilization practices. From an economic point of view, a higher efficiency is translated into potential cost savings by reducing the frequency and amount of the necessary fertilizer applications while maximizing crop productivity and quality. Such practices are consistent with long-term agricultural goals through the balance of productivity with environmental management.[4]

Nutrient solutions are modern agricultural solutions that allow farmers to provide essential nutrients to plants precisely and rapidly, contributing to increased growth and better crop quality.[5] However, the limited use of these fertilizers due to factors such as a lack of awareness of their importance, high costs, or limited availability has limited the productivity of some strategic crops.[6]

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Therefore, evaluating the overall performance of fertilizers, specifically Al-Nibras and Kinglife on brinjal cultivars such as Barcelona and Jawaher in this study, is crucial to providing insight into their effects on plant growth, productivity, fruit quality, and soil chemical properties, such as the concentration of nutrients and their distribution.[7] Macronutrients such as nitrogen, phosphorus, and potassium (NPK) are important nutrients required for brinjal plant growth and productivity: nitrogen for vegetation, phosphorus for root formation and flowering, and potassium for fruit quality and plant resistance to diseases. Thus, the fertilization tested in the current study increased the productivity and absorption capacity efficiencies of the Barcelona and Jawaher cultivars.[8]

Effects of fertilizers on the growth, yield, and quality of brinjal (*S. melongena* L.) were investigated in previous studies. For instance, an increase in nutritional concentrations, plant productivity, and soil quality associated with the use of a multi-micronutrient fertilizer (NPK^+ Fe, Zn, and B) was reported.[9] Using fertilization with natural compounds (ascorbic acid, chitosan, and moringa oil) also elevated the productivity of *Amaranthus*, as well as increased the concentration of chlorophyll a and antioxidant levels.[10] Similarly, other studies also showed that fertilization with zinc oxide nanoparticle-containing fertilizers increased yield, leaf nutrient concentrations, and drought tolerance by improving water use efficiency.[11] Interestingly, removing feeding also acts as a good strategy to enhance the performance of brinjal, especially when subjected to environmental stress.[12]

Brinjal (S. melongina L.) is a significant vegetable plant in the Solanaceae family. Besides significant element contents, including calcium, iron and potassium, its fruits posses huge nutritional values, with 14.34% proteins, fibers, fats, and carbohydrates.[8] Brinjal is also considered an important plant due to its availability of several energy molecules for the synthesis of vitamins, lipids, and proteins.[13] Foliar feeding is currently the preferred fertilization technique, owing to its affordability, simplicity, and rapid effectiveness. It addresses soil challenges, particularly problems with micro- and macronutrients that are prone to sedimentation when added to the soil, reducing their availability to plants. Since all parts of plants can absorb nutrients quickly and evenly, foliar feeding significantly supports plant nutrition.[14] Foliar feeding also reduces the reliance on heavy fertilizer applications. Compared to soil fertilization, foliar feeding offers several advantages, including faster correction of nutrient deficiencies, which often manifest first in the leaves. In addition, it saves considerable time and labor by allowing the combination of growth regulators and nutrients in one application.[15]

The presence of nutrients in the soil is a key to agricultural productivity. However, their contents are influenced by soil chemical and physical properties, including pH, salinity, and aeration. In this context, the use of soil conditioners is significant. These conditioners promote the content of soil and the retention of water and nutrients in the soil, aiding the absorption of vital nutrients by plants.[16] The combination of nutritional provision and soil amelioration creates many opportunities for the future design of more efficient and sustainable agricultural systems, enhancing the odds of successful investment in agricultural activities. The genotypic difference of the two brinjal hybrids, Barcelona and Jawaher, may result in variations in their response to fertilization through leaf or root. Hence, to plan and design effective fertilization programs, it is necessary to understand the interaction effect of fertilizers and cultivars and elucidate the physical properties of each cultivar.[18,19]

Besides their effects on plants, these fertilizers ameliorate the soil chemical and physical properties by increasing nutrient uptake by plants and reducing nutrient loss. These enhance the nutritional balance in the root zone while promoting the soil's microbial activity. When they are used in the optimal mode, they can also reduce the loss of nutrients in the soil and lessen the possibility of soil environment pollution and nutrient imbalance.[20]

The method of irrigation used is essential to achieve good absorption of the nutrients from fertilizers, especially in modern irrigation systems (such as drip irrigation), where fertilizers are supplied directly to the root zone, aiding in the efficient absorption of nutrients and reducing the loss of nutrients.[21,22] Thus, the interaction between solution type and irrigation system is important to promote higher crop yields and quality.

Eggplant is a vegetable crop of high economic and nutritional importance and is widely grown in greenhouses and open fields. To achieve high productivity and excellent fruit quality, environmental and management factors, such as fertilization, irrigation, and tillage, are crucial. These factors directly affect the efficiency of water and nutrient use.[23]

Focusing on these aspects is essential to achieving sustainable agriculture, as improving soil fertility and quality, along with increasing plant efficiency, leads to an integrated production system that achieves food security goals and reduces the environmental impact of using traditional fertilizers. Therefore, this study hypothesized that foliar application of Kinglife and Al-Nibras at different concentrations would significantly improve eggplant growth, yield, and nutrient availability, particularly for the Jawaher cultivar.

This study aimed to determine the most suitable eggplant cultivar for cultivation by comparing the growth and yield of two different cultivars. It also sought to identify the optimal combination of three nutritional elements and explore the ideal concentration of the applied solution.

2. Materials and methods

In one of the fields at the College of Agriculture, University of Baghdad, a field experiment was conducted during the 2023 – 2024 growing season. The objective was to investigate how the two cultivars of eggplant (Barcelona and Jawaher) responded to the nutrient solutions (Al-Nibras and Kinglife) in terms of plant yields, their traits, and nutrient availability. Three parameters were included in the experiment based on the split-split plot arrangement and the randomized complete block design. Soil samples were collected and analyzed before the experiment to assess uniformity in baseline nutrient levels. The field was homogenized through standard tillage and amendment practices to ensure consistent initial conditions across all plots.

Initially, the main plots (main plot) were occupied by the cultivars (Barcelona and Jawaher), the secondary plots (subplot) were occupied by two types of foliar nutrients (Al-Nibras and Kinglife), and the tertiary plots (sub-subplot) were occupied by four spray concentrations (0, 3, 6, and 9 g/L) for both nutrient solutions. The experiment included three replicates for each treatment. To calculate the average, samples were randomly selected from each experimental unit at a rate of eight plants for the attributes under study. Following the preparation of the field soil through plowing, leveling, smoothing, and amending, several samples were extracted from the trial soil to perform physical and chemical analyses. The samples were analyzed at the soil and water laboratories at the Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University (Table 1). The field was arranged in rows, with 40 cm between plants and 1.5 m between rows. On March 25, 2024, the seedlings were transferred to their permanent location once three to four true leaves had formed. All agricultural practices, including fertilization, irrigation, weeding, and pest control, were performed uniformly across all treatments. Approximately 45 days after moving the seedlings to their permanent site, the first spray was applied. For both cultivars, this was done 4 times for each foliar nutrient on the vegetative portion of the plant, until the plant was completely wet. A 16-liter sprayer was used for the early morning spraying, with a 20-day interval between each application (Table 2).

2.1. Meteorological data

Babylon Governorate is located in central Iraq and is characterized by a hot and dry desert climate, with long, extremely hot summers and mild, rainy winters (Figure 1):

- Temperatures:
  - Summer (June – August): Maximum temperatures range between 42°C and 50°C.
  - Winter (December – February): Minimum temperatures range between 5°C and 10°C, with maximum temperatures between 15°C and 20°C.
- Rainfall:
  - Annual average: 100 – 150 mm, with rainfall occurring primarily in November and December.
  - Summer: Rainfall is rare during this period.
- Wind:
  - Speed: 10 – 20 km/h, with an increase in speed during the summer.
  - Direction: Predominantly from the northwest direction.
- Humidity:
  - Summer: Humidity is low, increasing the feeling of heat.
  - Winter: Humidity increases slightly, but remains moderate.

The Kinglife foliar fertilizer has the following ingredients: NPK (20:20:20), iron, manganese, zinc, copper, boron, and molybdenum.

In this study, the characteristics examined are as follows:

(i) Plant height: Measured from the plant's point of contact with the soil surface to the end of the main stem, or growth tip.

(ii) Branch number: The branch number was calculated per plant.

(iii) Fruit number: Determined by dividing the total number of fruits in the experimental unit by the number of plants from all harvests, starting with the first harvest 4 months after planting and ending with the final harvest at the end of the season.

(iv) Available molybdenum: Measured in the extracted solution using an atomic absorption spectrophotometer (Model AA-7000, Shimadzu, Japan) at a wavelength of 313.3 nm after acid digestion with ammonium oxalate, following standard soil analysis procedures. The values represent the bioavailable fraction rather than the total molybdenum content.

(v) Available iron: Iron was extracted using a chelating agent (diethylenetriaminepentaacetic acid) at

Table 1. Characteristics of the soil before the experiment

Traits	Values
Electrical conductivity (dS/m)	4.30
pH (1 soil: 1 water)	81.7
Cation exchange capacity (cmol[+]/kg)	25.2
Organic matter (g/kg)	1.22
Carbonate minerals (g/kg)	251
Gypsum (g/kg)	2.31
Ca^{2+} (mmol/L)	12.54
Mg^{2+} (mmol/L)	8.16
Na^{+} (mmol/L)	3.76
K^{+} (mmol/L)	1.50
HCO^{3-} (mmol/L)	3.50
SO_4^{2-} (mmol/L)	5.40
Cl^{-} (mmol/L)	22.02
CO_3^{2-} (mmol/L)	-
Available nitrogen (NH_4^+/NO_3^-) (mg/kg)	27.14
Available phosphorus (mg/kg)	20.5
Available potassium (mg/kg)	194.7
Iron (mg/kg)	79.3
Zinc (mg/kg)	0.710
Molybdenum (mg/kg)	0.154
Bulk density (mg/kg)	1.39
Sand (g/kg)	345
Silt (g/kg)	443
Clay (g/kg)	212
Texture	Loam

Table 2. Contents of AL-Nibras foliar fertilizer

Element	Value
Nitrogen (%)	10
Phosphorus (%)	8
Potassium (%)	6
Chelated magnesium (ppm)	160
Chelated copper (ppm)	25

0.005 M and ammonium bicarbonate (NH_4HCO_3) at 1.0 M. Available iron was measured using a spectrophotometer at a wavelength of 672 nm.[25]

(vi) Available zinc: Zinc was extracted according to the method described by Lindsay and Norvell.[26] Available zinc was then determined in the digester solution using an atomic absorption spectrophotometer at a wavelength of 540 nm.[27,28]

All data represent the mean of three replicates per treatment or the average of multiple data. The Genstat software (VSNi, United Kingdom) was used to statistically analyze the data and compare the averages using the analysis of variance (ANOVA) with the least significant difference at the 0.05 level.[24]

3. Results

3.1. Plant height

The Barcelona and Jawaher cultivars differed significantly in plant height (Figure 2). The Barcelona cultivar recorded a lower average plant height (79.70 cm) compared to the Jawaher cultivar (86.82 cm). In terms of fertilizer type, Kinglife resulted in the highest average plant height (86.66 cm) in the Jawaher cultivar across the 3, 6, and 9 g/L concentrations, whereas Al-Nibras in the Jawaher cultivar resulted in the lowest average (83.37 cm). In addition, there were considerable differences among the spray concentrations. The Al-Nibras/Kinglife control treatment (without spraying) recorded the lowest average plant height (64.88 cm) across all cultivars, whereas the highest average (100.39 cm) was observed in the 9 g/L Al-Nibras/Kinglife. Moreover, the results reveal a notable interaction between cultivar type and fertilizer type. The Barcelona cultivar treated with Kinglife recorded the lowest average plant height (88.89 cm) across the 3, 6, and 9 g/L concentrations, whereas the Jawaher cultivar treated with Kinglife resulted in the highest average (96.57 cm). Furthermore, in the Jawaher cultivar treated with 9 g/L Al-Nibras, the highest average plant height (109.38 cm) was recorded, while in the Barcelona cultivar treated with 9 g/l Kinglife, the lowest average (99.75 cm) was recorded. These findings suggest a significant improvement in the height of plants due to the interaction between spray concentration and cultivar type.

3.2. Branch number

The Jawaher variety presented an average frequency of 7.27 branches/plant, higher than the Barcelona variety (4.88) (Figure 3). The fertilizer type had a reasonable positive effect, where 7.18 branches/plant were recorded in Kinglife while 6.00 branches/plant in Al-Nibras. On the other hand, the fertilizer treatments were superior to the control in branch number. The 9 g/L Al-Nibras/Kinglife recorded the highest mean with 7.68 branches/plant, while the control recorded the lowest value of mean with 5.07 branches/plant. Of particular importance is that this feature was highly influenced by the interaction between the cultivar type and fertilizer type, where the

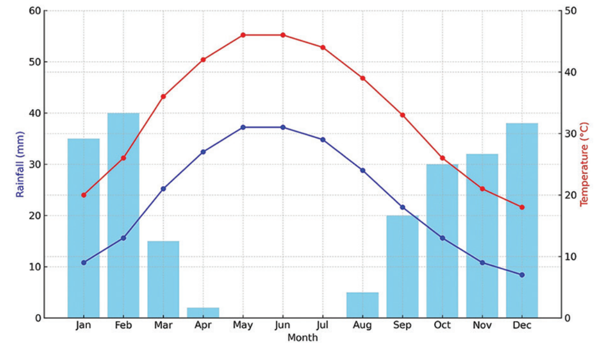

Figure 1. Climate data in the study area

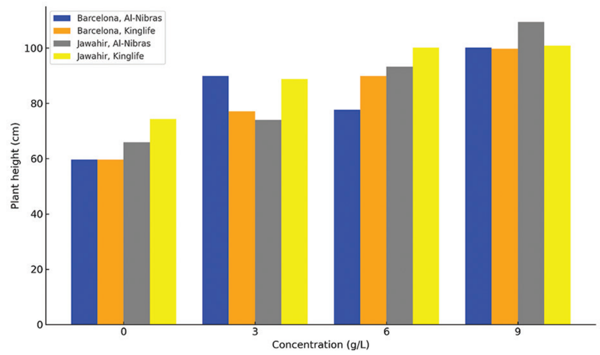

Figure 2. Effects of cultivar type, fertilizer type, and spray concentration on plant height

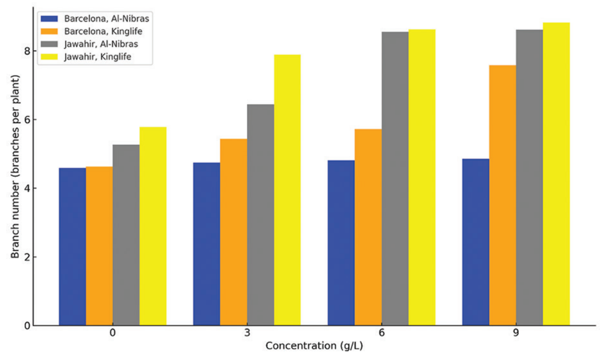

Figure 3. Effects of cultivar type, fertilizer type, and spray concentration on branch number

Jawaher cultivar treated with Al-Nibras had the highest mean of 7.78 branches/plant at 3, 6, and 9 g/L levels, and the lowest mean of 4.59 branches/plant was recorded from the Barcelona cultivar and Al-Nibras treatment. Similarly, the highest average number was observed with the Jawaher cultivar and Kinglife interaction (8.71 branches/plant) at 3, 6, and 9 g/L, whereas the least was with the Barcelona cultivar and control treatment (4.15 branches/plant). For the interaction between fertilizer types and spray concentration, while the 9 g/L Kinglife recorded the highest average of 8.82 branches/plant, the lowest average of 4.95 branches/plant was recorded in the Al-Nibras control treatment. The results also demonstrate the significant impact of the interaction among cultivar type, fertilizer type, and spray concentration. While the Barcelona cultivar with the Al-Nibras control treatment recorded the lowest average of 4.59 branches per plant, the Jawaher cultivar treated with the 9 g/L Kinglife resulted in the highest average of 8.82 branches/plant.

3.3. Fruit count

Figure 4 demonstrates significant differences between the cultivar types, with the Barcelona cultivar yielding a lower average of 41.7 fruits/plant compared to 44.3 fruits/plant in the Jawaher cultivar. Noticeable effects were seen in the fertilizer types: Kinglife recorded a higher average of 47.7 fruits/plant compared to 38.0 fruits/plant in Al-Nibras. Furthermore, spray concentrations increased fruit production, with a maximum average of 50.7 fruits/plant recorded in the 9 g/L Al-Nibras/Kinglife across cultivars and the lowest average of 35.5 fruits/plant observed in the control treatment. The results of the interaction between the types of cultivar and the types of fertilizer varied markedly. While the Jawaher cultivar treated with 3, 6, and 9 g/L Kinglife recorded the highest average of 50.6 fruits/plant, the Barcelona cultivar treated with Al-Nibras resulted in the lowest average of 38.3 fruits/plant. On the other hand, the results of the interaction between the type of cultivar and spray concentration showed that the Jawaher cultivar with the 9 g/L Al-Nibras/Kinglife recorded the highest average of 51.1 fruits/plant, compared to 34.2 fruits/plant in the Barcelona cultivar control treatment. In addition, the interaction between the type of fertilizer and spray concentration demonstrated a significant effect. The 9 g/L Kinglife group recorded the highest average of 53.5 fruits per plant across cultivars, compared to the lowest average of 27.3 fruits/plant in the Al-Nibras control treatment. In terms of overall interaction, whereas the Jawaher cultivar treated with the 9 g/L Kinglife recorded the highest average of 53.8 fruits/plant, the Jawaher cultivar treated with the Al-Nibras control treatment resulted in the lowest average of 24.8 fruits/plant.

3.4. Available molybdenum

As shown in Figure 5, Jawaher cultivar showed a mean level of 0.105 mg/kg, while Barcelona cultivar showed 0.071 mg/kg. By fertilizer type, the highest average (0.129 mg/kg) was obtained in Kinglife, and the lowest average (0.075 mg/kg) in Al-Nibras, indicating that the type of fertilizer has a high influence. With regard to spray concentration, the 9 g/L Al-Nibras/Kinglife exhibited a mean of 0.113 mg/kg, markedly higher than the 0.078 mg/kg recorded in the control treatment. Similarly, the Jawaher cultivar treated with Kinglife had the highest mean concentration of 0.169 mg/kg. In contrast, the lowest mean of 0.050 mg/kg was observed in the Al-Nibras-treated Jawaher cultivar. Besides, substantial differences were observed for the interaction between cultivar type and spraying concentrations. The

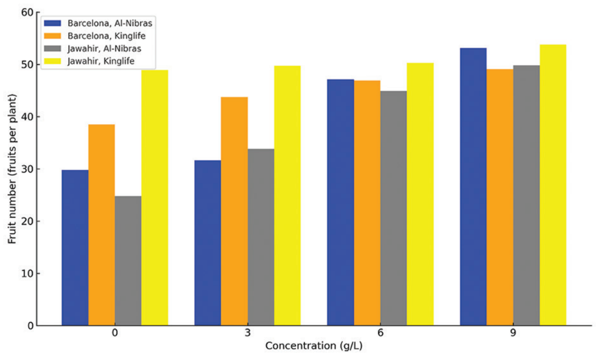

Figure 4. Effects of cultivar type, fertilizer type, and spray concentration on fruit number

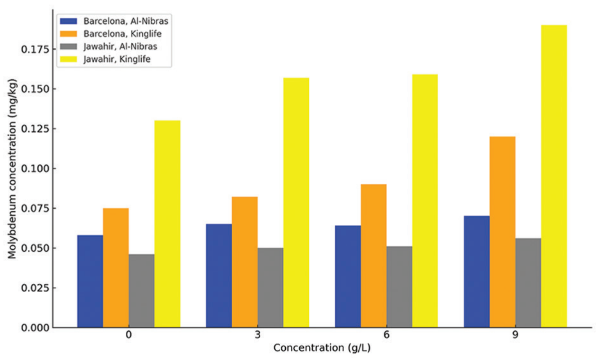

Figure 5. Effects of cultivar type, fertilizer type, and spray concentration on molybdenum concentration in the soil

control Barcelona cultivar recorded the lowest mean of 0.061 mg/kg, while the Jawaher type treated with 9 g/L Al-Nibras/Kinglife had a higher mean of 0.127 mg/kg. Regarding the fertilizer type and spray concentrations interaction effect, the least average Cu accumulation of 0.051 mg/kg was observed in the Al-Nibras control treatment across cultivars, while the highest was observed in 9 g/L Kinglife with an average value of 0.160 mg/kg. This suggests a substantial interaction between the spray concentration and the fertilizer type. In terms of overall interaction, the Jawaher variety treated with 9 g/L Kinglife had the highest mean of 0.190 mg/kg, compared to the 0.046 mg/kg in the Jawaher variety treated with the Al-Nibras control treatment.

3.5. Iron availability

Figure 6 emphasizes a clear difference between the Barcelona cultivar (with an average iron concentration of 3.69 mg/kg) and the Jawaher cultivar (5.73 mg/kg). A remarkable impact was observed based on the type of fertilization, where Kinglife had a higher mean of 5.80 mg/kg and 3.90 mg/kg for Al-Nibras. With respect to spray concentrations, the control treatment recorded the lowest mean iron level of 3.88 mg/kg across cultivars, and the 9 g/L dosage recorded 5.04 mg/kg. In addition, the interaction effects between cultivar type and fertilizer type indicate that the treatment of Jawaher cultivar with Kinglife had the highest mean (6.45 mg/kg) across 3, 6, and 9 g/L concentrations, while the treatment of Jawaher cultivar with Al-Nibras had the lowest mean value (3.15 mg/kg). Moreover, for the interaction effect of cultivar type and spray concentration, there were remarkable variations: the Jawaher cultivar treated with 9 g/L Al-Nibras/Kinglife had the highest average (5.00 mg/kg), while the Barcelona cultivar with the control treatment had the lowest average (3.69 mg/kg).

Additionally, the 9 g/L Kinglife had the highest mean of 6.40 mg/kg, whereas the Al-Nibras control treatment had the lowest mean of 3.00 mg/kg. For overall interactions, the Jawaher cultivar that received Al-Nibras control treatment had the lowest average value (3.11 mg/kg), while the average value for the Jawaher cultivar that received 9 g/L Kinglife was 6.78 mg/kg.

3.6. Zinc availability

A striking difference in zinc levels can be seen in Figure 7. The Jawaher variety had a higher average (1.29 mg/kg) than that of the Barcelona variety (0.71 mg/kg). With regard to the type of fertilizer, Kinglife (2.26 mg/kg) was higher than Al-Nibras (0.50 mg/kg), indicating an extraordinary effect. In respect of spray concentration, the untreated control had the lowest average (0.84 mg/kg) across cultivar and fertilizer types, compared to the highest average of 1.68 mg/kg in the 9 g/L Al-Nibras/Kinglife spray treatment, showing the potency of fertilizer. Considering the cultivar type and fertilizer type, the highest mean value of 2.73 mg/kg was obtained in the Jawaher cultivar treated with 3, 6, and 9 g/L Kinglife, while the lowest mean value of 0.31 mg/kg was recorded in the Jawaher cultivar treated with Al-Nibras. These results show substantial interaction between the cultivar type and the type of fertilizer. Moreover, marked differences were observed in the interaction between the cultivar type and spray concentration: the control treatment showed the lowest mean for the Barcelona cultivar (0.75 mg/kg), while the Jawaher cultivar treated with 9 g/L Al-Nibras/Kinglife recorded the highest mean value (1.79 mg/kg). As for the type of fertilizer and the spray concentration, the 9 g/L Kinglife gave the highest mean value (2.53 mg/kg), while the Al-Nibras control treatment gave the lowest value (0.46 mg/kg), showing a striking effect in the interaction between the type of

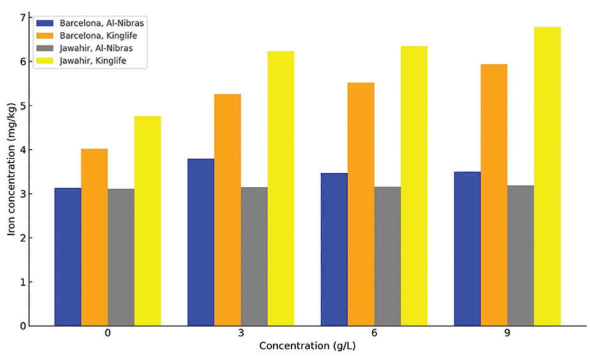

Figure 6. Effects of cultivar type, fertilizer type, and spray concentration on iron concentration in the soil

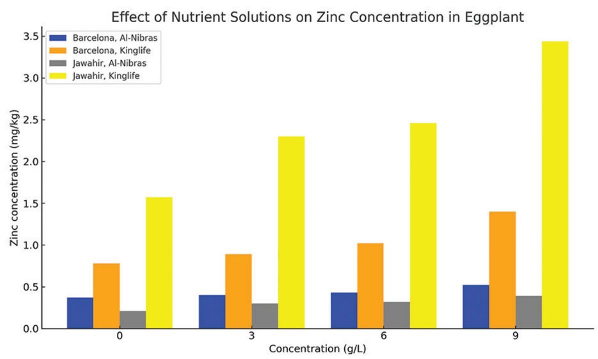

Figure 7. Effects of cultivar type, fertilizer type, and spray concentration on zinc concentration in the soil

fertilizer and the concentration of spray. Considering a total interaction effect, the highest mean of 3.44 mg/kg was observed in the Jawaher cultivar treated with 9 g/L Kinglife, while the lowest mean of 0.21 mg/kg was recorded from the Jawaher cultivar treated with the Al-Nibras control treatment.

4. Discussion

The results show a substantial effect of foliar fertilizers on plant growth and yield enhancement, attributed to the effectiveness of the treatments employed in this study (Table 2), the rapid uptake of nutrients by the plants, and their subsequent effect on the growth of the crop's vegetative mass. Conversely, the quality of the foliar fertilizers used is reflected in their contents, including growth-promoting elements like phosphorus and nitrogen, which are among the most crucial elements for plant development, growth, and productivity.[29-32] Besides, potassium also plays an important role in promoting vegetative growth and mass.[33]

Additionally, when applied to eggplant plants at high concentrations, foliar fertilizer had a notable impact on enhancing plant height in comparison to the majority of other treatments.[34-37] Some nutrients, such as nitrogen, are involved in the synthesis of numerous organic compounds crucial to the plant's vital processes; this demonstrates the benefits of using foliar fertilizers to supply plants with nutrients—their beneficial role in the growth and development of the vegetative structure, the increase in the number of aerial stems, and their effects on photosynthesis, respiration, and protoplasmic structure. In addition to being part of cytochrome enzymes and chlorophyll molecules, which are crucial in the synthesis of numerous compounds, including ATP and nucleic acids, some of these nutrients also enter the composition of nucleic acids, including RNA and DNA.[38] Furthermore, they also enhance the amount of carbohydrates produced by the carbon metabolism process, aid in the formation and division of cells, promote the growth and development of roots, and are involved in the maturation of the plant, particularly through micronutrients such as zinc. Vegetative and fruit features, such as the quantity of plant branches and fruits, have therefore increased significantly.[39-41]

By reducing the pH of the soil to dissolve potassium compounds, foliar fertilizers that include a variety of elements, including readily available potassium, can help increase the amount of potassium in the soil.[37] This result is consistent with previous studies,[42,43] which demonstrated that the use of potassium fertilizer, known for being highly soluble, increased the soil's potassium content after harvest. The study also showed that when the iron-containing fertilizer was applied, the soil's availability of readily available elements (e.g., N, P, K, Fe, and Zn) increased dramatically. Iron contributes to increased enzyme activity involved in cell formation when photosynthesis is efficient. The ferredoxin enzyme, which uses iron as an electron carrier, accelerates photosynthesis and enhances development markers, such as the vegetative and qualitative characteristics of plants.[44,45] Previous studies indicated that the critical level of iron in soil available to plants ranges from 2.5 to 5.0 mg/kg, while that of zinc ranges from 0.5 to 1.0 mg/kg, depending on the soil type and crop.

Accordingly, some treatments—such as the Jawhar cultivar treated with the 9 g/L Kinglife—significantly exceeded these levels (e.g., 6.78 mg/kg for iron and 3.44 mg/kg for zinc), indicating high availability of these elements. In contrast, other treatments showed levels below the critical threshold; for example, the Jawhar cultivar treated with the Al-Nibras control treatment recorded the lowest average values (3.11 mg/kg for iron and 0.21 mg/kg for zinc).

These analyses and their correlation to the critical thresholds are included in the discussion section to illustrate the effectiveness of the different treatments in improving micronutrient availability and to explain their potential impact on plant growth. These additions also enhance the practical value of the results and support the agricultural recommendations drawn from the study.

5. Conclusion

According to the study's findings, the Jawaher cultivar performed better than the Barcelona cultivar in every measured trait. This was particularly remarkable when combined with the 9 g/L Kinglife foliar nutrition, increasing plant height, branch and fruit counts, and soil micronutrient availability, including those of iron, zinc, and molybdenum. Growth and productivity metrics were drastically impacted by significant interactions among the elements under study (cultivar type, foliar fertilizers, and spray concentrations). These results emphasize how crucial it is to choose the optimal cultivar, provide efficient foliar nutrition, and maintain an ideal concentration to achieve optimal yield. It has been demonstrated that applying optimal amounts of foliar fertilizers increases soil nutrient availability and nutrient uptake efficiency. To improve crop growth and quality, it is advised to use the Jawaher cultivar with the 9 g/L Kinglife foliar nutrition.

This study provides compelling evidence that foliar application of nutrient solutions, particularly the 9 g/L Kinglife, significantly enhances the growth, yield, and nutrient uptake of eggplant, especially for the Jawaher cultivar. To further advance our understanding of foliar nutrition efficiency, future research is recommended to explore a broader spectrum of eggplant cultivars and to assess the long-term effects of these nutrient treatments under various agroecological conditions. Moreover, investigating the physiological mechanisms underlying nutrient absorption at the cellular level could yield valuable insights for optimizing crop productivity and sustainability.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: All authors
Formal analysis: All authors
Investigation: All authors
Methodology: All authors
Writing – original draft: All authors
Writing – review & editing: All authors

Availability of data

All data generated or analyzed during this study are included in the published article.

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