Improving Growth and Chemical Contents of Grape Saplings Using Spraying with Iron and Magnesium Nano- Particles.

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Abstract

The study was carried out at the First Agricultural Research Station in Al-Bu'aitha area belong to the College of Agriculture – University of Anbar (37°45′33″ N and 43°32′65″ E) on one-year-old grape saplings, with the aim to assess how foliar applications of nano-iron and nano-magnesium affect certain vegetative and chemical growth traits in four grape cultivars: Baydh Al-Hamam, Al-Shidda Al-Sawda, Al-Halwani, and Al-Kishmishi, during the 2025 growing season The experiment examined two factors: the first was spraying treatments at four levels: distilled water only (F_0), nano ferrous oxide 200 mg L^{-1} (F_1), nano magnesium oxide 200 mg L^{-1} (F_2), and a combination of nano ferrous oxide + nano magnesium oxide at 200+200 mg L^{-1} (F_3). Second factor was using Four cultivar (V_1–V_4) following the previously mentioned order. . The results revealed that the combined nano-spray (F_3) significantly improved leaf area, chlorophyll a and b levels, concentrations of nitrogen, phosphorus, potassium, and magnesium in the leaf petioles. Additionally, leaf iron content . At the cultivar level, the cultivar Al-Kishmishi (V_4) was significantly superior in all studied traits. As for the two-way interaction, the treatment V_4F_3 achieved the highest values in leaf area, , and N, P, K contents in leaf petioles and their iron content, recording (65.49 cm², 27.01 mm, 1.836%, 0.3767%, 1.336% and 168.6 mg $L^{-1)}$, respectively, while the treatment $_{V4F2}$ was distinguished in chlorophyll b content, reaching 25.66 mg 100 g^{-1} fresh weight.

Keywords: Grape, Iron, Magnesium, Foliar Spraying, Nanotechnology

Introduction

Grape (*Vitis vinifera* L.) belongs to the grape family (Vitaceae) and is considered one of the most important fruit shrubs from both nutritional and economic perspectives. It is the largest crop among other fruit shrubs in terms of production quantity. At present, it is cultivated in many countries between latitudes (20–40) south of the Equator and (20–50) north of the Equator [1]. The importance of grape is high due to its distinctive taste, high nutritional value, and the diversity of its uses, in addition to its good economic return. They serve as an excellent source of vitamins such as C, B_1, and B_2, sugars, and nutrients such as Mg, Fe, and Ca, and it has many other uses [2]. Therefore, studying the possibility of stimulating vegetative growth of the saplings of these cultivars in the first year of planting is extremely important for selecting strong shoots in the following year according to the adopted training system.

Nanotechnology has entered the agricultural field, especially in plant nutrition, because it may be an alternative or a complement to conventional fertilizers. This is due to increasing the speed of absorption by plants, and the reduction in the quantity of chemical fertilizers required. Furthermore, these materials have the ability to remain within the plant for longer periods, enhancing crop quality and ensuring sustainable productivity [3].

The distinctive fact is that nano-fertilizers are characterized by a high absorption rate by leaves because they have small-sized particles and are readily available to the plant, which

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leads to increased photosynthesis and stimulation of plant growth when they are applied at low levels appropriate for plants [4, 5]. From here, the use of the nutrients iron and magnesium was proposed. Iron contributes to vital plant processes, acting as an activator for enzymes responsible for electron transport and respiration, and it is involved in the structure of chloroplasts and many other enzymes [6].

Magnesium enters into the structure of chlorophyll, which enhances the photosynthesis process, improves the saplings' resistance to heat stress and drought, and also contributes to activating some enzymes responsible for phosphorus and nitrogen uptake [7].

There are several cultivars cultivated widely in orchards, and among these cultivars are (Baydh Al-Hamam, Al-Shidda Al-Sawda, Al-Halwani, and Al-Kishmishi). They are local cultivars distinguished by the quality of their fruits and their suitability to local environmental conditions. Therefore, studying the possibility of stimulating vegetative growth of the saplings of these cultivars in the first year of planting is extremely important for selecting strong shoots in the following year according to the adopted training system.

Based on the above, this study aims to evaluate the response of these cultivars to foliar applications of nano-iron and nano-magnesium and its effect on vegetative growth, It also aims to examine the interaction between iron and magnesium, as well as the effects of their combination on the physical and chemical vegetative growth characteristics across the different cultivars

Materials and Methods

1. Experimental site

The experiment was conducted at the Agricultural Research Station located in Al-Bu'aitha area belong to the College of Agriculture – University of Anbar, at latitude 37°45′33″ N and longitude 43°32′65″ E, on one-year-old grape saplings, in order to determine the effect of foliar spraying with nano ferrous oxide and nano magnesium oxide on vegetative growth and chemical characteristics of saplings of four grape cultivars: Baydh Al-Hamam, Al-Shidda Al-Sawda, Al-Halwani, and Al-Kishmishi, during the 2025 growing season from 14/2/2025 until 30/12/2025.

2. Land preparation and planting

The field soil was prepared for planting the saplings. The saplings were brought on 14/2/2025 from the nursery of the Horticulture Directorate in Al-Qaim district, Anbar Governorate, and planted in the field. One row was planted for each cultivar, with a distance of 4 m between rows and 1.75 m between saplings within the row. In the first row, the cultivar Baydh Al-Hamam was planted; in the second row, Al-Shidda Al-Sawda; in the third row, Al-Halwani; and in the fourth row, Al-Kishmishi. Irrigation was carried out using the drip method. Sapling management was performed by removing weeds, controlling diseases and insects using fungicides and insecticides, and applying DAP fertilizer at a rate of 50 g sapling^{-1}; the application was repeated twice [8]. Soil samples were also taken from the field at a depth of 30 cm from five different locations for the purpose of conducting some chemical and physical analyses at the implementation of the experiment (Table 1).

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Table 1. Some physical and chemical properties of the field soil before planting

Property	Value	Unit
Electrical conductivity	1.9	dS m-1
Total dissolved salts (TDS)	931	mg L-1
pH	7.2	—
Soil separates		
Clay	280	g kg-1
Silt	640	g kg-1
Sand	80	g kg-1
Texture	Silty clay loam	
Available nitrogen	15.1	mg kg-1
Available phosphorus	6.62	mg kg-1
Available potassium	232	mg kg-1
Calcium	5.3	mmol L-1
Magnesium	3.65	mmol L-1
Sodium	0.92	mmol L-1
Bicarbonate	1.7	mmol L-1
Carbonate	Nil	
Gypsum	0.46	g kg-1
Lime	268	g kg-1
Cation exchange capacity	21	cmol charge kg-1

3. Study factors

3.1. Foliar spraying with nano-iron and nano-magnesium

Spraying was carried out at different levels of nano-iron in the form of Fe_2O_3 and nano-magnesium in the form of MgO:

1. Spraying with distilled water only, F0.
2. Spraying nano ferrous oxide at a rate of (200 mg L^{-1} of Fe_2O_3) F_1.
3. Spraying with nano MgO at a rate of (200 mg L^{-1}, F_2.
4. Spraying with a combination of nano ferrous oxide and nano magnesium oxide at concentrations of (200 mg L^{-1} of Fe_2O_3 + 200 mg L^{-1} of MgO), F_3.

[9, 10]

Spraying were carried out starting from 15/4/2025, with four sprays as follows:

1. The first date was on 15/4/2025.
2. The second date was on 15/5/2025.
3. The third date was on 15/6/2025.
4. The fourth date was on 15/9/2025.

3.2. Cultivars

The cultivars used: Four grape sapling cultivars were used and coded as V as follows:

1. Cultivar Baydh Al-Hamam, V_1.
2. Cultivar Al-Shidda Al-Sawda, V_2.
3. Cultivar Al-Halwani, V_3.
4. Cultivar Al-Kishmishi, coded as V_4.

4. Design of Experiment and Statistical Analysis

The field trial was implemented using a split-plot arrangement, with cultivars assigned to main plots and spraying treatments to subplots. There were 16 treatments replicated three times, resulting in a total of 48 experimental units. In each experimental unit, there were two saplings, so the total number of saplings was 96 saplings. After the end of the experiment, following the experiment, data analysis was conducted with means compared using the Least Significant Differences Test (L.S.D.) at a 5% probability level [11].

5. Studied traits

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1. Leaf area (cm^2)

The average leaf area at full expansion was determined at the end of June using the Digimzer program according to the method of [12]. "Ten leaves were taken from each plant within the same treatment. Two saplings were used for each treatment, which means collecting (20) leaves per treatment. The leaves were scanned using a scanner, with using a reference indicator for a longer distance, such as (10) cm, with a colored line. Then the image was transferred to the program on the computer, which determines the boundaries of the plant part while taking into account not touching the edges of the fixed leaf, and calculates the total area of the specified part". After that, the mean leaf area was calculated.

2. Increase in sapling height (cm)

Initial readings were taken on 22/3/2025 for sapling height using a measuring tape, and the second reading was taken on 1/12/2025. The average increase in seedling height was calculated using the following formula Mean increase in height of sapling = second reading – first reading

3. Increase in main shoot diameter of saplings (mm)

Initial readings were taken on 22/3/2025 for the diameter of a stem 5 cm above soil surface using Vernier caliper, and a second reading was taken on 1/11/2025. The average was calculated using the following equation: Average increase in stem diameter = Second reading – First reading

4. Leaf Chlorophyll a and b Content (mg/100 g fresh weight)

Leaf chlorophyll a and b contents were estimated in September according to the method of [13] "Ten leaves were collected from each experimental unit and washed with distilled water. After that, 0.5 g of fresh, chopped leaves were taken; the leaves were cut into strips and placed in a dark glass bottle. To this, 20 mL of 85% acetone was added, and the samples were left for 48 hours. After that, the filtrate was separated from the residue using filter paper, and it was read using a Spectrophotometer at wavelengths of 645 and 663 nm". Absorbance readings were taken using a spectrophotometer at wavelengths of 645 and 663 nm at the Central Laboratory of the College of Agriculture, University of Anbar. The total chlorophyll pigment amount was initially calculated in mg/50 g of fresh leaf tissue using the following equations:

$$\text{Chlorophyll a} = 9.78\,(A663) - 5.00\,(A645)$$
$$\text{Chlorophyll b} = 21.4\,(A645) - 4.65\,(A663)$$

In these equations, A represents the absorbance reading at the specified wavelength. The final results were then converted to mg/100 g fresh weight to ensure consistency in the reporting of the data.

5. Nitrogen percentage in leaf petioles (%)

The nitrogen percentage in leaf petioles was estimated in mid-January by collecting samples from the middle region of mature canes. They were cut into small parts. These samples were then dried in an electric oven at 65°C until a constant weight was reached, after which they were ground into a fine powder. After that, 0.5 g portion of each sample was then digested using sulfuric acid and perchloric acid, and colorless extracts ready for mineral estimation were obtained, following the procedure described by Al-Sahhaf [14]. Nitrogen was then quantified using a Micro-Kjeldahl apparatus according to the method provided by Jackson [15].

6. Potassium percentage in leaf petioles (%)

The potassium percentage in mid-January was

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estimated using a Flame photometer, and the readings were taken at a wavelength of 766 nm, following the standard procedures described by the A.O.A.C [16].

7. Phosphorus percentage in leaf petioles (%)

The phosphorus percentage was estimated in mid-January using a spectrophotometer at a wavelength of 665 nm. The procedure utilized ammonium molybdate and ascorbic acid, following the methodology described by Olsen and Sommers [17].

8. Iron content in leaf petioles (mg/L)

The iron percentage was calculated using a spectrophotometer according to the method described by Olsen and Sommers [17].

9. Magnesium percentage in leaf petioles (%)

The magnesium percentage was calculated by taking a quantity of dried canes and analyzing them using a flame photometer, following the procedure outlined by Lanyon and Heald [18].

Results and Discussion

1. Leaf area (cm²)

The results in Table (2) showed significant differences among spraying treatments in leaf area in grape cultivars. The treatment (spraying with nano-iron + nano-magnesium at 200 mg L-1) F3 recorded the highest overall mean, reaching (47.50 cm²), followed by treatment F2 (spraying with nano-magnesium at 200 mg L-1), which gave (45.30 cm²), then treatment F1 (spraying with nano-iron at 200 mg L-1), which recorded (42.73 cm²), whereas treatment F0 (without spraying) gave the lowest mean, reaching (40.60 cm²). The cultivars also showed variation in their response, as cultivar V4 (Al-Kishmishi) recorded the highest mean among cultivars, reaching 60.89 cm², followed by cultivar V2 (Al-Shidda Al-Sawda) with (49.88 cm²), then cultivar V1 (Baydh Al-Hamam) with (35.50 cm²), while cultivar V3 recorded the lowest mean, reaching (29.86 cm²). As for the interaction between spray treatments and cultivars (F × V), the highest value at the interaction V4F3, where the value reached (65.49 cm²), whereas the lowest value within the interaction was at treatment V3F0 with a mean of (28.42 cm²).

Table 2. Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on leaf ara (cm^2)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	32.51	45.29	28.42	56.19	**40.60**
F1 (200 mg L-1 Fe)	34.24	48.30	29.18	59.22	**42.73**
F2 (200 mg L-1 Mg)	36.66	51.33	30.55	62.66	**45.30**
F3 (200 mg L-1 Fe + Mg)	38.61	54.61	31.32	65.49	**47.50**
V mean	**35.50**	**49.88**	**29.86**	**60.89**	
LSD = 0.05	**F= (0.0785)**		**V= (0.4633)**		**F×V= (0.8046)**

Sapling height (cm)

The statistical analysis reported in Table (3) confirmed that the spraying treatments had no significant effect on sapling height. As for the cultivars, evident differences in their response were obtained and the cultivar V4 recorded the highest value of 236.1 cm,, which did not differ significantly from cultivar V3 (180.2 cm). Cultivar V2 gave (136.0 cm) and did not differ significantly from cultivar V3, but these did differ from cultivar V1, which showed the lowest mean (69.1 cm). Regarding the interaction treatments, they did not give any difference between means for sapling's height characteristic.

Table 3. Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on sapling height (cm)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	59.3	108.9	166.7	221.5	**139.1**
F1 (200 mg L-1 Fe)	69.2	131.5	171.1	223.1	**148.7**
F2 (200 mg L-1 Mg)	72.6	141.6	174.9	233.1	**155.6**
F3 (200 mg L-1 Fe + Mg)	75.4	162.0	208.3	266.7	**178.1**
V mean	**69.1**	**136.0**	**180.2**	**236.1**	
LSD = 0.05	**F= (N.S)**	**V= (0.4633)**		**F×V= (N.S)**	

Diameter of the main branch of the saplings (mm)

The results in Table (4) show that foliar spraying treatments significantly affected the diameter of saplings of grape cultivars. Treatment F3 achieved the highest mean (21.73 mm), followed by treatment F2, which recorded (20.54 mm), then treatment F1 (19.82 mm), whereas treatment F0 gave the lowest mean, reaching (19.08 mm). Significant differences were also observed among the four cultivars, as cultivar V4 achieved the highest mean (25.04 mm), followed by cultivar V3 with (22.07 mm), then cultivar V2 with (18.96 mm), while cultivar V1 recorded the lowest mean among cultivars (15.09 mm). Regarding the interaction, the highest value appeared in treatment V4F3 with a mean of (27.01 mm), whereas the lowest value was in treatment V1F0, which recorded (14.10 mm).

Table 4 Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on branch diameter (mm)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	14.10	17.48	21.03	23.71	**19.08**
F1 (200 mg L-1 Fe)	14.70	18.62	21.81	24.16	**19.82**
F2 (200 mg L-1 Mg)	15.12	19.50	22.24	25.31	**20.54**
F3 (200 mg L-1 Fe + Mg)	16.44	20.25	23.22	27.01	**21.73**
V mean	**15.09**	**18.96**	**22.07**	**25.04**	
LSD = 0.05	**F= (0.0327)**		**V= (0.0521)**		**F×V= (0.0937)**

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Leaf chlorophyll a content (mg 100 g^{-1} fresh weight)

The results presented in Table (5) showed a clear significant effect among the treatments sprayed with nano-iron and nano-magnesium. Treatment F3 achieved the highest mean for chlorophyll a content, reaching (38.08 mg 100 g^{-1} fresh weight), followed by treatment F2, which did not differ significantly from it (37.92 mg 100 g^{-1} fresh weight), then treatment F1 with (35.33 mg 100 g^{-1} fresh weight), compared with treatment F0, which gave the lowest mean (33.17 mg 100 g^{-1} fresh weight).

Regarding cultivars, they differed among themselves, as cultivar V4 achieved the highest mean chlorophyll content (37.17 mg 100 g^{-1} fresh weight), followed by cultivar V2 with (36.25 mg 100 g^{-1} fresh weight), then cultivar V1 with (35.58 mg 100 g^{-1} fresh weight), which did not differ significantly from cultivar V3 that recorded the lowest mean (35.50 mg 100 g^{-1} fresh weight).

With respect to the interaction between the study factors, no significant effect was recorded on the leaf chlorophyll a content trait.

Table 5 Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on chlorophyll a content (mg 100 g^{-1} fresh weight)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	32.33	33.00	33.33	34.00	**33.17**
F1 (200 mg L-1 Fe)	35.00	35.33	34.33	36.67	**35.33**
F2 (200 mg L-1 Mg)	37.33	38.00	37.00	39.33	**37.92**
F3 (200 mg L-1 Fe + Mg)	37.67	38.67	37.33	38.67	**38.08**
V mean	**35.58**	**36.25**	**35.50**	**37.17**	
LSD = 0.05	**F= (0.726)**		**V= (0.681)**	**F×V= (N.S)**	

Leaf chlorophyll b content (mg 100 g^{-1} fresh weight)

The results presented in Table (6) showed that foliar spraying treatments affected leaf chlorophyll b content. Treatment F3 recorded the highest overall mean, reaching (25.00 mg 100 g^{-1} fresh weight), followed by treatment F2, which gave (24.41 mg 100 g^{-1} fresh weight), and then the treatment F1 reaching 22.16 mg/100 g fresh weight, while the F0 treatment recorded the lowest average of 20.16 mg/100 g fresh weight.

Significant differences were also observed between cultivars, with V4 achieving the highest average chlorophyll b content of 23.50 mg/100 g fresh weight, which did not differ significantly from V2 at 23.16 mg/100 g fresh weight. V3 followed at 22.83 mg/100 g fresh weight, while V1 recorded the lowest average at 22.25 mg/100 g fresh weight. Regarding interaction, the highest value achieved in the V2F3 treatment at 26.00 mg/100 g fresh weight, whereas the lowest interaction value was found in the V1F0 treatment with an average of 19.66 mg/100 g fresh weight.

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Table 6. Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on chlorophyll b content (mg 100 g^{-1} fresh weight)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	19.66	20.00	20.66	20.33	**20.16**
F1 (200 mg L-1 Fe)	21.66	22.33	21.66	23.00	**22.16**
F2 (200 mg L-1 Mg)	23.66	24.33	24.00	25.66	**24.41**
F3 (200 mg L-1 Fe + Mg)	24.00	26.00	25.00	25.00	**25.00**
V mean	**22.25**	**23.16**	**22.83**	**23.50**	
LSD = 0.05	**F= (0.594)**		**V= (0.516)**	**F×V= (1.014)**	

Nitrogen percentage in leaf petioles

The results in Table (7) showed that the foliar spray treatments significantly affected the nitrogen percentage in leaf petioles, with treatment F3 achieving the highest average (1.506%), followed by treatment F2, which recorded (1.468%), then F1, which reached (1.436%), while treatment F0 gave the lowest average (1.391%). Differences were also observed among the four varieties, with variety V4 achieving the highest average of 1.760%, followed by variety V3 with an average of (1.547%), then variety V2, which reached (1.285%), while variety V1 recorded the lowest average among the varieties at (1.210%). Interaction also significantly impacted the nitrogen percentage in petioles, with the highest value occurring in the V4F3 treatment at 1.836%, whereas the lowest value was recorded in the V1F1 treatment at 1.200%.

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Table 7 Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on petioles nitrogen content(%)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	1.203	1.246	1.430	1.686	**1.391**
F1 (200 mg L-1 Fe)	1.200	1.263	1.546	1.736	**1.436**
F2 (200 mg L-1 Mg)	1.220	1.313	1.560	1.780	**1.468**
F3 (200 mg L-1 Fe + Mg)	1.220	1.316	1.653	1.836	**1.506**
V mean	**1.210**	**1.285**	**1.547**	**1.760**	
LSD = 0.05	**F= (0.0151)**		**V= (0.0161)**	**F×V= (0.0304)**	

Phosphorus percentage in leaf petioles (%)

The data in Table (8) show significant differences among the spraying treatments in leaf petioles phosphorus percentage. Treatment F3 with mean of 0.3033% was highest and followed by treatment F2 which recorded (0.2842%) and treatment F1 with (0.2742%), while treatment F0 had a lowest mean value of (0.2725%).

In relation to the cultivated plants, diversity was found in their response. Cultivar V4 had the highest means among cultivars (0.3375%) followed by V3 with a mean of (0.2950) then V2 (0.260%) and finally V1 recorded the lowest mean of (0.2417%).

The result revealed a significant interaction between study factors, and the maximum value was for treatment V4F3 content (0.3767%), though the minimum ratio was found with means of (0.2333%) in treatment V1F0).

Table 8. Effect of foliar spraying with nano iron, nano magnesium and grape cultivars and their interaction on petioles phosphorus content(%)

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	0.2333	0.2533	0.2867	0.3167	**0.2725**
F1 (200 mg L-1 Fe)	0.2333	0.2533	0.2900	0.3200	**0.2742**
F2 (200 mg L-1 Mg)	0.2467	0.2600	0.2933	0.3367	**0.2842**
F3 (200 mg L-1 Fe + Mg)	0.2533	0.2733	0.3100	0.3767	**0.3033**
V mean	**0.2417**	**0.2600**	**0.2950**	**0.3375**	
LSD = 0.05	**F= (0.0137)**		**V= (0.0083)**	**F×V= (0.0184)**	

Potassium percentage in leaf petioles (%)

The results in Table (9) show differences in potassium content among the different cultivars and among the spraying treatments with iron and magnesium (foliar fertilization). Treatment F3 recorded the highest mean potassium content, reaching (1.212%), followed by treatment F2 with (1.196%), then treatment F0 which recorded (1.174%), whereas treatment F1 recorded the lowest mean (1.172%).

The cultivars also differed among themselves, as cultivar V4 achieved the highest mean potassium content (1.285%), followed by cultivar V3 with (1.188%), then cultivar V2 which gave (1.158%), while cultivar V1 recorded the lowest mean (1.124%).

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Regarding the interaction, the highest value was achieved in treatment V4F3 (1.336%), whereas the lowest value was in treatment V1F0 with a mean of (1.110%).

Table 9. Effect of foliar spraying with nano iron and nano magnesium on potassium percentage in leaf petioles (%) of four grape cultivars

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V**				**F mean**
	Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	
F0 (distilled water only)	1.110	1.153	1.180	1.253	**1.174**
F1 (200 mg L-1 Fe)	1.113	1.146	1.183	1.246	**1.172**
F2 (200 mg L-1 Mg)	1.130	1.163	1.190	1.303	**1.196**
F3 (200 mg L-1 Fe + Mg)	1.143	1.170	1.200	1.336	**1.212**
V mean	**1.124**	**1.158**	**1.188**	**1.285**	
LSD = 0.05	**F= (0.0098)**		**V= (0.0094)**	**F×V= (0.0181)**	

Iron content in leaf petioles (mg kg⁻ ¹ dry matter)

The data presented in Table (10) show differences in iron content among the different cultivars and among the spraying treatments. Treatment F3 recorded the highest mean, reaching (137.4 mg kg⁻ ¹ dry matter), followed by treatment F2 with (131.9 mg kg⁻ ¹ dry matter), then treatment F1 with (125.3 mg kg⁻ ¹ dry matter), whereas treatment F0 gave the lowest mean (122.3 mg kg⁻ ¹ dry matter).

The cultivars also varied among themselves. Cultivar V4 recorded the highest mean (158.3 mg kg⁻ ¹ dry matter), followed by cultivar V3 with (136.5 mg kg⁻ ¹ dry matter), then cultivar V2 with an average of (121.0 mg kg⁻ ¹ dry matter), while the lowest mean was in cultivar V1 (101.0 mg kg⁻ ¹ dry matter).

Regarding the interaction, the highest value was in treatment V4F3, achieving (168.6 mg kg⁻ ¹ dry matter), whereas the lowest value was in treatment V1F0 with a mean of (94.33 mg kg⁻ ¹ dry matter).

Table 10. Effect of foliar spraying with nano iron and nano magnesium on iron content in leaf petioles (mg kg⁻ ¹ dry matter) of four grape cultivars

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V**				**F mean**
	Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	
F0 (distilled water only)	94.33	115.0	131.3	148.6	**122.3**
F1 (200 mg L-1 Fe)	94.67	117.3	134.0	155.3	**125.3**
F2 (200 mg L-1 Mg)	105.3	126.0	135.6	160.6	**131.9**
F3 (200 mg L-1 Fe + Mg)	110.0	126.0	145.0	168.6	**137.4**
V mean	**101.0**	**121.0**	**136.5**	**158.3**	
LSD = 0.05	**F= (2.440)**		**V= (2.342)**	**F×V= (4.502)**	

Percentage of Magnesium in Leaf Petioles (%)

The results in Table 11 show that spraying with nano-iron and nano-magnesium clearly influenced the magnesium percentage in the leaf petioles of the grape cultivars. Treatment F3 recorded the highest mean of 0.1416%. This was followed by treatment F2 at 0.1400%, and then treatment F1 at 0.1350%. The control

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treatment F0 yielded the lowest mean of 0.1241%.

The cultivars also showed clear differences in their response. Cultivar V4 recorded the highest magnesium content at 0.1766%, followed by cultivar V3 with a mean of 0.1441%, then cultivar V2 at 0.1183%, while cultivar V1 had the lowest mean of 0.1016%.

The statistical analysis indicates that the interaction effect between the study factors was not significant for the magnesium percentage in leaf petioles.

Table 11. Effect of foliar spraying with nano iron and nano magnesium on percentage of magnesium in leaf petioles (%) of four grape cultivars

Nano iron and nano magnesium foliar spraying (F)	Cultivars **V** Bayd Al-Hamam V1	Al-Shadda Al-Sawda V2	Al-Halwani V3	Al-Kishmishi V4	**F mean**
F0 (distilled water only)	0.0966	0.1100	0.1300	0.1600	**0.1241**
F1 (200 mg L-1 Fe)	0.1000	0.1233	0.1433	0.1733	**0.1350**
F2 (200 mg L-1 Mg)	0.1033	0.1166	0.1533	0.1866	**0.1400**
F3 (200 mg L-1 Fe + Mg)	0.1066	0.1233	0.1500	0.1866	**0.1416**
V mean	**0.1016**	**0.1183**	**0.1441**	**0.1766**	
LSD = 0.05	**F= (0.0096)**		**V= (0.0058)**	**F×V= (N.S)**	

Discussion

The results of this study indicated that, in the majority of the studied physiological and chemical properties, combined spraying with nano ferrous oxide and nano magnesium oxide was significantly better than other treatments. Iron has been indispensable in photosynthetic and electron transport processes of plants, because it serves as an integral element of the electron-rich proteins and enzymes involved with building chlorophyll for energy transfer. It was reported that nano-fertilizers of iron enhance leaf area by enhancing photosynthetic efficiency and increasing the accumulation of carbohydrates that support cell growth [19]. For instance, it was found in cabbage that the photosynthesis rate and leaf area of spray were significantly higher than those of control with nano-iron treatment [20].

Chlorophyll molecule contains magnesium at its core so that presence of magnesium promotes light-absorbing process for the efficient conversion of light energy to chemical energy. The rising of chlorophyll content results from improved sugar formation and brings more material for vegetative growth, which may contribute to the increase in leaf area size and vascular tissue. These mechanisms collectively drive enlargement of the main stem girth by stimulating cell division and elongation in expanding regions [21].

The availability of these elements improves the plant’s assimilatory capacity and increases the accumulation of photosynthesis products, which is reflected in a higher percentage of mineral elements in leaf petioles. The nano-spray combination also contributed to improving the nitrogen content in leaf petioles, and this is attributed to the high photosynthetic efficiency that leads to increased formation of amino acids and proteins, in addition to the role of magnesium in activating enzymes associated with nitrogen metabolism.

The increase in leaf chlorophyll a and b content is attributed to spraying with magnesium, as magnesium is an essential element in the structure of the chlorophyll molecule, occupying the central position in its molecular structure; therefore, its sufficient availability directly contributes to increasing chlorophyll synthesis and raising its concentration in leaves. In contrast, iron plays an indirect but fundamental role in the synthesis process, as it enters into the structure of many enzymes and electron-transport proteins, such as cytochromes and ferredoxin, which are necessary for the progress of light reactions and the stability of chloroplasts. Taiz et al. [22] indicated that iron deficiency leads to the leaf yellowing phenomenon (chlorosis) as a result of disruption of chlorophyll formation, despite the fact that iron does not directly enter into its composition. Marschner [23] points out that improving the plant's micronutrient nutritional status contributes to increasing the efficiency of uptake of macronutrients, including nitrogen.

The increase in nitrogen, potassium, phosphorus, and magnesium contents in leaf petioles can be explained by improved metabolic activity and the movement of elements within the plant due to nano spraying. Potassium functions in regulating osmotic balance and sugar translocation, whereas phosphorus enters into the structure of energy compounds (ATP) necessary for biosynthetic processes. Photosynthetic efficiency increases absorption and transfer of potassium and phosphorus to woody organs [24].

Similarly, a significantly higher concentration of leaf petiole Fe was also found when the nano-spray combination was applied, and is likely due to the physical properties of nano materials such as their small particle size and high surface area that enhances absorption and decreased loss relative to bulk fertilizers. Raliya *et al.* [25] stated that the use efficiency of micronutrients is significantly enhanced by nano-fertilizer and so is the level of accumulation in plant tissue. These findings are in line with those reported by Romani and Maguire [26], with what is reported by Rahemi et al. [27] in the quince tree research, and that by Al-Azzawi [28] in strawberry plants.

Conclusion

Based on the above, it can be concluded that the superiority of spraying with the combined nutrient elements nano-ferrous and nano-magnesium oxide as well as grape cultivar Al-kishmishi is due to its response to treatment with these two nanoelements. This resulted in enhanced vegetative growth parameters, and subsequently an increased uptake of nutrients and higher accumulation of carbohydrate materials which in turn conferred to it a distinct superiority over the other cultivars under investigational conditions

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