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A Comparison of the Effects of Several Foliar Forms of Magnesium Fertilization on 'Superior Seedless' (*Vitis vinifera* L.) in Saline Soils

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Abstract: Magnesium (Mg) is the most essential element constituent in chlorophyll molecules that regulates photosynthesis processes. The physiological response of 'Superior Seedless' grapes was evaluated under different foliar magnesium fertilization such as sulfate magnesium ($MgSO_4 \cdot 7\ H_2O$), magnesium disodium EDTA (Mg-EDTA), and magnesium nanoparticles (Mg-NPs) during the berry development stages (flowering, fruit set, veraison, and harvest). In general, the 'Superior Seedless' vine had a higher performance in photosynthesis with Mg-NPs application than other forms. The Fy/Fm ratio declined rapidly after the fruit set stage; then, it decreased gradually up until the harvesting stage. However, both $MgSO_4$ and Mg-EDTA forms showed slight differences in Fv/Fm ratio during the berry development stages. The outcomes of this research suggest that the Fv/Fm ratio during the growth season of the 'Superior Seedless' vine may be a good tool to assess magnesium fertilization effects before visible deficiency symptoms appear. Mg-NPs are more effective at improving 'Superior Seedless' berry development than the other magnesium forms. These findings suggest that applying foliar Mg-NPs to vines grown on salinity-sandy soil alleviates the potential Mg deficiency in 'Superior Seedless' vines and improves bunches quality.

Keywords: fruit quality; nutrient concentration; chlorophyll concentration

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1. Introduction

Grapes are one of the most important fruit crops on the planet. Grape is a member of the Vitis genus, which is part of the Vitaceae family, which contains more than 60 genera. Grapes (*Vitis vinifera* L.) are cultivated in more than 100 countries throughout the world, with an estimated area of 7.8 million hectares in 2016. Wine, jam, juice, grape seed extract, dried grapes, vinegar, and grape seed oil are among the many goods made from grapes. In 2016, the world produced 75.8 million tons of grapes, with 39% produced in Europe, 34% produced in Asia, 18% produced in the Americas, and 9% produced in Africa [1]. Grapes are Egypt's second most important fruit crop, after citrus. Egypt's agriculture has succeeded in increasing vineyard area by 220,665 hectares over the past decade, yielding 1,586,342 tons of grapes [2]. The grapevine is one of the most important horticultural crops in the world. The high value of table grapes is primarily attributed to bio-compounds

required for human health, such as antioxidants, anthocyanins, and phenolics, which include gallic acid, catechin, anthocyanins, and resveratrol [3].

The fundamental issue with newly reclaimed and cultivated fields was that they were often sandy and calcareous soils with poor nutrient concentration, especially magnesium. Recently, research on magnesium nutrition has begun, with the goal of determining the Mg requirements of Egypt's most important crops. Magnesium deficiency has been discovered in some Egyptian soils such as clay or newly reclaimed soils [4]. Therefore, magnesium (Mg) is the most essential element constituent in chlorophyll molecules that regulates the photosynthesis processes [5,6]. The deficiency of Mg during growth seasons limits photosynthesis performance [7]. The physiological functions of Mg in plants have also been characterized for flowering induction [8]. Mg is required for the growth and development of plants [9]. It is also a cofactor in the biosynthesis of various enzymes, including those involved in respiration and photosynthesis. It is a phloem-mobile nutrient that migrates between older and younger leaves [10]. Mg is also a significant component of the chlorophyll molecule's ring structure [11]. Additionally, it alleviates abiotic stress conditions, such as dryness and heat, which can significantly enhance Mg deficit by inhibiting its absorption due to its mass flow transit [9]. Additionally, it mitigates aluminum toxicity in acid soils at micromolar concentrations, as opposed to calcium, which is required at millimolar concentrations [12]. A Mg shortage has been shown to adversely influence ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), which is involved in CO_2 fixation [13], resulting in a decrease in photosynthetic performance [14], which is correlated to a decrease in photosynthesis performance and stomatal mechanism [15]. Furthermore, it plays a role of metabolism nitrogen in plant [16]. The inhibitory influence of Mg loss on photosynthetic capacity and net CO_2 absorption was marked in several plant species [5,17,18]. As a result, in certain species, magnesium deprivation affects the structure and function of the PSI and PSII systems [19]. As a result, a decrease in the Fv/Fm ratio (maximum quantum efficiency of PSII) was observed in citrus seedlings [20]. Despite this, the Mg shortage had no effect on Fy/Fm and other fluorescence metrics in *Helianthus annuus* plants under Mg deficiency conditions. A rise in the chlorophyll a/chlorophyll b ratio is typically reported [21]. The decrease in light-harvesting complex II (LHC-II) abundance in Mg the absence of *Arabidopsis thaliana* leaves is caused by thylakoid membrane dysfunction [22].

Many researchers have begun to investigate magnesium nutrition and the determination of magnesium requirements for economically important crops [23] such as 'Washington navel' orange trees [24] and banana plants, and they have reported on the influence of magnesium on yield and fruit quality, stating that magnesium fertilization increased the yield and fruit quality of the aforementioned fruit species [25]. In addition, using the magnesium application can induce a state of magnesium deficiency during growing [26]. Furthermore, fertilizing "Grand Nain" bananas with 100 g/plant magnesium chelate plus a foliar spray of 2% magnesium sulfate increased growth metrics, yield, and fruit quality [27]. In addition, treating Le Conte pear plants with compost 45 kg/tree + biofertilizers 20 g/tree plus 1.5% magnesium sulfate produced the best production and fruit quality [28]. The foliar Mg (137.5 ppm) application boosted the growth characteristics and yield of Washington Navel orange trees [29]. Moreover, some studies were conducted to improve bunches of color quality of Crimson seedless by using foliar application of Mg [30].

'Superior seedless' is one of the first seedless table grapes to be produced in the Mediterranean region, and it adapts well to and performs well in Egyptian circumstances as well. It was harvested when the meat was yellow-white and the skin was green, as requested by the European market [31]. 'Superior Seedless' is also considered as one of the most important international grape variety with a good economic return [32]. Consumers value this grape selection for its excellent nutritional value, great taste, versatile application, and higher economic returns [33]. The world's vineyard area is growing as a result of a continual and unrelenting shift [34]. The purpose of this study is to determine the difference among foliar magnesium forms on 'Superior Seedless' vines grown in salinity sandy soil.

Furthermore, this study also aims to determine the optimal magnesium form for vine nutrition under soil salinity conditions.

2. Materials and Methods

2.1. Vine and Experimental Setup

A commercial vineyard in the Nobaria area of Egypt (31.23° N, 29.96° E) was studied for two growth seasons (2020 and 2021). The soil was sandy in texture (*Entisol-Typic Torripsamments*), and the soil composition is described in Table 1. The farm consists of 6-year-old vines of the 'Superior Seedless' cv. grafted on 1103 Paulsen rootstock. Three-by-three-meter vines were planted in sandy soil using a drip watering system. The pruning level was done on all vines at 70 bud vines^{-1} (7 cans × 10 buds can^{-1} each on four cardons), and all vines were trained by the Y system. Table 1 summarizes the physical and chemical examination of the field experiment with 'Superior Seedless' vines [35,36]. All vines were pruned to a height of 60 buds' vine^{-1}, with the length of the cans ranging from 6 to 8 buds per can, and each can contain 12–14 buds and were produced until mid-July in European countries. Additionally, according to the Egyptian Agriculture Ministry, all vines received the same management program as for NPK fertilizer (300, 200, and 250 Kg were afforded on three portions from growth starting until harvesting (one portion was added at the vine dormancy stage) in sandy soil. Uniform vines (48) were chosen and treated with four different types of magnesium; each treatment consisted of three duplicates with four vines per replication. All treatments receive 750 g of magnesium sulfate per 600 L of irrigation water, which was employed to avoid magnesium shortages. It is distinguished by the yellowing of older leaves and a yellow tint between the veins of the leaves.

Table 1. Soil and irrigation-water traits analysis.

Soil Analysis													
Physical Properties						**Soluble Anions (meq L^{-1})**			**Soluble Cations(meq L^{-1})**				
Sand %	Clay %	Silt %	Texture	EC dsm^{-1}	pH	HCO_3	Cl^-	SO_4	Na^+	K^+	Mg++	Ca^{++}	SAR
85.8	6.90	11.30	Sandy	4.50	7.93	2.80	14.10	13.10	25.00	3.00	3.80	12.00	8.89
Irrigation-Water Analysis													
-	-	**Anions (meq L^{-1})**							**Cations (meq L^{-1})**				
pH	EC (dS m^{-1}) 0.85	CO_3^-	HCO_3^-	Cl^-	SO_4^-	Ca^{++}	Mg^{++}	Na^+	K^+	-	-	-	
7.18	567 ppm	0.20	2.45	0.90	1.18	1.73	0.67	2.60	0.16	-	-	-	

2.2. Magnesium Fertilization Forms Treatment Protocol

The foliar magnesium application was laid out as control (0.5 g L^{-1}), $MgSO_4 \cdot 7H_2O$ (0.5 g L^{-1}), Mg-EDTA (Mg chelate 0.5 g L^{-1}), and Mg-NPs powder (0.5 g L^{-1}). Nanomaterials provided magnesium nanoparticles (MgO, 99%+ purity, 20 nm) in powder form at sundown. This optimal concentration was used for application. At sundown during the four stages of growth (flowers, fruit set, veraison, and harvest), foliar treatments were made (7:00 pm). In a bath of warm tap water, the magnesium compounds were melted. Using a knack-sap pump, the solutions were sprayed over the entire vine monthly until the leaves became saturated. The rest of the magnesium salts were acquired from EL-Gomhoria Co. Ltd. in Egypt from EL-Gomhoria Co. Ltd. In Mansoura city, Egypt.

2.3. Magnesium Deficiency Index

Magnesium deficiency (MD) results in interveinal yellowing or reddening on old leaves, beginning at the leaf edge and proceeding to the leaf veins' petiole-connected point. These symptoms progress to necrotic brown patches, and in severe MD, the leaves exhibit necrosis, dray, and premature fall. The Mg deficiency was inspected and scored on a scale from 0 (no injury) to 5 (very severe injury) [37].

2.4. Leaf Pigments Content and Chlorophyll Fluorescence

Total chlorophyll (Chls) and carotenoid (Car) content were determined spectrophotometrically [38] on the 7th leaf (ten leaves) from the shoot base.

Individual dark-leaf CF data were recorded. The data were acquired using a commercial fluorimeter (Mini-PAM, Walz, Effeltrich, Germany) and data gathering software (Win Control, Walz, Effeltrich, Germany). These data included F_0 (minimum fluorescence), Fm (light-saturated fluorescence), and the Fv/Fm ratio (the difference between maximum fluorescence and minimum fluorescence is Fv or variable fluorescence divided by maximum fluorescence). A fall in the Fv/Fm ratio below 0.75–0.78 suggests a decline in photosystem II photochemical transformation capability [39,40]. On the 7th leaf, CF parameters were determined.

2.5. Leaf Area, Total Carbohydrate Content, Ion Leakage Percentage, and Malondialdehyde (MDA)

On the 7th leaf, the Sokkia Planix 7 Digital Planimeter was used to quantify leaf area during four developmental stages. However, the vine canes' cumulative carbohydrate content was assessed according to [41]. The leaf petiole cell permeability was also tested. After three washes with deionized water, the rachis samples were put in 10 mL of 0.4 M mannitol at 24 °C for three hours. After measuring the EC of the aqueous phase (M1), the rachis samples were killed in a water bath at 100 °C for 20 min. This was followed by room-temperature cooling. Then, it was estimated as a percentage of the relative electrolyte loss from M1 rachis samples using the equation: ion leakage percent = (M1M2)/M1 × 100 [42,43]. However, MDA was a by-product of lipid peroxidation that accumulated during salinity stress. They used 2.5 g of leaf petiole samples for MDA extraction [44,45]. This was done by measuring 0–3 mM of TBARS (equal to 0–1 mM MDA) in 1,3,3-tetraethoxypropane (Sigma, St. Louis, MO, USA). During the assay's acid-heating halt, TEOP is stoichiometrically transformed to MDA.

2.6. Leaf Minerals Content

Leaf mineral content was measured on the 7th leaf from the base of the shoot during four vegetative growth stages. Nitrogen % [46], phosphorous [47], and potassium content [35] as well as the magnesium, calcium, chloride, and sodium content percentages were demined [48].

2.7. Yield and Berry Properties

At harvest, the number of clusters per vine, average cluster weight (Kg), and yield per vine (Kg) were determined. In addition, the pruned wood was weighted. The SSC % of berry juice was measured with a digital refractometer (PR32 ALA-GO Co., Tokyo, Japan) at lab temperature, and it was represented as a percentage. As for TA %, berry juice (20 mL) was used for titrating by NaOH (0.1N). The outcome was shown as a percentage. However, the SSC/TA-ratio was computed to judge bunch maturity [49,50].

2.8. Statistical Analysis

The experiment was designed as a randomized complete block in three-way ANOVA with three factors: seasons (2 levels), berry developmental phase (4 levels), and foliar magnesium forms (3 levels) with three replicates per treatment. The mean separations were run with Tukey's HSD test ($p \leq 0.05$). Pearson's correlation matrix among the studied parameters and principal component analysis (PCA) were applied. Tukey's HSD test was run using the JMP Pro 16 software, with $p < 0.05$ taken as indicating a statistically significant difference (SAS Institute, Cary, NC, USA).

3. Results

3.1. Magnesium Deficiency Index (MD-Index)

Figure 1 depicts the magnesium deficiency index (MD-index), which is a function of berry developmental stages (BDSs) for all magnesium types. When seasons, BDSs, and

magnesium application forms are examined, the MD-index demonstrates a significant influence of $p < 0.05$. Considering the different magnesium forms, it is obvious that the Mg-NPs treatment produced fewer symptoms of magnesium deficiency than the other magnesium forms. Observably, the effect of 'Mg-NPs' was that there was no evidence of deficient symptoms prior to the veraison stage (berry change color) and that it rose somewhat until the harvesting stage was completed. For vines treated with Mg-EDTA, $MgSO_4$, and control treatments, deficit symptoms were observed prior to fruit set, increased significantly during veraison, and persisted until harvesting. However, during the vegetative growth stages, the 'Control' treatment exhibited the most deficiency symptoms. The severity of Mg was noticed on 'Control' vines that were unaffected by the Mg forms, but the control vines had more symptoms throughout the vegetative growth stages. On sandy soils, symptoms of a magnesium deficit appear on vines during the growth season, necessitating monthly spraying of vines to compensate for the shortfall and thereby avoiding deficient occurrence. Regardless of the magnesium supply to the vines, 750 g of magnesium sulfate per 600 L of irrigation water is employed to avoid magnesium shortages. It is distinguished by the yellowing of older leaves and a yellow tint between the veins of the leaves.

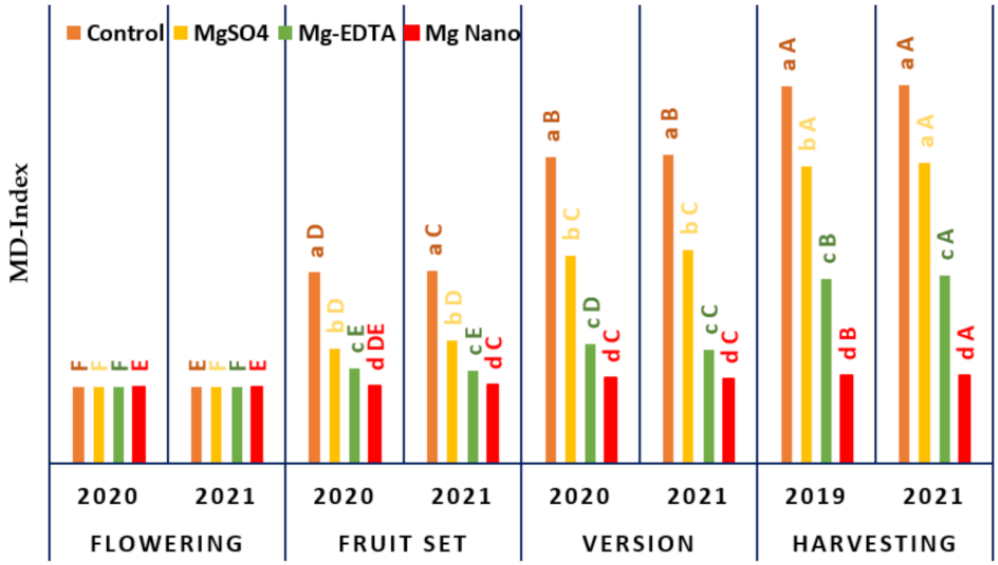

Figure 1. The influence of various magnesium fertilizer forms on 'Superior seedless' vines throughout four berry development phases (flowering, fruit set, veraison, and harvesting) under soil salinity conditions on magnesium shortage during the four stages. The values represent the mean affect levels in each application plus standard error ($n = 3$). Tukey's HSD test ($p \leq 0.05$) used mean severance between blocks (capital letters) to detect significant differences between growing seasons and Mg applications (capital letters) to distinguish significant differences between Mg types.

3.2. Photosynthetic Pigments: Chlorophyll (Chls) and Carotene (Car)

Photosynthetic pigments as a function of BDSs for all foliar magnesium application forms are shown in Tables 2 and 3. Leaf pigments show a significant interaction at $p \leq 0.05$ when the seasons, BDSs, and foliar magnesium treatments were considered. Generally, chlorophyll compounds (Chl A and Chl B) and carotenoid (Car) were raised gradually during BDSs until the harvest stage for all Mg treatments, whereas the untreated vines (control) treatment presented the lowest decreases in Chls and Car until the end of the experiment. Despite this, there is a significant variance between Mg treatment on pigment content that was observed during both growing seasons. The obvious outcomes are that the Mg-NPs presented the highest amount of Chl A and Chl B and Car compared to the other Mg treatments and control vines. They were marked with the highest amount at the harvest stage. Moreover, the Car exhibited the highest content at the harvest time stage compared to other foliar treatments. Regarding the Chl A:b ratio, the lowest rates at the harvesting

stage of the vegetative growth period decreased progressively until grape harvesting with all Mg treatments. Nevertheless, the Chl A:b ratio of Mg-NPs had more stable outcomes than those shown with other Mg treatments throughout the growing season.

3.3. Parameters of Chlorophyll Fluorescence (CF) (Fv/Fm, Fm, and F0)

A significant interaction between seasons and berry developmental stages was found as well as the influence of Mg treatments on Fm and F0 ($p < 0.001$). No significant variations in Fv/Fm ratio were observed for the interaction effect of seasons, berry developmental stages, and mg treatments, but significant differences in Fm and F0 were observed, whereas a significant difference ($p < 0.01$) was noted for the magnesium effect ($p < 0.001$). The Fv/Fm ratio of 'Superior seedless' vines was proposed as a function of BDSs; when seasons, BDSs, and foliar Mg form fertilization were considered, substantial results were obtained (Table 4). On average, untreated vines exhibit a higher decline in the Fv/Fm ratio than vines treated with other Mg compounds. It is drastically reduced until the harvest stage. Except for Mg-NPs treatment, the drop in the Fv/Fm ratio appears to be more gradual and progressive, including a trend toward a more inferior Fv/Fm ratio during vegetative growth stages.

Both Fm and F0 rates increased significantly in overall Mg treatments from the initial stage (flowering) to the veraison stage (Table 4), and this increase was significant for both Fm and F0. It was discovered that the effect of Mg treatments on Fm and F0 varied according to the Mg forms. Then, both are steady until the experiment's duration expires. In comparison to other treatments, the application of Mg-NPs resulted in the greatest Fm and F0 values. Thus, when the Fv/Fm ratio of the 'Superior Seedless' vine was changed, Mg-NPs enhanced CF parameters more than other Mg treatments. As a result, this sample fluorescence parameter can detect magnesium insufficiency.

3.4. Leaf Area, Shoot Carbohydrate, Ion Leakage, and Malondialdehyde Content

Table 5 presents the differences in leaf area, shoot carbohydrate, ion leakage, and malondialdehyde accumulation as a function of berry developmental stages. The interaction ($p < 0.001$) was significant between the berry developmental stages and the Mg foliar fertilization forms and season. The leaf area (cm^2) and shoot carbohydrate content (%) have significantly ($p < 0.008$) higher values when vines receive the Mg-NPs form than other forms. Whereas, when considering the ion leakage percent and MDA content, there were significantly ($p < 0.0005$) lower values throughout the berry developmental stages. This implies that there is variability based on Mg type for previous variables.

3.5. Mineral Content in Leaves

Tables 6 and 7 exhibit the significant variances ($p > 0.001$) between seasons, BDSs, and Mg application foliar form treatments in the 7th leaf from the base of the shoot N, P, K^+, Ca^{++}, Mg^{++}, Na^+, and Cl^- content when all were considered as experimental factors. Na^+ and Cl^- content significantly decreased with Mg-NPs application compared to other Mg forms. However, the rest of the mineral increased during the growth stages.

3.6. Yield and Berry Quality Properties

Table 8 presents the yield and berry quality properties. The quality variables were significantly affected by foliar fertilization at harvesting time by 5%. The yield was significantly affected more by using foliar Mg-NPs (9.13 kg $vine^{-1}$) compared to other forms and control treatments.

Table 2. The influence of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on leaf chlorophyll parameters pigment of 'Superior seedless' vines, which were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Chl A	Control	1.77 ± 0.011 dA *	1.81 ± 0.005 d	1.62 ± 0.008 dB	1.66 ± 0.005 dB	1.33 ± 0.008 dC	1.16 ± 0.005 dC	0.86 ± 0.018 dD	0.76 ± 0.008 dE
	$MgSO_4$	1.87 ± 0.023 cC	1.91 ± 0.005 cABC	1.90 ± 0.005 cBC	1.91 ± 0.008 cABC	1.93 ± 0.008 cAB	1.96 ± 0.005 cA	1.94 ± 0.005 cAB	1.89 ± 0.005 cBC
	Mg EDTA	2.07 ± 0.024 bE	2.07 ± 0.011 bE	2.16 ± 0.011 bD	2.18 ± 0.005 bCD	2.24 ± 0.026 bABC	2.26 ± 0.005 bAB	2.30 ± 0.005 bA	2.21 ± 0.005 bBCD
	Mg-NPs	2.16 ± 0.012 aD	2.17 ± 0.005 aD	2.27 ± 0.005 aC	2.28 ± 0.008 aC	2.47 ± 0.011 aB	2.52 ± 0.014 aB	2.66 ± 0.017 aA	2.64 ± 0.005 aA
Chl b	Control	0.59 ± 0.008 cB	0.55 ± 0.005 dB	0.53 ± 0.011 dBC	0.51 ± 0.005 dCD	0.84 ± 0.005 dDE	0.45 ± 0.005 dEF	0.43 ± 0.005 dF	0.39 ± 0.005 dG
	$MgSO_4$	0.65 ± 0.011 bB	0.66 ± 0.005 cB	0.73 ± 0.028 cAB	0.71 ± 0.003 cAB	0.72 ± 0.005 cAB	0.72 ± 0.028 bAB	0.73 ± 0.008 cA	0.65 ± 0.005 cB
	Mg EDTA	0.78 ± 0.005 aD	0.79 ± 0.008 bCD	0.83 ± 0.011 bBCD	0.85 ± 0.015 bB	0.87 ± 0.005 bB	0.84 ± 0.005 cBC	0.92 ± 0.015 bA	0.81 ± 0.005 bBCD
	Mg-NPs	0.83 ± 0.012 aD	0.84 ± 0.012 aD	0.94 ± 0.005 aC	0.96 ± 0.012 aC	0.97 ± 0.005 aC	0.98 ± 0.012 aBC	1.04 ± 0.008 aA	1.03 ± 0.005 aAB
Chl A + B	Control	2.36 ± 0.020 dA	2.36 ± 0.011 dA	2.15 ± 0.020 dB	2.17 ± 0.011 dB	1.59 ± 0.014 dC	1.61 ± 0.011 dC	1.29 ± 0.024 dD	1.15 ± 0.014 dE
	$MgSO_4$	2.52 ± 0.034 cD	2.57 ± 0.011 cBCD	2.62 ± 0.033 cABCD	2.63 ± 0.012 cABCD	2.65 ± 0.014 cABC	2.68 ± 0.033 cAB	2.70 ± 0.014 cA	2.54 ± 0.011 cCD
	Mg EDTA	2.85 ± 0.029 bD	2.86 ± 0.020 dD	2.99 ± 0.017 bC	3.03 ± 0.020 bBC	3.11 ± 0.032 bBC	3.10 ± 0.011 bB	3.22 ± 0.020 bA	3.02 ± 0.011 bBC
	Mg-NPs	2.99 ± 0.023 aD	3.01 ± 0.017 aD	3.21 ± 0.032 aC	3.25 ± 0.020 aC	3.44 ± 0.017 aB	3.51 ± 0.026 aB	3.70 ± 0.026 aA	3.67 ± 0.011 aA
Chl A:B	Control	2.98 ± 0.027 aB	3.29 ± 0.023 aA	3.07 ± 0.052 aB	3.25 ± 0.026 aA	2.32 ± 0.010 aD	2.57 ± 0.020 aC	2.01 ± 0.020 aE	1.96 ± 0.006 aE
	$MgSO_4$	2.87 ± 0.014 bA	2.89 ± 0.014 bA	2.63 ± 0.092 bB	2.67 ± 0.003 bAB	2.68 ± 0.008 bAB	2.72 ± 0.095 aAB	2.54 ± 0.020 aB	2.91 ± 0.017 bA
	Mg EDTA	2.66 ± 0.020 cAB	2.61 ± 0.015 cABC	2.60 ± 0.028 bABC	2.56 ± 0.038 bBC	2.57 ± 0.013 bAB	2.69 ± 0.011 aAB	2.50 ± 0.035 aC	2.73 ± 0.011 cA
	Mg-NPs	2.63 ± 0.049 cA	2.57 ± 0.030 cA	2.42 ± 0.015 bB	2.36 ± 0.021 cB	2.54 ± 0.003 cA	2.57 ± 0.015 aA	2.55 ± 0.008 bA	2.56 ± 0.008 dA

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 3. The effect of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on leaf carotene pigment and the ratio of chlorophyll and carotenoid of 'Superior seedless' vines, which were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Car	Control	2.18 ± 0.017 dC *	2.23 ± 0.005 dBC	2.23 ± 0.005 dBC	2.28 ± 0.005 dAB	2.31 ± 0.032 cA	2.33 ± 0.005 dA	2.20 ± 0.005 dC	2.17 ± 0.012 dC
	$MgSO_4$	2.26 ± 0.008 cE	2.28 ± 0.014 cDE	2.31 ± 0.008 cCD	2.34 ± 0.005 cBC	2.37 ± 0.008 cAB	2.39 ± 0.008 cA	2.39 ± 0.005 cA	2.37 ± 0.005 cAB
	Mg EDTA	2.60 ± 0.014 bC	2.66 ± 0.008 bBC	2.64 ± 0.008 bB	2.67 ± 0.008 bB	2.69 ± 0.005 bB	2.76 ± 0.005 bA	2.72 ± 0.008 bA	2.73 ± 0.012 bA
	Mg-NPs	2.79 ± 0.011 aE	2.81 ± 0.008 aE	2.94 ± 0.008 aD	3.07 ± 0.011 aC	3.16 ± 0.008 aB	3.19 ± 0.008 aB	3.40 ± 0.020 aA	3.36 ± 0.017 aA
Chl:Carratio	Control	1.08 ± 0.000 aA	1.05 ± 0.003 cA	0.96 ± 0.012 cB	0.95 ± 0.003 cB	0.69 ± 0.015 cC	0.69 ± 0.003 bC	0.59 ± 0.012 cD	0.53 ± 0.003 cE
	$MgSO_4$	1.11 ± 0.012 aA	1.12 ± 0.003 aA	1.13 ± 0.008 aA	1.12 ± 0.003 aA	1.11 ± 0.003 abA	1.12 ± 0.010 aA	1.13 ± 0.015 bA	1.07 ± 0.003 bB
	Mg EDTA	1.09 ± 0.017 aCD	1.07 ± 0.003 bD	1.13 ± 0.008 aB	1.13 ± 0.003 aB	1.15 ± 0.014 aB	1.12 ± 0.003 aBC	1.18 ± 0.003 aA	1.10 ± 0.003 aBCD
	Mg-NPs	1.07 ± 0.005 aAB	1.06 ± 0.003 bcAB	1.09 ± 0.010 bAB	1.06 ± 0.000 bB	1.08 ± 0.003 bAB	1.10 ± 0.005 aA	1.08 ± 0.014 bAB	1.09 ± 0.003 aAB

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 4. The impact of various magnesium fertilization types ($MgSO^4$, Mg-EDTA, and Mg-NPs) on chlorophyll fluorescence parameters of 'Superior seedless' vines, which were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Fv/Fm	Control	0.806 ± 0.00 dA *	0.800 ± 0.00 dAB	0.780 ± 0.00 dABC	0.743 ± 0.02 bC	0.756 ± 0.00 dBC	0.740 ± 0.00 dC	0.670 ± 0.00 dD	0.660 ± 0.00 dD
	$MgSO_4$	0.820 ± 0.00 cA	0.810 ± 0.00 cB	0.793 ± 0.00 cC	0.776 ± 0.00 bDE	0.780 ± 0.00 cD	0.756 ± 0.00 cF	0.770 ± 0.00 cE	0.740 ± 0.00 cG
	Mg EDTA	0.853 ± 0.00 bA	0.860 ± 0.00 bA	0.840 ± 0.00 bA	0.820 ± 0.02 abAB	0.813 ± 0.00 bAB	0.830 ± 0.00 bA	0.780 ± 0.00 bBC	0.770 ± 0.00 bC
	Mg-NPs	0.870 ± 0.00 aABC	0.860 ± 0.00 aAB	0.880 ± 0.00 aA	0.860 ± 0.01 aBC	0.880 ± 0.00 aA	0.870 ± 0.00 aABC	0.870 ± 0.00 aABC	0.856 ± 0.00 aC
Fm	Control	1697.33 ± 2.18 dA	1702.33 ± 1.45 dA	1626.67 ± 3.38 dB	1603.33 ± 1.20 dC	1591.00 ± 1.154 dD	1494.67 ± 2.60 dF	1556.33 ± 1.76 dE	1442.00 ± 0.55 dg
	$MgSO_4$	1738.33 ± 3.17 cG	1739.33 ± 0.88 cG	1886.33 ± 1.76 cD	1805.33 ± 2.60 cF	1955.00 ± 2.309 cC	1851.66 ± 1.20 cE	2020.33 ± 0.88 cA	1992.00 ± 1.52 cB
	Mg EDTA	1990.67 ± 1.20 bF	1995.00 ± 0.57 bF	2015.66 ± 1.76 bE	2105.67 ± 2.84 bD	2193.00 ± 2.309 bD	2222.66 ± 0.88 bB	2205.67 ± 1.76 bC	2314.66 ± 2.02 bA
	Mg-NPs	2137.34 ± 3.33 aH	2152.00 ± 1.52 aG	2359.00 ± 1.15 aF	2413.00 ± 1.15 aE	2585.33 ± 1.452 aD	2604.67 ± 2.02 aB	2595.33 ± 1.85 aC	2664.00 ± 1.52 aA

Table 4. *Cont.*

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
F0	Control	364.00 ± 1.52 cB	372.00 ± 1.52 dA	357.66 ± 1.76 dB	362.00 ± 0.57 dB	304.33 ± 1.763 dD	332.00 ± 0.57 dC	296.00 ± 2.51 dE	285.66 ± 1.20 dF
	$MgSO_4$	393.00 ± 1.15 bF	403.00 ± 1.52 cE	407.33 ± 1.20 cDE	414.00 ± 1.52 cBC	420.00 ± 1.527 cAB	426.00 ± 0.57 cA	412.00 ± 0.57 cCD	417.66 ± 1.45 cBC
	Mg EDTA	422.66 ± 11.34 aD	442.33 ± 1.20 bCD	459.00 ± 1.15 bBC	457.33 ± 1.85 bBC	517.33 ± 2.333 bBC	474.00 ± 1.52 bB	532.66 ± 0.88 bA	457.00 ± 1.15 bBC
	Mg-NPs	441.00 ± 1.15 aH	461.66 ± 0.88 aG	552.66 ± 1.45 aE	526.33 ± 2.40 aF	792.33 ± 1.201 aC	693.33 ± 1.76 aD	817.66 ± 2.60 aB	827.00 ± 2.51 aA

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 5. The impact of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on leaf area (cm^2), shoot carbohydrate content percentage, ion leakage percentage, and malondialdehyde of 'Superior seedless' vines, which were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Leaf area (cm^2)	Control	105.20 ± 0.883 dF *	113.02 ± 1.229 dE	116.11 ± 1.790 dDE	120.14 ± 0.586 dCD	125.41 ± 1.469 dBC	126.69 ± 0.904 dAB	129.94 ± 0.560 dAB	131.94 ± 0.589 dA
	$MgSO_4$	115.15 ± 1.212 bE	123.72 ± 1.212 cD	125.18 ± 0.600 cD	129.22 ± 0.586 cC	135.21 ± 0.873 cB	139.56 ± 0.583 cA	140.65 ± 0.589 cA	141.94 ± 0.335 cA
	Mg EDTA	128.32 ± 0.892 cE	132.64 ± 0.562 bD	137.85 ± 0.580 bC	139.75 ± 0.580 bC	142.00 ± 1.216 bC	148.78 ± 0.331 bB	150.79 ± 0.898 bB	154.43 ± 0.574 bA
	Mg-NPs	139.53 ± 0.881 aE	143.26 ± 0.885 aE	149.60 ± 2.623 aD	153.00 ± 1.460 aCD	154.87 ± 1.212 cBCD	159.14 ± 0.554 aBC	160.75 ± 0.586 aAB	166.40 ± 0.580 aA
Shoot carbohydratecontent %	Control	19.56 ± 0.591 cD	21.64 ± 0.568 cCD	21.82 ± 0.597 dCD	22.74 ± 0.568 cC	24.45 ± 0.565 cBC	26.45 ± 0.580 dB	26.62 ± 0.597 cB	29.64 ± 0.565 dA
	$MgSO_4$	23.20 ± 0.580 cD	26.34 ± 0.588 bC	26.66 ± 0.591 cC	30.96 ± 0.328 bB	30.55 ± 0.583 bB	32.66 ± 0.580 cAB	32.35 ± 0.586 bAB	34.36 ± 0.597 cA
	Mg EDTA	27.88 ± 1.208 bD	29.35 ± 0.574 bD	30.75 ± 0.566 bCD	32.66 ± 0.346 bBC	32.92 ± 0.591 bBC	35.74 ± 0.594 bAB	34.65 ± 0.571 bAB	37.67 ± 0.594 bA
	Mg-NPs	33.45 ± 1.169 aD	33.45 ± 1.169 aD	36.63 ± 0.560 aCD	39.74 ± 0.560 aBC	40.87 ± 0.586 aB	42.95 ± 0.583 aAB	41.94 ± 0.586 aAB	45.57 ± 0.583 aA
Ion leakage %	Control	12.29 ± 0.502 aC	12.67 ± 0.617 aBC	14.65 ± 0.566 aBC	15.10 ± 0.345 aAB	22.57 ± 0.580 aA	23.93 ± 0.591 aA	28.76 ± 0.673 aC	30.72 ± 0.671 aC
	$MgSO_4$	10.33 ± 0.494 abE	11.14 ± 0.447 aDE	13.58 ± 0.574 abCD	13.27 ± 0.330 bBC	19.73 ± 0.560 bAB	19.95 ± 0.332 bA	24.58 ± 0.583 bA	28.97 ± 0.377 aAB
	Mg EDTA	8.36 ± 0.565 bC	9.25 ± 0.577 bB	11.27 ± 0.586 bB	10.68 ± 0.340 cB	15.84 ± 0.600 cB	17.19 ± 1.323 bA	21.05 ± 0.600 cA	20.73 ± 0.333 bA
	Mg-NPs	5.07 ± 0.048 cE	4.99 ± 0.058 cE	6.04 ± 0.338 cD	6.10 ± 0.336 dC	7.25 ± 0.571 dB	6.84 ± 0.310 cB	10.56 ± 0.588 dA	8.64 ± 0.588 cA

Table 5. *Cont.*

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Malondialdehyde (MDA; ηM g^{-1} FW)	Control	0.15 ± 0.005 aD	0.16 ± 0.003 aD	0.20 ± 0.005 aC	0.21 ± 0.005 aC	0.24 ± 0.005 aB	0.25 ± 0.005 aB	0.29 ± 0.005 aA	0.31 ± 0.008 aA
	$MgSO_4$	0.13 ± 0.003 abE	0.14 ± 0.005 aE	0.17 ± 0.005 bD	0.18 ± 0.005 bD	0.22 ± 0.005 aC	0.23 ± 0.005 aC	0.26 ± 0.005 bB	0.28 ± 0.003 aA
	Mg EDTA	0.11 ± 0.003 bD	0.11 ± 0.005 bCD	0.13 ± 0.003 cBCD	0.14 ± 0.005 cBC	0.14 ± 0.005 bBC	0.20 ± 0.005 bA	0.15 ± 0.005 cB	0.21 ± 0.005 bA
	Mg-NPs	0.09 ± 0.005 cBC	0.08 ± 0.005 cC	0.10 ± 0.005 dBC	0.09 ± 0.005 dBC	0.11 ± 0.005 cAB	0.11 ± 0.005 cAB	0.13 ± 0.005 dA	0.13 ± 0.005 cA

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 6. The effect of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on leaf mineral compositions of 'Superior seedless' vines, which were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
N%	Control	2.57 ± 0.014 dA *	2.48 ± 0.017 cA	2.64 ± 0.012 dA	2.76 ± 0.015 dA	2.76 ± 0.005 cA	2.56 ± 0.177 bA	2.61 ± 0.008 dA	2.58 ± 0.005 dA
	$MgSO_4$	2.67 ± 0.008 cE	2.77 ± 0.017 bBCD	2.75 ± 0.011 cCD	2.87 ± 0.012 cA	2.80 ± 0.005 cBC	2.80 ± 0.008 bB	2.73 ± 0.008 cD	2.65 ± 0.008 bE
	Mg EDTA	2.79 ± 0.011 bCD	2.82 ± 0.012 bBCD	2.90 ± 0.012 bABC	2.93 ± 0.014 bAB	3.00 ± 0.014 bAB	2.98 ± 0.063 abA	2.85 ± 0.014 bBC	2.72 ± 0.012 cD
	Mg-NPs	2.85 ± 0.014 aF	3.01 ± 0.018 aD	2.98 ± 0.015 aDE	3.10 ± 0.005 aC	3.10 ± 0.008 aC	3.26 ± 0.012 aA	2.93 ± 0.008 aE	3.17 ± 0.012 aB
P%	Control	0.13 ± 0.005 dC	0.14 ± 0.005 dBC	0.16 ± 0.005 dABC	0.17 ± 0.005 dAB	0.17 ± 0.008 dA	0.19 ± 0.005 dA	0.18 ± 0.008 cA	0.17 ± 0.005 dAB
	$MgSO_4$	0.20 ± 0.005 cB	0.21 ± 0.005 cAB	0.22 ± 0.005 cAB	0.23 ± 0.005 cAB	0.24 ± 0.005 cA	0.24 ± 0.005 cA	0.21 ± 0.008 cAB	0.20 ± 0.005 cB
	Mg EDTA	0.25 ± 0.005 bCD	0.25 ± 0.005 bCD	0.27 ± 0.005 bCD	0.28 ± 0.005 bAB	0.29 ± 0.005 bAB	0.30 ± 0.005 bA	0.26 ± 0.005 bBCD	0.24 ± 0.005 bD
	Mg-NPs	0.30 ± 0.005 aD	0.32 ± 0.005 aCD	0.33 ± 0.005 aC	0.34 ± 0.005 aBC	0.37 ± 0.005 aA	0.38 ± 0.005 aA	0.33 ± 0.005 aC	0.36 ± 0.005 aAB
K%	Control	1.53 ± 0.008 dC	1.60 ± 0.008 dB	1.59 ± 0.011 dB	1.66 ± 0.005 dA	1.60 ± 0.005 dB	1.69 ± 0.008 dA	1.54 ± 0.008 dC	1.44 ± 0.008 dD
	$MgSO_4$	1.62 ± 0.005 cE	1.70 ± 0.005 cC	1.67 ± 0.005 cCD	1.74 ± 0.015 cAB	1.70 ± 0.008 cBC	1.77 ± 0.005 cA	1.64 ± 0.005 cDE	1.55 ± 0.005 cF
	Mg EDTA	1.71 ± 0.008 bB	1.74 ± 0.005 bB	1.75 ± 0.005 bB	1.81 ± 0.008 bA	1.80 ± 0.005 bA	1.84 ± 0.012 bA	1.75 ± 0.011 bB	1.63 ± 0.017 bC
	Mg-NPs	1.78 ± 0.008 aE	1.85 ± 0.012 aD	1.80 ± 0.005 aE	1.91 ± 0.005 aC	1.86 ± 0.008 aD	2.03 ± 0.014 aA	1.81 ± 0.005 aE	1.96 ± 0.008 aB

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 7. The influence of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on the leaf mineral compositions of 'Superior seedless' vines was studied for four terms in various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

-	-	Berry Developmental Stages							
-	-	Flowering		Fruit Set		Veraison		At Harvesting	
-	-	Growth Seasons							
Variables	**Treatment**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Mg%	Control	0.31 ± 0.008 dA *	0.32 ± 0.005 dA	0.30 ± 0.008 cAB	0.30 ± 0.005 dAB	0.25 ± 0.009 dC	0.27 ± 0.005 dBC	0.21 ± 0.007 dD	0.21 ± 0.008 dD
	$MgSO_4$	0.64 ± 0.008 cE	0.65 ± 0.005 cE	0.71 ± 0.008 cbD	0.70 ± 0.005 cD	0.77 ± 0.009 cBC	0.76 ± 0.005 cC	0.81 ± 0.007 cA	0.80 ± 0.008 cB
	Mg EDTA	0.70 ± 0.008 bD	0.71 ± 0.005 bD	0.88 ± 0.008 aB	0.79 ± 0.005 bC	0.91 ± 0.009 bC	0.89 ± 0.005 bB	0.96 ± 0.007 bA	0.97 ± 0.008 bA
	Mg-NPs	0.78 ± 0.008 aE	0.79 ± 0.005 aE	0.91 ± 0.008 aD	0.94 ± 0.005 aCD	0.97 ± 0.005 aC	1.07 ± 0.005 aB	1.04 ± 0.007 aB	1.13 ± 0.008 aA
Ca%	Control	2.27 ± 0.008 dD	2.30 ± 0.007 dCD	2.32 ± 0.005 dBC	2.33 ± 0.005 dBC	2.38 ± 0.015 dA	2.36 ± 0.005 dAB	2.32 ± 0.008 dBC	2.29 ± 0.008 cCD
	$MgSO_4$	2.35 ± 0.008 cC	2.39 ± 0.007 cB	2.44 ± 0.005 cB	2.43 ± 0.011 cB	2.51 ± 0.005 cA	2.52 ± 0.008 cA	2.49 ± 0.005 cA	2.44 ± 0.005 bcB
	Mg EDTA	2.44 ± 0.008 bA	2.49 ± 0.007 bA	2.54 ± 0.005 bA	2.52 ± 0.008 bA	2.65 ± 0.011 bA	2.59 ± 0.008 bA	2.61 ± 0.005 bA	2.60 ± 0.098 abA
	Mg-NPs	2.58 ± 0.008 aF	2.65 ± 0.007 aE	2.68 ± 0.014 aDE	2.72 ± 0.005 aCD	2.75 ± 0.017 aBC	2.81 ± 0.012 aA	2.80 ± 0.005 aAB	2.82 ± 0.005 aA
Cl%	Control	1.24 ± 0.014 aE	1.25 ± 0.005 aE	1.31 ± 0.008 aD	1.35 ± 0.005 aCD	1.39 ± 0.015 aBC	1.38 ± 0.012 aBC	1.41 ± 0.014 aAB	1.45 ± 0.005 aA
	$MgSO_4$	1.23 ± 0.008 aC	1.23 ± 0.005 aC	1.26 ± 0.005 bC	1.26 ± 0.005 bC	1.30 ± 0.005 bB	1.30 ± 0.005 bB	1.34 ± 0.005 bA	1.34 ± 0.008 bA
	Mg EDTA	1.19 ± 0.005 abD	1.20 ± 0.005 bCD	1.22 ± 0.005 cC	1.22 ± 0.005 cC	1.24 ± 0.005 cC	1.28 ± 0.005 bA	1.25 ± 0.005 cB	1.29 ± 0.005 cA
	Mg-NPs	1.13 ± 0.021 bB	1.12 ± 0.005 cB	1.19 ± 0.005 cA	1.13 ± 0.005 dB	1.22 ± 0.005 cA	1.20 ± 0.005 cA	1.23 ± 0.005 cA	1.23 ± 0.005 dA
Na%	Control	0.40 ± 0.005 aE	0.42 ± 0.005 aDE	0.43 ± 0.005 aD	0.44 ± 0.005 aCD	0.46 ± 0.005 aBC	0.46 ± 0.005 aBC	0.48 ± 0.005 aAB	0.49 ± 0.005 aA
	$MgSO_4$	0.39 ± 0.005 abD	0.39 ± 0.005 bD	0.42 ± 0.005 aBC	0.41 ± 0.005 bCD	0.44 ± 0.005 aAB	0.43 ± 0.005 bABC	0.45 ± 0.003 bA	0.45 ± 0.005 bA
	Mg EDTA	0.36 ± 0.005 bC	0.37 ± 0.005 bC	0.38 ± 0.005 bBC	0.38 ± 0.005 cBC	0.39 ± 0.008 bBC	0.40 ± 0.005 cAB	0.40 ± 0.003 cAB	0.42 ± 0.005 cA
	Mg-NPs	0.31 ± 0.008 cBC	0.30 ± 0.005 cC	0.33 ± 0.005 cABC	0.32 ± 0.005 dBC	0.34 ± 0.005 cAB	0.33 ± 0.005 dABC	0.35 ± 0.005 dA	0.34 ± 0.005 dAB

* The mean and standard error of the mean are used to represent the data. Tukey's HSD test at $p < 0.05$ for mean separation among columns (small letters) and rows (capital letters). Data were obtained at various stages of berry growth.

Table 8. The impact of various magnesium fertilization types ($MgSO_4$, Mg-EDTA, and Mg-NPs) on 'Superior seedless' vines on yield, berries proprieties, and fruit quality of 'Superior seedless' vine. Treatments were used four times on various phases during berry growth (flowering, fruit set, version, and at harvest time) throughout two summers (2020 and 2021).

Treatments	**Cluster Weight (Kg)**	**Cluster Number Vine^{-1}**		**Yield Vine^{-1} (Kg)**	**Wood Pruned Weight (Kg)**	**Berry Weight (g)**	**Berry Size (Cm^3)**	**Total Soluble Solid (SSC %)**	**Total Acidity (TA %)**	**SSC:TA-Ratio**
	Yield and Berry Properties							**Berry Juice Proprieties**		
Control	0.440 ± 0.002 ^{d}	13.56 ± 0.233 ^{c}	5.91 ± 0.073 ^{d}	14.19 ± 0.134 ^{d}	3.46 ± 0.029 ^{d}	3.31 ± 0.008 ^{d}	15.95 ± 0.014 ^{d}	0.713 ± 0.001 ^{a}	22.35 ± 0.062 ^{d}	0.713 ± 0.001 ^{a}	22.35 ± 0.062 ^{d}
$MgSO_4$	0.502 ± 0.003 ^{c}	14.71 ± 0.020 ^{b}	7.39 ± 0.055 ^{c}	14.67 ± 0.023 ^{c}	3.85 ± 0.020 ^{c}	3.66 ± 0.005 ^{c}	16.71 ± 0.028 ^{b}	0.684 ± 0.002 ^{c}	24.41 ± 0.029 ^{b}	0.684 ± 0.002 ^{c}	24.41 ± 0.029 ^{b}
Mg-EDTA	0.525 ± 0.002 ^{b}	15.51 ± 0.340 ^{a}	8.15 ± 0.210 ^{b}	15.94 ± 0.086 ^{b}	4.16 ± 0.029 ^{b}	4.17 ± 0.023 ^{b}	16.33 ± 0.014 ^{c}	0.699 ± 0.000 ^{b}	23.36 ± 0.020 ^{c}	0.699 ± 0.000 ^{b}	23.36 ± 0.020 ^{c}
Mg-Nano	0.582 ± 0.002 ^{a}	15.98 ± 0.015 ^{a}	9.13 ± 0.038 ^{a}	16.85 ± 0.272 ^{a}	4.67 ± 0.021 ^{a}	4.56 ± 0.008 ^{a}	17.38 ± 0.038 ^{a}	0.661 ± 0.000 ^{d}	26.30 ± 0.066 ^{a}	0.661 ± 0.000 ^{d}	26.30 ± 0.066 ^{a}

The main data of two seasons are analyzed using one-way (complete block randomized design) on 'Superior seedless' vines. Each value represents mean and ±SE ($n = 4$) replicates. The superscript letters differ ($p < 0.05$) and represent the significance between treatments using Tukey's HSD test at $p \leq 0.05$. Data were collected at different berry developmental stages.

3.7. Multivariate Analysis of Leaf Parameters

A PCA for physiological and biochemical variables data obtained from leaves was conducted from the tested different foliar magnesium fertilization forms (MgSO4, Mg-EDTA, and Mg-NPs) applied four times on different fruit developmental stages (flowering, fruit set, version, and at harvest time) throughout two growth seasons (2020 and 2021) of 'Superior Seedless' vines. The PCA separated the effect of magnesium forms under each seasonal stage. The PC1 explained 70.9% of the variability in the data, while PC2 explained 16.1% of the variability (Figure 2A). Figure 2B displays the negative correlation between MD-index with all the parameters except for EL%, MDA, Na+ %, and Cl− %. Chlorophyll a and b and total chlorophyll contents were negatively correlated with chlorophyll fluorescence variables (Fv/Fm; Fm, and F0). These four valuables (MD, MDA, Na+ %, and Cl− %) had a negative correlation with the other variables. Chl B showed negative correlation with Chl A:B. Chl A:B was positively correlated with Chls:Caro and Fv/Fm, whereas it had a negative correlation with the other valuables. Pearson's correlation matrix among the examined parameters shows the correlation and shows these results (Table 9).

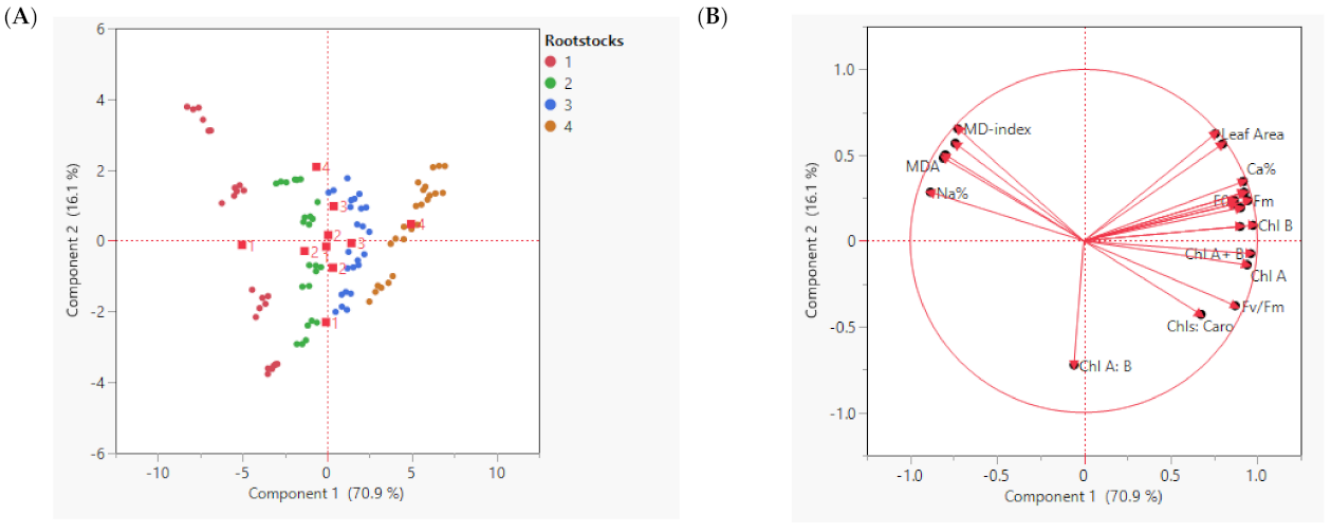

Figure 2. Principal Component Analysis (PCA) representing seasons and magnesium application forms to 'Superior seedless' vine grown in sandy soil and salt conditions, plotted with the contribution of each parameter on the two PCA axes (**A**) and all the physiological and biochemical parameters measured in leaf during the growing season (**B**). Principal Component Analysis (PCA)-Variable correlation of 7th leaf.

Table 9. Pearson's correlation pattern among the considered variables of 'Superior seedless' vines under four levels of magnesium foliar application.

Variables	MD−Index	Chl A	Chl B	Chl A+ B	Chl A:B	Caro	Chls: Caro	Fv/Fm	Fm	F0	Leaf Area	Shoot Car.	IL%	MDA	N%	P%	K%	Ca%	Mg%	Cl%	Na%
MD−index	* 1.0000																				
Chl A	−0.7543	1.0000																			
Chl B	−0.6424	0.9441	1.0000																		
Chl A+ B	−0.7307	0.9955	0.9712	1.0000																	
Chl A:B	−0.3765	0.2037	−0.1244	0.1114	1.0000																
Caro	−0.4960	0.8004	0.8970	0.8375	−0.2487	1.0000															
Chls:Caro	−0.7281	0.8552	0.7100	0.8232	0.4610	0.3803	1.0000														
Fv/Fm	−0.8758	0.8250	0.7977	0.8267	0.1369	0.7291	0.6523	1.0000													
Fm	−0.5258	0.8958	0.9557	0.9234	−0.1487	0.9469	0.5785	0.7285	1.0000												
F0	−0.4961	0.8148	0.8561	0.8361	−0.0965	0.9203	0.4576	0.6603	0.9097	1.0000											
Leaf Area	−0.1279	0.6528	0.8011	0.7032	−0.4336	0.8714	0.2790	0.4121	0.8757	0.7871	1.0000										
Shoot Car	−0.2059	0.6896	0.8255	0.7368	−0.3968	0.8856	0.3232	0.4662	0.8955	0.8277	0.9790	1.0000									
IL%	0.9348	−0.6787	−0.6213	−0.6700	−0.2364	−0.5626	−0.5611	−0.9008	−0.5262	−0.5085	−0.1789	−0.2593	1.0000								
MDA	0.9291	−0.7360	−0.7122	−0.7377	−0.1362	−0.6206	−0.6101	−0.9185	−0.5984	−0.5474	−0.2709	−0.3283	0.9527	1.0000							
N%	−0.4926	0.7260	0.8258	0.7632	−0.2568	0.8262	0.4332	0.6697	0.8156	0.7583	0.7545	0.7847	−0.5803	−0.6122	1.0000						
P%	−0.4905	0.7736	0.8962	0.8180	−0.3349	0.9253	0.4230	0.7248	0.9070	0.8319	0.8593	0.8810	−0.5735	−0.6271	0.9067	1.0000					
K%	−0.5934	0.7846	0.8409	0.8099	−0.1109	0.8390	0.5053	0.7460	0.8091	0.7626	0.7150	0.7489	−0.6685	−0.6911	0.9052	0.9047	1.0000				
Ca%	−0.4310	0.8136	0.9189	0.8534	−0.2780	0.9441	0.4630	0.6707	0.9491	0.8796	0.9144	0.9243	−0.4833	−0.5620	0.8649	0.9440	0.8655	1.0000			
Mg%	−0.5068	0.9090	0.9481	0.9308	−0.1059	0.8098	0.7315	0.6645	0.9205	0.7906	0.8300	0.8466	−0.4472	−0.5441	0.7670	0.8473	0.7656	0.8847	1.0000		
Cl%	0.8988	−0.7761	−0.7405	−0.7748	−0.1586	−0.5961	−0.7000	−0.8990	−0.6271	−0.4973	−0.3131	−0.3722	0.8944	0.9394	−0.5932	−0.6408	−0.6783	−0.5710	−0.6240	1.0000	
Na%	0.8310	−0.7779	−0.7937	−0.7915	−0.0073	−0.7709	−0.5462	−0.9271	−0.7360	−0.6594	−0.4830	−0.5469	0.9058	0.9311	−0.7271	−0.7797	−0.7809	−0.7134	−0.6535	0.9181	1.0000

* Values represent average values per season, berry developmental phases, and magnesium foliar application treatments. Chl A—Chlorophyll a content; Chl B—Chlorophyll b content; Chl A + B—Total chlorophyll content; Chl A:B—The ratio between chlorophyll A and B; Car—Carotene content; Chls:Car—The ration between total chlorophyll and Carotene; Fv/Fm—Chl fluorescence ratios; Fm—Maximum Chl fluorescence in the light-adapted state; F0—Ground fluorescence; IL%—Ion leakage percentage; MDA—Malondialdehyde accumulation; N%—Nitrogen content; P%—Phosphor content; K%—Potassium content; Ca%—Calcium content; Mg%—Magnesium content; Cl%—Chloride content; Na%—Sodium content.

4. Discussion

Magnesium is involved in a number of biochemical and physiological processes that influence plant growth and development [51]. As a result, the wounded bunches' early-stage leaves fall off throughout the growing season. However, under soil salinity conditions, a variety of mechanisms occur that result in Mg loss [52]. As a result, Mg insufficiency occurred on control vines earlier in the growth season than on vines treated with other Mg treatments. This can be seen in the slower transport of Mg through the soil profile, which results in more Mg adsorption [53]. In addition, changes in Ca and K content across Mg application rates suggest that Mg and two other cations interact throughout the season [54]. Foliar spraying is a common way for plants to adjust for nutritional deficiencies in the soil [55]. During the trial period, the efficiency of the nano-magnesium image revealed the fewest symptoms on the leaves. This result could be attributed to magnesium absorption being faster than the rest of the pictures, resulting in better photosynthetic efficiency [56]. These conclusions were reached because of the results shown in the graph. The presence of EDTA in chelated Mg form, on the other hand, has been shown to improve vine growth and biomass [57], and the sulfate part plays a critical role in the catalytic or electrochemical functions of the biomolecules in the cells [58].

Chlorophylls (Chls) are reputedly the most outstanding natural syntheses on the planet, as they are required for the photosynthesis process [59,60]. This method of vegetation occurs primarily based on gaining light rays by chlorophyll and especially chlorophyll A [61]. Photosynthesis is a very powerful method wherein it is supplied with 5 to 11 μmol CO_2 m^{-2} s^{-1}. This process is involved in the biosynthesis of essential organic molecules required for plant growth and development [62]. The photosynthesizing cells need a large amount of assimilatory pigment that reaches up to 5% of typical dry matter [63,64]. Most plant species have photosynthetic pigment content in their leaves (chlorophyll and carotene), which plays a fundamental function in the physiological overall performance of plants [65,66]. Mg participates in a variety of biochemical and physiological processes that contribute to vine growth. It is a critical component of the chlorophyll molecule, affecting both its structure and function [67]. Foliar magnesium fertilization compensates for deficits in the vines' growth stages. Additionally, it reflected the quantity and activity of photosynthetic pigments [54]. Mg is a mineral activator constituent of the chlorophyll molecule, which is responsible for photosynthetic regulation [68]. As a result, as compared to other Mg forms, the usage of Mg-NPs increased the chlorophyll components and carotene content [69]. Our findings corroborated those published in Tables 1 and 2. This comparison most likely reflects Mg-NPs' superior mobility and absorption capacity when compared to other forms [70].

Chlorophylls are critical functional and structural cofactors for all photosynthetic pigment proteins involved in oxygenic and anoxic photosynthesis, and so magnesium fertilization throughout the growing season contributes to photosynthesis's efficacy. The pigments' distinctiveness is owing to the porphyritic chromophore's extensive electron system, which chelates the Mg^{2+} ion in the center [71]. The results in Table 3 can be clarified by the variation in the Fv/Fm ratios of the various forms of foliar magnesium fertilization applied at various growth stages. In comparison to other forms, Mg-NPs dramatically boosted nucleic acid and carbohydrate enzymes [68]. However, the onset of magnesium deficit during the growing season may result in a reduction in chlorophyll and carotene levels [72]. Our findings established that Mg-NPs boosted photosynthetic pigment in comparison to other Mg forms, and our findings corroborated those of [56].

Since magnesium is required for carbohydrate accumulation in plants, its absence has an effect on the overall biomass production and distribution among plant sections [73,74]. This shows that three major factors could influence Mg effects. These are the magnesium forms, mobility, and absorption capacity of magnesium [75]. Our data indicated that the Mg-NPs increased the leaf area and carbohydrate content of the shoots during the growing season, owing to the higher photosynthesis performance. We observed reduced values for ion leakage and MDA quantity when vines were treated with Mg-NPs compared to

other types. One may argue that increasing magnesium absorption in nano form [69] resulted in a reduction in the size of the cell wall, which was most likely because of its role in ion transport across the membrane and involvement in membrane-center ATPase activity [76,77]. This conclusion was consistent with previous research on citrus [78], banana [19], and coffee [79]. On the current experiment, we discovered a similar pattern of carbohydrate accumulation in vines stressed with evident leaf symptoms in the presence of a magnesium deficiency.

Normally, in plants, an element's uptake and distribution are controlled by both its supply conditions and interactions with other elements [80]. Mg, K, and Ca have been considered to exhibit opposing interactions as cation ions. Mg absorption was restricted when K or Ca concentrations increased and vice versa [81,82]. However, under salinity stress, the application of Mg-NPs increases the content of macro and micro-nutrients (Tables 5 and 6). This may be explained by the inaction between Ca^{++} and K^{+} and Mg^{++}, which increased the abortion of both cations by using Mg-NPs more than other forms [52]. The achieved outcomes regarding the effect of foliar Mg forms on leaf mineral content proved that the magnesium nano form has a pronounced effect on micronutrient status. The results agree with the findings of [56]. In addition, the foliar magnesium fertilizer improved the leaf mineral content of the mentioned fruit crop species.

This could be explained by the fact that the Mg-NPs enhanced photosynthesis during the growth stages [54]. As a result, the carbohydrate content of the product increased [7]. Our findings established that Mg-NPs raised carbohydrate content more than other forms (Table 4) and wood-trimmed weight more than other forms (Table 8). However, Mg-NPs had a considerably greater effect on berry quality features than other treatments, as measured by SSC percent (17.50%), TA percent (0.805%), and SSC:TA ratio (21.63%) (Table 7). The lowest SSC:TA ratio observed with Mg-NPs application might be read as indicating that bunches collected from vines treated with other Mg forms had a significantly longer shelf life. Additionally, magnesium has a role in protein synthesis as a bridge element that aids in ribosome assembly [83]. Additionally, it catalyzes about 300 enzymes, including phosphoenolpyruvate carboxylase, glutathione synthase, phosphatases, kinases, RNA polymerases, and ATPases [74].

A negative connection was detected between Chl B and Chl A:B. Chls:Caro and Fv/Fm were positively linked with Chl A:B but negatively with the other assets. Our observations were acknowledged by both parties [19].

5. Conclusions

The outcomes of this research recommend that the Fv/Fm ratio during the growth season of 'Superior Seedless' vines may be a good tool to assess magnesium fertilization effects before visible deficiency symptoms appear. Mg-NPs are more effective at improving 'Superior Seedless' vine growth than the other magnesium forms. Moreover, a comparison validated that the application of different forms of Mg foliar fertilization for 'Superior Seedless' vines does affect the yield and berry quality at harvest time as a final determination of the impact of Mg foliar fertilization. Overall, Mg-NPs are the most effective form for application to 'Superior Seedless' vines when compared to other Mg forms under saline soil. It enhanced biochemical and bunched quality variables.

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