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Determination of Mineral Matter Changes in Leaves Taken at Different Times in Some Table Grape Varieties

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ABSTRACT

The mineral composition of grapevines is of great importance for the healthy development of the plant and the production of high-quality fruit. Moreover, it is known that the mineral content enhances the vine's resistance to diseases and its tolerance to cold stress. In this study, the mineral content of the leaves of six different grape cultivars (Isabella (*Vitis labrusca* L.), Barış, Italia, Tekirdağ Çekirdeksizi, Trakya İlkeren, and Yalova İncisi (*Vitis vinifera* L.) was examined over a two-year period, with samples collected on June 15, July 15, and August 15. In this context, changes in the levels of nitrogen, potassium, phosphorus, calcium, magnesium, iron, zinc, manganese, copper, and sodium in leaf samples collected at different times were evaluated. The results revealed that the amounts of the examined macro- and micronutrients varied significantly depending on both the genotypes and the sampling dates. The findings of this study contribute to more effective nutrient management in viticulture, thereby supporting increased productivity and improved fruit quality.

Bazı Sofralık Üzüm Çeşitlerinde Farklı Dönemlerde Alınan Yapraklardaki Mineral Madde Değişimlerinin Belirlenmesi

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ÖZET

Asmanın mineral bileşimi, bitkinin sağlıklı gelişimi ve kaliteli meyve üretimi açısından büyük önem taşımaktadır. Ayrıca, mineral içeriğinin asmanın hastalıklara karşı direncini ve soğuk stresine karşı dayanıklılığını artırdığı da bilinmektedir. Bu çalışmada, altı farklı üzüm çeşidinin (Isabella (*Vitis labrusca* L.), Barış, Italia, Tekirdağ Çekirdeksizi, Trakya İlkeren ve Yalova İncisi (*Vitis vinifera* L.)) yapraklarındaki mineral madde miktarları, 15 Haziran, 15 Temmuz ve 15 Ağustos tarihlerinde olmak üzere iki yıl boyunca incelenmiştir. Bu kapsamda, farklı dönemlerde alınan yaprak örneklerinde azot, potasyum, fosfor, kalsiyum, magnezyum, demir, çinko, mangan, bakır ve sodyum miktarlarındaki değişimler değerlendirilmiştir. Araştırma sonucunda, incelenen makro ve mikro minerallerin miktarlarının hem genotiplere hem de örnekleme tarihlerine bağlı olarak önemli farklılıklar gösterdiği belirlenmiştir. Elde edilen bulgular, asma yetiştiriciliğinde besin elementi yönetiminin daha etkin planlanmasına olanak sağlayarak, verimliliğin ve ürün kalitesinin artırılmasına katkı sunmaktadır.

1. Introduction

The mineral composition of the soil has been demonstrated to have a direct impact on both the yield and the quality of the grapes. It is evident that macro- and microelements play a pivotal role in the general physiology of vines, as well as in the quality of the grapes and wine produced. The specific role played by each of these nutrients is well understood (Brunetto et al., 2015; James et al., 2022). The mineral nutrition of a plant is one of the various factors that influence the physiological behavior of a genotype. It is estimated that the water content of plants ranges from 70% to 95%, with the remaining percentage being accounted for by minerals, which comprise a mere 1% of the plant. Nevertheless, the mineral composition of grapevines is of considerable importance, given its effect on vitality, photosynthesis, cell wall growth and fruit set (Keller et al., 2003; Fernandes et al., 2013; Rogiers et al., 2020).

Furthermore, it has been demonstrated to affect the resistance of diseases (Bavaresco & Einbach, 1987; Marcianò et al., 2023) and cold hardiness (Wample et al., 1993; Nojavan et al., 2020).

Vines continuously absorb various mineral nutrients from their environment in order to sustain their growth and development. As the growth period progresses, the types and amounts of nutrients in different organs show distinct differences (Karl et al., 2023). The demand for plant minerals is subject to variation depending on the different physiological stages of the grapevine (Christensen, 1969). It is evident that the mineral composition of grapevines is subject to variation according to the sampling dates (Pradubsuk et al., 2010; Brunetto et al., 2015). While the mineral uptake capacity of the grapevine can increase shortly after bud break, most mineral uptake from soil has most often been found between bloom and veraison (Bates et al., 2002; Chen et al., 2025).

The macronutrients, nitrogen (N), potassium (K) and phosphorus (P) play a key role in grapevine nutrition and are the three primary mineral nutrients whose absorption varies significantly across different growth stages

(Brunetto et al., 2020). However, trace elements such as iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and boron (B) also play an important role in grapevine growth. Deficiencies in mineral nutrients, particularly those required by grapevines, strongly affect plant metabolism and consequently have negative effects on plant growth, yield, and the nutritional and organoleptic quality of agricultural products (Cug et al., 2020; James et al., 2022). For this reason, fertilization management is of vital importance to vine-growers, with recommendations often based on leaf and stem diagnostics (Romero et al., 2010). In the preceding thirty years, several significant studies were conducted to ascertain the seasonal mineral requirements of field-grown grapevines and to quantify the partitioning of minerals (Christensen, 1984; Peacock et al., 1991; Peuke, 2009; Pradubsuk et al., 2010). The majority of studies have concentrated on macro elements, including N, P and K (Bates et al., 2002; Domagala-Swiatkiewic & Gastol, 2013; Rustioni et al., 2015; Stefanello et al., 2023).

This study aimed to examine the composition of macro and micro minerals present in the leaves of six table grapes collected at three distinct sampling dates under Tekirdağ conditions. The study is also important in providing a better understanding of the mineral dynamics in grapevine leaves at different phenological stages and in establishing a roadmap for optimizing fertilization management in grapevines.

2. Materials and Methods

The field experiment was conducted using *Vitis labrusca* L. cv. Isabella and *Vitis vinifera* L., cvs. In 2005 and 2006, grapevines of the Barış, Italia, Tekirdağ Çekirdeksizi, Trakya Ilkeren, and Yalova Incisi varieties were grafted on Kober 5 BB rootstock. These vines were propagated from a vineyard planted in 1990 at the Viticulture Research Station in Tekirdağ, Turkey. The grapevines were trained in a bilateral cordon configuration, with a planting density of 1.5 within rows and 3 m between rows. The experimental design employed was a randomized block design with three replications, thus giving a total of 30 vines. The soil of the vineyard was characterized by a sandy loam texture, with a pH of 7.2 and a notably low organic matter content (0.95-1.01%).

In order to ascertain the composition of the macro minerals (including Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micro minerals (including iron (Fe), zinc (Zn), manganese (Mn), copper (Cu) and sodium (Na), 15 whole, healthy leaves in each replication were collected from between the sixth and twelfth nodes from the base of the shoots at three different sampling dates (15 June, 15 July and 15 August). The leaf blades were separated, washed with tap water, and then rinsed with distilled water. Subsequently, the samples were subjected to a drying process at a temperature of 65°C in an oven. Thereafter, they were ground through a sieve ring with a mesh size of 0.5 mm using an ultracentrifugal mill. The N content was determined by the Kjehdahl method (Bradford, 1976). The determination of P, K, Ca, Mg, Fe, Zn, Mn, Cu, and Na was performed by Inductively Coupled Plasma-Optic Emission Spectroscopy (ICP-OES). The microwave system (Milestone-Ethos plus 900) was employed for the sample preparation stage. For the digestion process, 0.5 g of powdered leaf samples (with a diameter of less than 1 mm) were transferred into Teflon beakers. A 6 ml volume of a freshly prepared mixture of HNO_3–H_2O_2 (5:1, v/v) was added to each Teflon beaker. Subsequent to the process of digestion, the volume of the sample was augmented to 25 ml with distilled water. The ICP-OES measurements were conducted using a PerkinElmer Optima 5300 DV ICP-OES instrument in accordance with the operating conditions specified in Table 1. The wavelengths utilized for the various elements are enumerated below: The following wavelengths were measured: 766.490 nm for K, 317.933 nm for Ca, 285.213 nm for Mg, 213.617 nm for P, 238.204 nm for Fe, 206.200 nm for Zn, 257.600 nm for Mn, 327.393 nm for Cu and 589.592 nm for Na. The values of detection limits were established as follows: 0.0045 mg/l for P; 0.0165 mg/l for K; 0.0228 mg/l for Ca; 0.0015 mg/l for Fe; 0.0018 mg/l for Mg; 0.0012 mg/l for Zn, Mn and Cu; 0.05 mg/l for Na. The data presented are the mean of three measurements.

Table 1. Operating conditions of the ICP-OES inductively coupled plasma-optical emission Spectrometry.
Tablo 1. ICP-OES indüktif eşleşmiş plazma-optik emisyon Spektrometresinin çalışma koşulları.

Parameter	**Value**
RF generator (plasma Ar–Ar)	40 MHz
RF incident power	1450 W
Viewing mode	Axial for P, Ca, Fe, Mg, Zn, Mn, Cu; radial for K, Na
Auxiliary argon flow rate	0.2 L/min
Nebulizer argon flow rate	0.55 L/min
Plasma gas flow rate	17 L/min
Sample uptake flow rate	1.5 ml/min

The collected data were then analyzed using variance analysis with mean separation using Duncan's multiple range test. Statistical significance was considered as $p \leq 0.05$. The statistical analysis was conducted using SPSS 10.0 for Windows software.

3. Results and Discussion

This study examined the impact of varying sampling dates (15 June, 15 July, and 15 August) on the mineral composition of leaf samples from six grape cultivars

(*Vitis labrusca* L. cv. Isabella and *Vitis vinifera* L. cvs.). The following conditions were determined in Tekirdağ: Barış, Italia, Tekirdağ Çekirdeksizi, Trakya Ilkeren and Yalova Incisi. The concentration of macro minerals (N, P, K, Ca, Mg) and micro minerals (Fe, Mn, Zn, Cu, and Na) in leaves was determined, and the results are presented in Tables 2 and 3.

It is evident that the mineral status of the leaves exerts a direct influence on total biomass production, including the allocation of minerals to fruits. N has been demonstrated to encourage vegetative growth, exerting a significant influence on both the yield and the quality of berries (Brunetto et al., 2007). Consequently, N is considered to be one of the most significant macro minerals in plants, with its concentration exhibiting substantial variations depending on the sampling dates and the grape cultivars (Christensen, 1984). The present study presents the amounts and variations of N in the leaves collected on different sampling dates in Table 2. It was hypothesized that the genotype, in conjunction with the sampling dates, would emerge as the principal factor influencing the relative concentrations of nitrogen in the leaves. This hypothesis was tested using a one-way ANOVA, with a significance level of $p \leq 0.05$. The results of the test indicated that the genotype and the sampling dates did indeed have a significant influence on the relative concentrations of nitrogen in the leaves ($p \leq 0.05$). An evaluation was conducted of the contents of nitrogen (N) in the leaves of various grape cultivars, with the sampling dates being a key factor in this study. The highest nitrogen contents were found to occur on 15 June and 15 July for Tekirdağ Çekirdeksizi, and on 15 June for the other cultivars (2005). In 2006, maximum N concentrations were observed in the leaves collected from 15 June for Italia, Tekirdağ Çekirdeksizi ve Yalova Incisi, while no differences were detected between 15 June and 15 July for Barış and Trakya Ilkeren. However, Isabella exhibited a divergent trend with regard to the sampling dates. The most abundant N content was found in the leaves collected on 15 July in this cultivar. Christensen (1984) conducted a study on the changes in nitrate levels during the season. The results of the study indicated that nitrate levels were highest at the beginning of the season, gradually declined through the bloom and berry set stages, and then increased slightly by veraison. As Schreiner et al. (2006) also determined, the level of nitrogen (N) decreased between the harvest and leaf fall. The findings of this study indicate a general decline in the N content of grape cultivars throughout the sampling periods. This finding aligns with the results of numerous studies (Schreiner et al., 2006; Peuke, 2009; Ferrara et al., 2018).

Table 2. The contents of macro minerals in the grapevines leaves collected at different sampling dates
Tablo 2. Farklı örnekleme tarihlerinde Farklı örnekleme tarihlerinde toplanan asma yapraklarındaki makro mineral içerikleri

Mineral	Year	Sampling date	Cultivars					
			Barış	**Isabella**	**Italia**	**Tekirdağ Çekirdeksiz**	**Trakya Ilkeren**	**Yalova Incisi**
N (%)	**2005**	**June 15**	3.53 b A*	3.54 b A	4.09 a A	3.13 c A	4.24 a A	3.56 b A
		July 15	2.94 B	2.96 B	3.03 B	3.19 A	3.07 B	3.12 B
		August 15	2.74 b B	3.07 a B	2.78 b B	2.73 b B	3.15 a B	2.97 b B
	2006	**June 15**	3.02 bA	2.27 c B	3.23 bA	3.32 b A	3.25 bA	3.60 a A
		July 15	3.13 abA	2.96 b A	2.37 c C	2.93 b B	3.24 a A	2.94 b B
		August 15	2.46 bB	2.31 b B	2.78 a B	2.49 b C	2.76 aB	2.45 bC
P (µg/g)	**2005**	**June 15**	0.23 e B	0.54 cA	0.94 aA	0.61 b A	0.59bc A	0.29 d A
		July 15	0.28 b A	0.21 cB	0.02 f C	0.04 eC	0.32 aB	0.09 d B
		August15	0.03 d C	0.02 e C	0.24 a B	0.12 bB	0.05 c C	0.03 dC
	2006	**June 15**	0.01 c C	0.01 c	0.02 bB	0.01 c C	0.05 aC	0.01 cB
		July 15	0.18 b A	0.01 e	0.30 aA	0.10 dA	0.28 a A	0.13 c A
		August 15	0.12 a B	0.01 e	0.03 d B	0.04 cB	0.09 b B	0.13 aA
K (µg/g)	**2005**	**June 15**	8.73 aAB	7.09 bB	8.29 aB	7.19 bC	8.59 aB	7.12 bA
		July 15	9.41 aA	6.75 bB	9.90 aA	10.01 aB	9.74 aA	5.92 cB
		August 15	8.16 cB	10.01 bA	9.74 bA	11.59 aA	7.27 dC	6.38 eB
	2006	**June 15**	12.94 aA	8.08 cA	10.54 bA	12.03 aA	8.97 cB	8.55 cB
		July 15	10.99 bB	4.83 dB	9.40 cB	9.72 cB	11.32 aA	10.68 bA
		August 15	7.84 cC	5.13 dB	9.93 aAB	8.70 bB	9.44 abB	9.12 bB
	2005	**June 15**	17.87 bB	14.15 dC	19.30 bB	16.11 cB	20.28 aB	10.17 eC
		July 15	17.81 cB	26.27 aA	12.36 eC	14.43 dB	20.35 bB	16.61 cB
		August 15	21.56 bA	21.49 bB	25.34 aA	21.20 bA	22.54 bA	18.85 cA

Ca (µg/g**)**	**2006**	**June 15**	13.67 bC	13.70 bB	18.00 aB	13.80 bC	13.63 bC	13.18 bC
		July 15	21.22 bB	26.24 aA	20.98 bA	25.34 aA	17.24 cB	20.70 bA
		August 15	26.58 aA	27.66 aA	19.59cA	22.68 bB	24.15 bA	18.59 cB
Mg µg/g)	**2005**	**June 15**	2.17 abB	1.44 eC	2.00 bcB	2.24 a	1.94 cA	1.76 dB
		July 15	2.86aA	1.89 cB	1.81 cB	2.16 b	2.12 bA	2.86 aA
		August 15	2.26 cB	2.56 bA	2.35 bcA	2.36 bc	1.74 dB	2.82 aA
	2006	**June 15**	2.20 abB	1.68 dB	1.99 cB	2.32 a B	2.08 bcB	2.31 aB
		July 15	2.68 bA	2.31 cA	2.41 cA	3.16 a A	2.02 dB	3.07 aA
		August 15	2.42 cB	2.28 cA	2.48 cA	3.25 aA	2.94 bA	2.89 bA

*Same capital letters in the columns are not statistically different among the sampling dates by the Duncan test ($p < 0.05$) and same lower small letters in the columns are not statistically different among cultivars by the Duncan test ($p < 0.05$).

Furthermore, it was determined in this study that not only the timing of the sampling but also the genotypes of the plants affect the N contents of grape leaves ($p \leq 0.05$)). In a similar vein, Christensen (1984) reported significant variations in mineral content among different grape cultivars.

P, a further macro mineral present in plants, is important due to its function in various metabolic processes, including photosynthesis and respiration (Lambers, 2022). In this study, the sampling date appeared to be a significant factor influencing the P concentrations of the grape cultivars ($p \leq 0.05$) (Table 2). A substantial variation was observed among grape cultivars with respect to leaf P concentrations, contingent on the designated sampling dates. It was thus demonstrated that all grape cultivars exhibited the highest leaf P contents in June 2005, with the exception of Barış, which demonstrated the highest P content in July 2005. However, analysis of the samples collected on 15 July 2006 revealed the highest levels of P in Barış, Italia, Tekirdağ Çekirdeksizi and Trakya Ilkeren. In contrast, no significant variations in P content were observed between 15 July and 15 August in Yalova Incisi. Conversely, substantial disparities were not identified among the sampling dates in Isabella.

The findings of this study on P levels in leaves are in relatively close agreement with the results of Christensen (1969) and Conradie (1981), in which a decline was observed through the bloom period, followed by a slight increase into summer. The flowering times of our grape cultivars were prior to 15 June. The monthly fluctuations in the calculated P content of each grape cultivar exhibited variations according to the year. It has been established that P is characterized by high mobility within the plant phloem (Epstein & Bloom, 2005) and that the greater remobilization of P engenders discrepancies between years (Schreiner et al., 2006).

The study demonstrated that K was also a key factor, given its essential role in grapevine growth and yield, in addition to its involvement in various plant functions. K is capable of efficient translocation throughout the grapevine and may play a role in carbohydrate transport and metabolism. K has been identified as an osmotic agent that plays a crucial role in the regulation of stomata, which is key to the process of vine-water relations. (Mullins et al., 1992). In this study, a significant alteration in leaf K concentrations of grapevine cultivars was observed according to sampling dates ($p \leq 0.05$) (Table 2). As demonstrated in Table 2, the variable K exhibited divergent trends, not only in relation to the sample dates but also in relation to the cultivars and the years. K is a highly mobile mineral that is transported via both the xylem and phloem (Epstein & Bloom, 2005). At harvest, clusters account for 60% or more of the total K of the above ground organs (Mpelasoka et al., 2003; Romero et al., 2010). Consequently, the most probable cause of K depletion in certain grape cultivars is likely to be the translocation of this mineral from the leaves to the ripening berries.

In this study, although there were some minor exceptions, the contents of N, P and K in the leaves of the grapevines generally decreased during the season. Consequently, the decline in mineral concentration, particularly N, P, and K, observed in grape leaves throughout the vegetative cycle can be attributed to a dilution effect resulting from leaf growth and to the redistribution of minerals to other plant organs until the cycle's conclusion (Da Silva et al., 2008). The seasonal trends of N, P and K in the leaves of the grape cultivars used in this study were found to be highly analogous to the results previously reported for other cultivars, including Tempranillo (Romero et al., 2010), Pinot Noir (Schreiner et al., 2006), Pinot Noir (Schreiner & Osborne, 2020).

In the present study, the disparities in Ca and Mg as macro minerals were ascertained in relation to the temporal parameters of the sampling dates ($p \leq 0.05$). Despite minor variations attributable to cultivar and sampling date, a generalized upward trend was observed in Ca levels throughout the season, with the highest concentrations being recorded in samples collected on 15 August. It was hypothesized that the genotype, in conjunction with the sampling dates, would prove to be the significant factor influencing the relative concentrations of Mg in the leaves. In all cultivars, Mg exhibited significantly different levels in leaves collected at different times ($p \leq 0.05$). In 2005, significant fluctuations in Mg concentrations were observed. In 2006, the lowest Mg contents in the leaves were recorded in samples collected on 15 June, followed by an increase towards 15 July and 15 August.

Ca is a nonmobile mineral, whereas Mg is a mobile mineral within the plant (Barker & Pilbeam, 2007). The increase in leaf Ca concentration over this period can be explained by the immobility of Ca in plant tissues and the absence of redistribution to other plant organs. Conversely, Mg increases are likely a consequence of reduced K competition, as evidenced by the decline in leaf K levels throughout the cycle. Consequently, Mg is hypothesised to be mobilised from old to new leaves, while Ca is predicted to accumulate in old leaves. Nevertheless, an accumulating pattern in leaves for these two minerals has been found in a wide range of grapevine cultivars, including Pinot noir (Schreiner et al., 2006) Cabernet sauvignon (Stevens, 2005) and Mencía (Cancela et al., 2018)

In this study, the effects of different sampling dates on leaf micromineral contents of grape cultivars were also determined (Table 3). The results of the study demonstrated that the genotype and the sampling dates had a significant effect on the content of micro-elements, including Fe, Zn, Mn, Cu and Na, in the leaves ($p \leq 0.05$). The concentrations of micro minerals in the leaves were found to be lower than those of macro minerals. The observed trends were found to vary according to the micro minerals, genotypes, sampling dates, and years.

The mineral demand of grapevines is subject to change in accordance with the different stages of the physiological development, resulting in differing mineral concentrations throughout the plant (Christensen, 1969). The mineral levels exhibited by the cultivars tended to demonstrate consistency both within the season and between years. As Schreiner et al. (2006) also reported, the uptake of most macro elements was found to be closely related to canopy demand. However, concentrations of microminerals, including Fe, Mn, B, Zn, and Cu, exhibited significant variation from vine to vine, even when considering the whole vine. The foliar concentrations of Cu and Mn increased concomitantly with the vine's growth, whereas the Zn and B concentrations decreased, presumably due to the dilution effect in the plant (Da Silva et al., 2008).

Table 3. The contents of micro minerals in the grapevines leaves collected at different sampling dates
Tablo 3. Farklı örnekleme tarihlerinde toplanan asma yapraklarındaki mikro mineral içerikleri

Mineral	**Year**	**Sampling date**	**Cultivars**					
			Barış	**Isabella**	**Italia**	**Tekirdağ çekirdeksiz**	**Trakya Ilkeren**	**Yalova Incisi**
Fe (µg/g)	2005	**June 15**	0.07 cB*	0.06 cC*	0.09 aB	0.08 b	0.08 bB	0.07 cB
		July 15	0.08 bA	0.10 aA	0.09 aB	0.08 b	0.10 aA	0.08 bA
		August 15	0.08 bA	0.08 bB	0.11 aA	0.08 b	0.09 bB	0.08 bA
	2006	**June 15**	0.08 d	0.22 aA	0.10 bA	0.09 c C	0.04 eC	0.08 dB
		July 15	0.08 c	0.11 aB	0.08 cB	0.12 b A	0.10 bA	0.06 dC
		August15	0.08 c	0.09 bB	0.08 cB	0.10 a B	0.08 cB	0.10 aA
Zn (µg/g)	2005	**June 15**	0.02 aB	0.02 aB	0.01 bC	0.02 a	0.02 aB	0.02 aB
		July 15	0.03 aA	0.03 aA	0.03 aB	0.02 b	0.03 aA	0.03 aA
		August 15	0.03 bA	0.02 cB	0.05 aA	0.02 c	0.02 cB	0.02 cB
	2006	**June 15**	0.03 aC	0.03 aC	0.03 aC	0.02 bB	0.02 bB	0.02 bC
		July 15	0.04 bB	0.06 aB	0.06 aA	0.03 cA	0.06 aA	0.04 bA
		August 15	0.06 bA	0.09 aA	0.04 cB	0.03 cA	0.05 bA	0.03 cB
Mn (µg/g)	2005	**June 15**	0.05 bA	0.04 cC	0.04 cC	0.04 c	0.06 aB	0.06 aC
		July 15	0.05 dA	0.18 aA	0.15 bA	0.04 e	0.07 cB	0.18 aA
		August 15	0.03 fB	0.06 dB	0.09 cB	0.04 c	0.10 bA	0.14 aB
	2006	**June 15**	0.06 cB	0.10 aC	0.08 bB	0.06 cC	0.08 bA	0.05 dA
		July 15	0.06 dB	0.16 aA	0.12 bA	0.08 cA	0.06 dC	0.04 eB
		August 15	0.10 bA	0.13 aB	0.08 cB	0.07 dB	0.07 dB	0.05 eA
Cu (µg/g)	2005	**June 15**	0.25 eB	0.57 cA	1.01 aA	0.66 bA	0.63 bcA	0.32 dA
		July 15	0.31 bA	0.23 cB	0.02 fC	0.05 eC	0.34 aB	0.09 dB
		August15	0.04 dC	0.02 eC	0.26 aB	0.13 bB	0.06 cC	0.04 dC
	2006	**June 15**	0.02 bC	0.02 bA	0.02 bB	0.01 cC	0.05 aC	0.02 bB
		July 15	0.20 bA	0.01 eB	0.32 aA	0.11 dA	0.30 aA	0.15 cA
		August 15	0.13 aB	0.01 eB	0.03 dB	0.05 cB	0.10 bB	0.14 aA
Na (µg/g)		**June 15**	0.01 eC	0.06 bA	0.07 aC	0.05 cC	0.02 dC	0.02 dC

	2005	**July 15**	0.42 bA	0.03 dB	0.50 aA	0.42 bA	0.05 cB	0.08 cB
		August 15	0.10 dB	0.07 eA	0.12 cB	0.12 cB	0.30 aA	0.23 bA
	2006	**June 15**	0.04 aB	0.04 aB	0.04 aB	0.03 bB	0.03 bC	0.01 cC
		July 15	0.01 dB	0.04 dB	0.57 aA	0.02 dB	0.34 bB	0.24 cB
		August 15	0.50 cA	0.64 bA	0.03 dB	0.66 bA	0.56 cA	0.90 aA

*Same capital letters in the columns are not statistically different among the sampling date by the Duncan test ($p < 0.05$) and same lower small letters in the columns are not statistically different among varieties by the Duncan test ($p < 0.05$).

Pradubsuk (2008) also determined that the concentrations of Cu and Zn in leaf blades of Concord grapes were highest at bloom and sharply reduced by veraison, then slowly decreased until the end of the season. Such a dilution effect of mineral concentration in leaf blades might result from rapid leaf expansion and translocation of nutrients from leaves to clusters. Conversely, concentrations of Mn in leaf blades exhibited a peak postharvest, presumably due to the immobility of these elements within the plant phloem, which rendered them static once deposited within individual leaves and led to a sustained increase in concentration throughout the season.

4. Conclusions

The present study established that both the sampling timing and the genotypes of the grapevines significantly impact the mineral composition of the vines. The grape cultivars' leaf macro and micro mineral composition exhibited divergent trends according to the sampling dates. The data obtained clearly reveal the seasonal and annual variations in the nutritional status of the grapevine. This allows for a better understanding of the plant’s nutrient requirements at different growth stages, enabling more informed planning of fertilization programs in terms of timing and composition. Consequently, this study makes a significant contribution to improving nutrient management in viticulture, as well as enhancing yield and fruit quality.

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Conflict of Interest

The authors declared that there is no conflict of interest.

Author Contributions

The authors declare that they have contributed equally to the article.

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