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RESEARCH ARTICLE

Effect of rootstock and cultivar on fruit quality attributes and nutrient concentration in cherry leaves

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ABSTRACT

A correct nutritional management of cherry crops has shown to be a contribution in achieving good fruit production and quality objectives, requiring nutritional standards that consider effects of rootstocks and cultivars. This study was conducted in sweet cherry (*Prunus avium* (L.) L.) 'Sweet Aryana', 'Santina', and 'Regina' commercial orchards, on three rootstocks, sour cherry (*Prunus cerasus* L.), 'Gisela 6' hybrid (*Prunus cerasus* L. × *Prunus canescens* Bois), and 'Maxma 14' hybrid (*Prunus mahaleb* L. × *Prunus avium*), evaluating firmness, size and weight of fruits, and nutrient concentration in leaves. Fruit quality attributes of 'Sweet Aryana' and 'Santina' were not affected by rootstock, while 'Regina' fruit weight was 13.8% higher with 'Maxma 14'. Fruit quality in different cultivars did not differ when using rootstock 'Gisela 6', while with 'Maxma 14' fruit weight of 'Regina' was 14.8% higher than 'Santina'. 'Sweet Aryana' had higher concentrations of N (2.7%), P (0.27%), S (0.13%), and Cu (9.5 mg kg^{-1}) with 'Gisela 6' compared to sour cherry. 'Santina' had the highest K concentrations (3.33%) and B (70 mg kg^{-1}) with sour cherry, while with 'Gisela 6' had higher P concentrations (0.31%) and Cu (10.5 mg kg^{-1}), and with 'Maxma 14' had the highest Zn concentration (19.1 mg kg^{-1}). 'Regina' achieved the highest Cu concentration (9.7 mg kg^{-1}) with 'Maxma 14', and the highest Mn concentration (41.4 mg kg^{-1}) with 'Gisela 6'. The greatest nutritional contrasts were obtained between 'Santina' and 'Regina', on 'Gisela 6'. This recompilation of data is a valuable argument to be considered in the development of successful fertilization programs for these cultivars in commercial orchards.

Key words: Mineral nutrition, nutritional diagnosis, *Prunus avium*, soil-plant relationship.

INTRODUCTION

Chile has endured a steady increase in the exportation of cherries with markets growing in China, USA and Europe (CIREN, 2025). To date, the area of production has reached 82 000 ha and ongoing demands from consumers has led producers to constantly improve the quality of the fruit produced, highlighting size and firmness, among other attributes. While there are several techniques to improve fruit quality, such as crop load regulation with winter and summer pruning, root darting, fruit thinning, and water and nutrient management, the choice of variety and rootstock strongly influences the quality of the fruit obtained. There is published information previously showing the effects of rootstock on the production and quality of fruit obtained from cherry (*Prunus avium* (L.) L.) (Facteau et al., 1996; Moreno et al., 2001; Jiménez et al., 2004a; Hrotkó et al., 2023), table grape (*Vitis vinifera* L.) (Pachnowska and Ochmian, 2018; Li et al., 2019) and lemon (*Citrus limon* (L.) Burm.) (Dubey and Sharma, 2016). Moreover, the use of different rootstocks can generate variations associated with differences in the nutritional composition of leaves, as shown in cherry (Jiménez et al., 2004b; 2007; Hrotkó et al., 2014), table grape (Li et al., 2019), apple (*Malus* ×*domestica* (Suckow) Borkh.) (Kurešová et al., 2018), almond (*Prunus dulcis* (Mill.) D.A. Webb) peach (*Prunus persica* L.) (Yahmed et al., 2020; Shahkoomahally et al., 2020) and mango (*Mangifera indica* L.) (Sarkhosh et al., 2021).

Authors Neilsen and Kappel (1996) reported differences for 'Bing' cherry in N, K, Mg, Zn and Mn concentrations in leaves as an effect of the used rootstock ('Colt', 'GM 79', 'GM 61/1', 'GM 9', 'MxM46', 'MxM2', 'Mazzard'). Kolega et al. (2024) published differences in nutritional concentrations of N, P, K, Ca and Mg in leaves of 'Lapins' related to the use of different rootstocks ('SL 64', 'Maxma 14' and 'Gisela 5'). Also, Jiménez et al. (2007) found certain differences in nutrient concentrations in leaves of 'Stark Hardy Giant' for P, K, Ca, Mg and Mn, when it was grown on the rootstocks 'Adara', 'CAB 6P', 'Gisela 5', 'Maxma 14', 'SL 64', 'SL 405' and 'Tabel'. However, no differences were found in the concentrations of N, Fe, Zn and Cu. For the same study with 'Van', differences were found in concentrations of P, Fe and Mn in the leaves of this cultivar associated with the aforementioned rootstocks.

When using different rootstocks in a same environment, these differences could be explained by genetic factors, exploratory capacity and radical architecture (ability to explore and find differences in the physical-chemical composition of the soil), quality of exudates into the rhizosphere, and interaction with soil microorganisms (Mengel and Kirkby, 2001; Bais et al., 2004; Kurešová et al., 2018; Mimmo et al., 2018; Mahmud et al., 2023). The study carried out by Jiménez et al. (2007) describes the different characteristics of the cherry rootstocks evaluated in terms of vigor and adaptation to different soil conditions.

Another factor that affects variation in the nutritional concentration of leaves of a fruit species is cultivar, as demonstrated for table grapes by Bianchi et al. (2020), for blueberries by Hirzel et al. (2024), for European hazelnuts by Holzapfel et al. (2022), and for cherry by Hrotkó et al. (2014). It is important to highlight that to date, we could not find new or recent reports of differences between cherry genotypes in Chile, a product with relevant commercial importance in the country. The present study was designed to determine the effect of different cherry rootstocks and cultivars on the nutritional composition of cherry leaves grown in Chile.

MATERIAL AND METHODS

Locations and sweet cherry orchards

The study was conducted in sweet cherry (*Prunus avium* (L.) L.) commercial orchards during season 2024-2025; with 'Sweet Aryana' (early season harvest) on 'Gisela 6' (*Prunus cerasus* L. × *Prunus canescens* Bois) and sour cherry (*Prunus cerasus* L.) rootstocks, 'Santina' (early season harvest) on 'Gisela 6', sour cherry and 'Maxma 14' (*Prunus mahaleb* L. × *Prunus avium*) rootstocks, 'Regina' (last season harvest) on 'Gisela 6' and 'Maxma 14' rootstock, collecting fruit samples at commercial maturity (mahogany red color), and leaves from the middle of annual shoot in 12 and 15 January 2025. The orchard geographical ubication is south-central Chile (34°57'38" S, 71°11'20" W) and the soil corresponds to an Inceptisol (USDA, 2014). Orchards fluctuated between 7 to 11 yr, and the plantation distance in 'Sweet Aryana', 'Santina' and 'Regina' was 3.5 m between rows and 1.8 m between plants on the row. Climatic characteristics during the growth season are presented in the Table 1. In addition, 1173 chill hours were accumulated between May and August 2024, which correspond to a 100% of the normal for the climatic zone (Agrometeorología INIA, 2025). The fruit load data (cumulative yield and fruit number per plant) are presented in the Table 2.

Table 1. Environmental condition during the growth season (flowering to late harvest) 2024 to 2025 in south central Chile.

Month	Phenological stage	Air temperature Mean	Min	Max	Rainfall	Solar radiation
		———	°C	———	mm	MJ m^{-2}
September	Flowering	11.9	6.4	17.3	57.4	11.8
October	Early fruit development	16.3	10.0	22.7	9.4	17.3
November	Fruit color change, start of harvest	18.0	10.7	25.2	40.2	22.1
December	Harvest	20.8	12.7	28.9	0.2	26.1
January	Late harvest	23.3	14.8	31.8	0.0	26.0
February	Late harvest	22.4	14.0	30.9	0.0	22.0
March	Late harvest	19.2	11.9	26.4	0.0	16.6

Table 2. Fruit load of three different sweet cherries cultivars cropped in south central Chile. SD: Standard deviation; SE: standard error.

Cultivars	Yield		Yield		Fruit load	
	Mean ± SD	SE	Mean ± SD	SE	Mean ± SD	SE
	——— kg ha^{-1} ———		——— kg plant^{-1} ———		——— Fruits plant^{-1} ———	
Sweet Aryana	14 860 ± 1 830	457	9.36 ± 1.15	0.28	769.0 ± 94.7	23.6
Santina	15 250 ± 1 375	280	9.61 ± 0.87	0.18	786.0 ± 72.1	14.7
Regina	14 520 ± 3 580	895	9.15 ± 2.26	0.56	714.0 ± 176.1	44.0

Soil analysis

Chemical soil properties were analyzed from 0 to 0.3 m of the sectors where the fruit and leaves samples were collected and are shown in Table 3. Analyses were performed using the methodologies indicated by Sadzawka et al. (2006) in the Laboratory of the Chilean Agricultural Research Institute, and the detail of each laboratory methodology was described by Hirzel et al. (2023).

Table 3. Soil physical and chemical properties at depth of 0 to 0.3 m.

Analysis	Minimum value	Maximum value
Sand, %	35.00	45.00
Loam, %	40.00	44.00
Clay, %	16.00	20.00
Organic matter content, g kg^{-1}	18.00	27.00
pH ($_{\text{soil:water 1:2.5}}$)	6.25	7.12
Electric conductivity, dS m^{-1}	0.39	0.53
Available N, mg kg^{-1}	25.00	43.00
Available P, mg kg^{-1}	14.00	32.00
Exchangeable Ca, cmol$_+$ kg^{-1}	8.50	11.30
Exchangeable Mg, cmol$_+$ kg^{-1}	1.86	3.21
Exchangeable K, cmol$_+$ kg^{-1}	0.35	0.72
Exchangeable Na, cmol$_+$ kg^{-1}	0.12	0.18
Available S, mg kg^{-1}	17.00	42.00
Available Fe, mg kg^{-1}	18.00	36.00
Available Mn, mg kg^{-1}	2.70	5.80
Available Zn, mg kg^{-1}	1.10	3.70
Available Cu, mg kg^{-1}	6.30	12.10
Available B, mg kg^{-1}	0.47	1.26

Fertilization and irrigation management

The fertilization applied during the growth season in all the cultivars was 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 180 kg K_2O ha^{-1}, 25 kg CaO ha^{-1} and 40 kg MgO ha^{-1}. Irrigation was made considering the reposition of the water evaporation pan corrected by the crop coefficient (Kc).

Sampling of fruits and leaves and analysis procedure

Methodology of collect of fruit samples was descripted by Hirzel and Díaz (2025). Fruits were sampled at the beginning of harvest of each cultivar. Each random sample consisted of 5 kg fruit from 20 plants from the middle section of each block or production unit (considering block from 10 000 to 30 000 m^2). For each cultivar, eight replicates were collected. The harvest criterion was fruit color, using the mahogany red color as an indicator. Fruit was collected between 08:00 and 10:00 h in plastic trays, transferred to a thermal isolation structure (144-L cooler, IGLOO Latitude, Katy, Texas, USA), and subsequently transported to both the fruits quality analysis and tissues chemical analysis laboratory of the Instituto de Investigaciones Agropecuarias, INIA Quilamapu, Chillán, for immediate determination of fruit firmness, size, and weight. Firmness and size were measured individually from 60 fruits from each sample with a FirmPro instrument (HappyVolt, Santiago, Chile), and fruit weight was determined with a digital balance (100A-300M, Precisa, Dietikon, Switzerland). Leaves were collected from middle of annual shoot located at high of 1.5 to 1.8 m, considering 20 trees and 4 leaves by tree (80 leaves for sample). To analyze mineral nutrient content, leaves samples were oven-dried at 70 °C to constant weight, milled and chemically analyzed. The methodologies described by Sadzawka et al. (2007) were used, and the detail of each methodology in laboratory is described by Hirzel et al. (2023; 2024).

Statistical analysis

For each combination of cultivar and rootstock, eight samples of 20 trees were considered. Taking in consideration that sweet cherries were grown in field conditions of a farm under the same environmental and growing conditions, results were subjected to one way ANOVA among rootstock or cultivars, using the same methodology as described by Ložienė et al. (2016), and Tukey's mean separation test at 5% level of significance for comparison of more to two treatments. Data was analyzed with software SAS 6.0 (SAS Institute, Cary, North Carolina, USA).

RESULTS

Fruit quality attributes

The fruit quality attributes of 'Sweet Aryana' and 'Santina' were not affected by the rootstock used ($p < 0.05$) (Figures 1 and 2), while 'Regina' fruit weight was higher with 'Maxma 14' rootstock ($p < 0.05$) (Figure 3), with a 13.8% weight increase compared to 'Gisela 6' rootstock. Regarding cultivars on the same rootstock, fruit quality attributes evaluated did not differ between cultivars when 'Gisela 6' rootstock was used (Figure 4), while with 'Maxma 14' we found a difference in fruit weight, with a value 14.8% higher in 'Regina' than in 'Santina' ($p < 0.05$) (Figure 5).

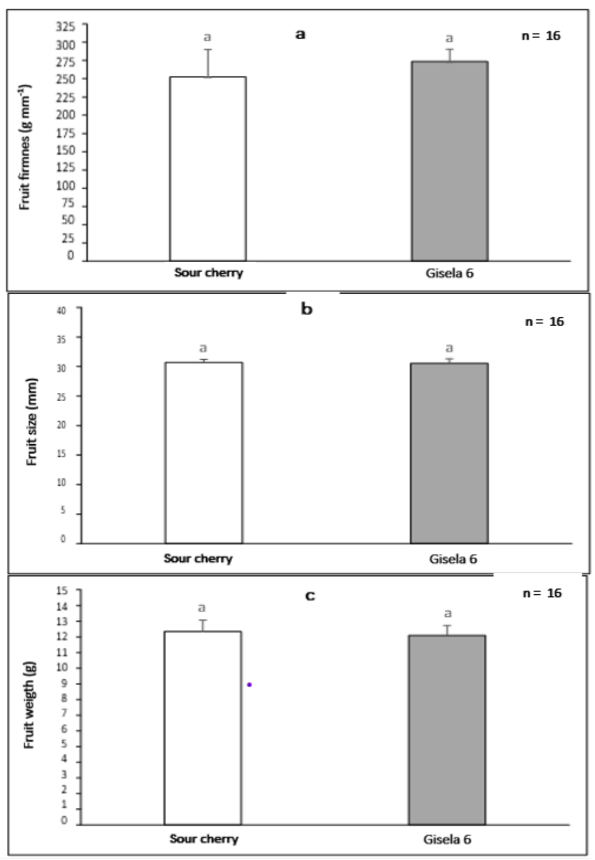

Figure 1. Fruits firmness (a), size (b) and weight (c) of 'Sweet Aryana' sweet cherry on sour cherry and 'Gisela 6' rootstocks. Lines over the bars indicate the standard error. Letter over the bars indicate significant difference according to Tukey' test ($p < 0.05$).

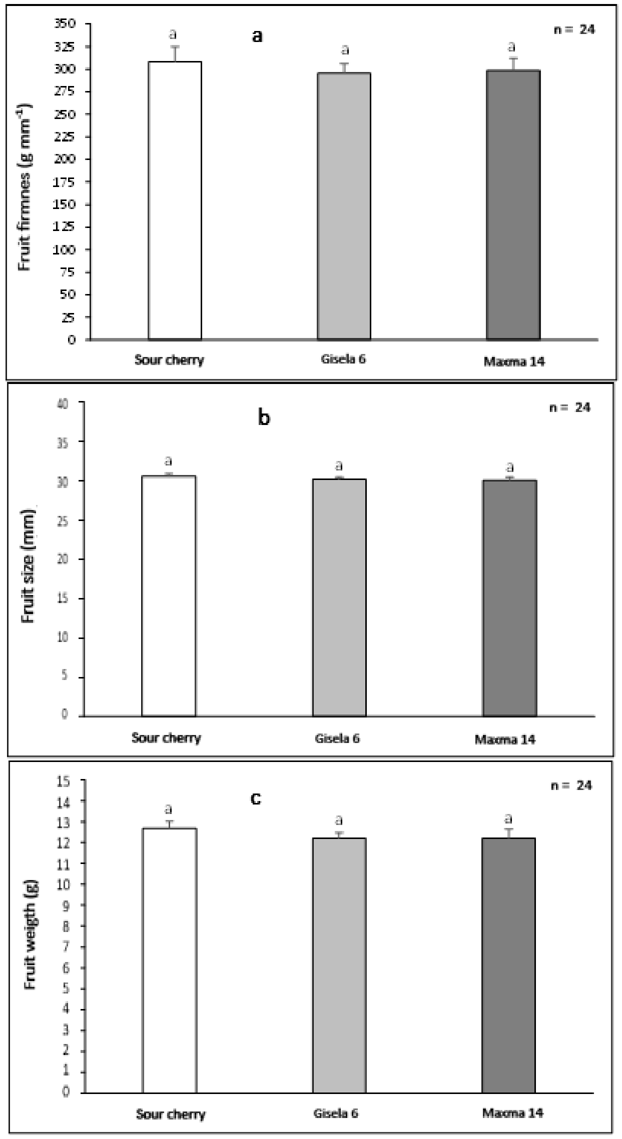

Figure 2. Fruits firmness (a), size (b) and weight (c) of 'Santina' sweet cherry on sour cherry, 'Gisela 6' and 'Maxma 14' rootstocks. Lines over the bars indicate the standard error. Letter over the bars indicate significant difference according to Tukey' test ($p < 0.05$).

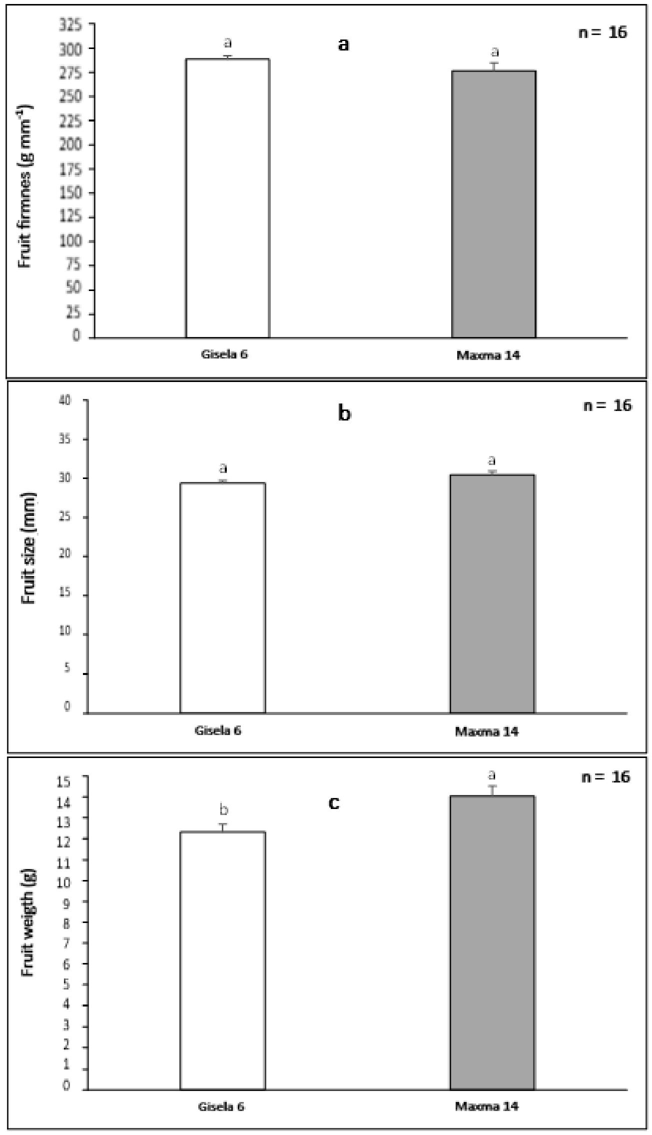

Figure 3. Fruits firmness (a), size (b) and weight (c) of 'Regina' sweet cherry on 'Gisela 6' and 'Maxma 14' rootstocks. Lines over the bars indicate the standard error. Letter over the bars indicate significant difference according to Tukey' test (p < 0.05).

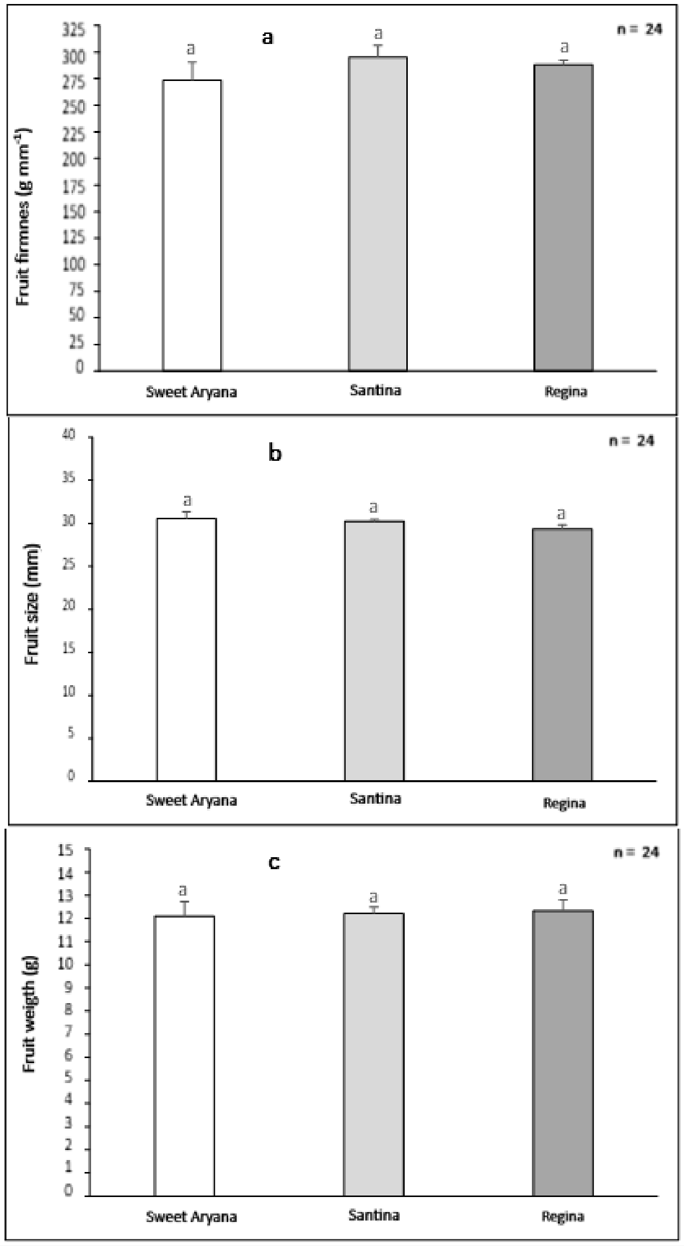

Figure 4. Fruits firmness (a), size (b) and weight (c) of sweet cherry 'Sweet Aryana', 'Santina' and 'Regina' on 'Gisela 6' rootstock. Lines over the bars indicate the standard error. Letter over the bars indicate significant difference according to Tukey' test (p < 0.05).

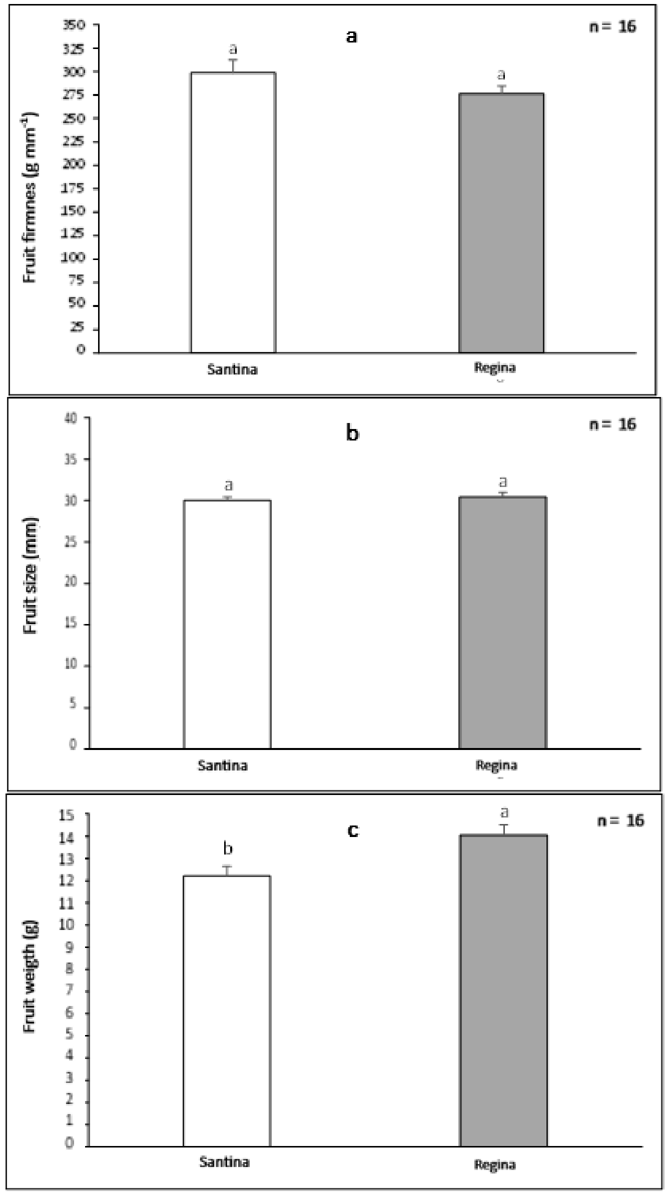

Figure 5. Fruits firmness (a), size (b) and weight (c) of sweet cherry 'Santina' and 'Regina' on the 'Maxma 14' rootstock. Lines over the bars indicate the standard error. Letter over the bars indicate significant difference according to Tukey' test ($p < 0.05$).

Leaves mineral nutrient concentrations

For cherry leaves, 'Sweet Aryana' had higher concentrations of N, P, S, and Cu when using 'Gisela 6' rootstock compared to the sour cherry ($p < 0.05$) (Table 4). There were differences in the concentrations of P, K, Cu, Zn, and B associated with rootstock in 'Santina' (Table 5); sour cherry rootstock showed the highest concentrations of K and B ($p < 0.05$), while with 'Gisella 6' achieved the highest concentrations of P and Cu ($p < 0.05$). Meanwhile, with 'Maxma 14' rootstock showed the highest concentrations of Zn ($p < 0.05$), as well as Cu and B, as did the sour cherry and 'Gisela 6' rootstocks, respectively (Table 5). In 'Regina' there were only differences in the concentration of Cu and Mn ($p < 0.05$), achieving the highest concentration of Cu with 'Maxma 14' and the highest concentration of Mn with 'Gisela 6' rootstock (Table 6).

Table 4. Nutrients concentration in leaves of sweet cherry 'Sweet Aryana' on sour cherry and 'Gisela 6' rootstocks. Different letters in the same row indicate significant differences between sweet cherry rootstocks according to Tukey's test ($p < 0.05$). ± Standard error.

Nutrient	Rootstocks		Significance value
	Sour cherry	Gisela 6	
N, %	2.40 ± 0.17^{b}	2.70 ± 0.18^{a}	0.05
P, %	0.16 ± 0.02^{b}	0.27 ± 0.01^{a}	0.016
K, %	2.76 ± 0.16^{a}	2.32 ± 0.14^{a}	0.28
Ca, %	1.23 ± 0.41^{a}	1.18 ± 0.08^{a}	0.91
Mg, %	0.24 ± 0.05^{a}	0.24 ± 0.01^{a}	0.91
S, %	0.12 ± 0.005^{b}	0.13 ± 0.006^{a}	0.04
Na, mg kg^{-1}	202.00 ± 60.00^{a}	169.00 ± 17.00^{a}	0.67
Cu, mg kg^{-1}	7.30 ± 0.70^{b}	9.50 ± 0.50^{a}	0.03
Fe, mg kg^{-1}	106.30 ± 10.40^{a}	124.30 ± 9.60^{a}	0.48
Mn, mg kg^{-1}	39.00 ± 8.30^{a}	32.90 ± 1.20^{a}	0.54
Zn, mg kg^{-1}	20.00 ± 4.30^{a}	13.20 ± 1.60^{a}	0.27
B, mg kg^{-1}	74.30 ± 4.40^{a}	80.60 ± 4.80^{a}	0.64

Table 5. Nutrients concentration in leaves of sweet cherry 'Santina' on sour cherry, 'Gisela 6' and 'Maxma 14' rootstocks. Different letters in the same row indicate significant differences between sweet cherry rootstocks according to Tukey's test ($p < 0.05$). ± Standard error.

Nutrient	Rootstocks			Significance value
	Sour cherry	Gisela 6	Maxma 14	
N, %	2.70 ± 0.13^{a}	2.79 ± 0.07^{a}	2.55 ± 0.10^{a}	0.18
P, %	0.27 ± 0.02^{ab}	0.31 ± 0.01^{a}	0.24 ± 0.02^{b}	0.015
K, %	3.33 ± 0.15^{a}	2.76 ± 0.12^{b}	2.92 ± 0.21^{ab}	0.03
Ca, %	1.42 ± 0.10^{a}	1.37 ± 0.09^{a}	1.50 ± 0.18^{a}	0.73
Mg, %	0.31 ± 0.03^{a}	0.30 ± 0.02^{a}	0.31 ± 0.03^{a}	0.92
S, %	0.14 ± 0.003^{a}	0.14 ± 0.005^{a}	0.13 ± 0.005^{a}	0.63
Na, mg kg^{-1}	182.00 ± 15^{a}	212.00 ± 15^{a}	208.00 ± 29^{a}	0.57
Cu, mg kg^{-1}	8.40 ± 0.4^{b}	10.50 ± 0.5^{a}	10.60 ± 0.8^{a}	0.04
Fe, mg kg^{-1}	130.10 ± 7.6^{a}	127.70 ± 8.1^{a}	133.80 ± 10.4^{a}	0.71
Mn, mg kg^{-1}	47.80 ± 6.9^{a}	42.80 ± 5.8^{a}	30.10 ± 3.5^{a}	0.13
Zn, mg kg^{-1}	12.10 ± 0.7^{b}	16.10 ± 0.9^{ab}	19.10 ± 2.6^{a}	0.03
B, mg kg^{-1}	70.00 ± 1.8^{a}	62.30 ± 4.0^{b}	74.40 ± 2.5^{a}	0.001

Table 6. Nutrients concentration in leaves of sweet cherry 'Regina' on 'Gisela 6' and 'Maxma 14' rootstocks. Different letters in the same row indicate significant differences between sweet cherry rootstocks according to Tukey's test ($p < 0.05$). ± Standard error.

Nutrient	Rootstocks		Significance value
	Gisela 6	Maxma 14	
N, %	2.73 ± 0.06^{a}	2.58 ± 0.14^{a}	0.41
P, %	0.24 ± 0.01^{a}	0.25 ± 0.02^{a}	0.68
K, %	3.46 ± 0.12^{a}	3.57 ± 0.21^{a}	0.56
Ca, %	1.29 ± 0.07^{a}	1.37 ± 0.10^{a}	0.50
Mg, %	0.31 ± 0.02^{a}	0.30 ± 0.02^{a}	0.79
S, %	0.14 ± 0.003^{a}	0.14 ± 0.006^{a}	0.75
Na, mg kg^{-1}	227.00 ± 10.00^{a}	241.00 ± 23.00^{a}	0.57
Cu, mg kg^{-1}	8.70 ± 0.25^{b}	9.70 ± 0.59^{a}	0.04
Fe, mg kg^{-1}	105.50 ± 4.70^{a}	120.90 ± 15.90^{a}	0.26
Mn, mg kg^{-1}	41.40 ± 2.27^{a}	24.70 ± 3.92^{b}	0.01
Zn, mg kg^{-1}	16.40 ± 1.30^{a}	14.10 ± 2.10^{a}	0.19
B, mg kg^{-1}	70.40 ± 3.00^{a}	77.30 ± 4.80^{a}	0.17

When comparing different cultivars on 'Gisela 6' rootstock (Table 7), differences were observed in the concentrations of P, K, Mg, Na, Cu, Fe and B. The highest concentration of P, Cu and Fe was obtained in 'Santina', surpassing only 'Regina' ($p < 0.05$). The highest concentration of K was achieved in 'Regina' ($p < 0.05$), also achieving higher concentrations of Mg and Na than 'Sweet Aryana' ($p < 0.05$). For its part, 'Sweet Aryana' presented the highest concentration of B ($p < 0.05$). In 'Maxma 14' rootstock (Table 8), there were only differences in the concentrations of K and Fe, achieving the highest K value in 'Regina' and the highest Fe value in 'Santina' ($p < 0.05$).

Table 7. Nutrients concentration in leaves of sweet cherry 'Sweet Aryana ', 'Santina' and 'Regina' on 'Gisela 6' rootstock. Different letters in the same row indicate significant differences between sweet cherry cultivars according to Tukey's test ($p < 0.05$). ± Standard error.

Nutrient	Cultivars			Significance value
	Sweet Aryana	Santina	Regina	
N, %	2.70 ± 0.18^{a}	2.79 ± 0.07^{a}	2.73 ± 0.07^{a}	0.77
P, %	0.27 ± 0.01^{ab}	0.31 ± 0.01^{a}	0.24 ± 0.01^{b}	0.0005
K, %	2.32 ± 0.14^{b}	2.76 ± 0.12^{b}	3.46 ± 0.15^{a}	0.0003
Ca, %	1.18 ± 0.08^{a}	1.37 ± 0.09^{a}	1.29 ± 0.08^{a}	0.28
Mg, %	0.24 ± 0.01^{b}	0.30 ± 0.02^{a}	0.31 ± 0.02^{a}	0.03
S, %	0.13 ± 0.006^{a}	0.14 ± 0.005^{a}	0.14 ± 0.003^{a}	0.14
Na, mg kg^{-1}	169.00 ± 17.00^{b}	212.00 ± 15.00^{ab}	227.00 ± 13.00^{a}	0.05
Cu, mg kg^{-1}	9.50 ± 0.50^{ab}	10.50 ± 0.50^{a}	8.70 ± 0.30^{b}	0.02
Fe, mg kg^{-1}	124.30 ± 9.60^{ab}	127.70 ± 8.10^{a}	105.50 ± 5.80^{b}	0.05
Mn, mg kg^{-1}	32.90 ± 1.20^{a}	42.80 ± 5.80^{a}	41.40 ± 2.80^{a}	0.35
Zn, mg kg^{-1}	13.20 ± 1.60^{a}	16.10 ± 0.90^{a}	16.40 ± 1.60^{a}	0.38
B, mg kg^{-1}	80.60 ± 4.80^{a}	62.30 ± 4.00^{b}	70.40 ± 3.60^{b}	0.01

Table 8. Nutrients concentration in leaves of sweet cherry 'Santina' and 'Regina' on 'Maxma 14' rootstock. Different letters in the same row indicate significant differences between sweet cherry cultivars according to Tukey's test ($p < 0.05$). ± Standard error.

Nutrient	Cultivars		Significance value
	Santina	Regina	
N, %	2.55 ± 0.10^{a}	2.58 ± 0.14^{a}	0.89
P, %	0.24 ± 0.02^{a}	0.25 ± 0.02^{a}	0.81
K, %	2.92 ± 0.21^{b}	3.57 ± 0.21^{a}	0.01
Ca, %	1.49 ± 0.17^{a}	1.37 ± 0.10^{a}	0.61
Mg, %	0.30 ± 0.02^{a}	0.30 ± 0.02^{a}	0.96
S, %	0.13 ± 0.005^{a}	0.14 ± 0.006^{a}	0.16
Na, mg kg^{-1}	208.00 ± 30.00^{a}	241.00 ± 23.00^{a}	0.52
Cu, mg kg^{-1}	10.60 ± 0.80^{a}	9.70 ± 0.60^{a}	0.46
Fe, mg kg^{-1}	133.80 ± 10.40^{a}	120.90 ± 15.90^{b}	0.02
Mn, mg kg^{-1}	30.10 ± 3.50^{a}	24.70 ± 3.90^{a}	0.44
Zn, mg kg^{-1}	19.10 ± 2.60^{a}	14.10 ± 2.10^{a}	0.17
B, mg kg^{-1}	74.40 ± 2.50^{a}	77.30 ± 4.80^{a}	0.53

DISCUSSION

It is important to notice that the accumulation of chilling hours during the 2024-2025 season was acceptable for cherry production, and that spring weather conditions favored fruit growth and development (Table 1), the soil load obtained was normal for the production area (Table 2) (Pino et al., 2023; Salvadores and Bastías, 2023). The physical and chemical properties of the soil were generally adequate for cherry cultivation (Table 3), except for the low organic matter content (which is normal for the evaluation area). However, the application and study of a good fertilization program allowed the nutritional needs of the orchards to be fulfilled, according to their vegetative load and development (Hirzel, 2014; Scofield et al., 2022).

Regarding fruit quality attributes, 'Sweet Aryana' presented the lowest firmness values compared to the other cultivars evaluated, probably due to its early habit, shorter production time of secondary metabolites associated with the texture and firmness of fruits (Escribano et al., 2017); however, there are no reports that provide firmness values for this cultivar. 'Santina' and 'Regina' presented similar firmness values and within the values reported for different cherry cultivars evaluated in Chile (Pino et al., 2023; Quiroz et al., 2023). Likewise, the caliber and weight values of fruits in the three cultivars evaluated were within the range described for different cultivars evaluated in Chile (Pino et al., 2023; Quiroz et al., 2023). The different rootstock applied to each cherry cultivar did not affect fruit quality attributes evaluated, except for the fruit weight of 'Regina', which was higher with 'Maxma 14' rootstock. In this sense, Hrotkó et al. (2023) reports that 'Maxma 14' is a rootstock with vigorous control and high productive efficiency, which in turn can generate a higher weight gain in the fruits compared to 'Gisela 6' for the conditions of this study. This author has also reported an increase in caliber and firmness of cherry fruits in four cherry cultivars ('Carmen', 'Vera', 'Paulus', 'Rita') on 'Maxma 14' rootstock compared to other rootstocks. As for the differences between cultivars for the same rootstock, an increase in fruit weight was only observed in 'Regina' compared to 'Santina' with the 'Maxma 14' rootstock. This weight difference between both cultivars in favor of 'Regina' may be explained by a lower fruit load (786 fruits per tree in 'Santina' and 714 fruits per tree in 'Regina') (Table 2), since the same population density (1587 pl ha^{-1}) was used in both cultivar/rootstock combinations and the light management and canopy size are similar to enhance orchard productivity (Scofield et al., 2022). The lack of differences in quality attributes of cherry fruits (firmness, size and weight) on the same rootstock has been reported by Hrotkó et al. (2023).

The concentration of nutrients in the leaves of the three cherry cultivars evaluated, in the different combinations with rootstock, were normal for the crop, except for K whose concentration was much higher than the standard indicated for cherry trees (Hirzel, 2014), associated with the dose of K used in the crop (180 kg K_2O ha^{-1}); which exceeds by more than 100% the extraction of the crop for average yields between 14 520 and 15 250 kg ha^{-1} (Hirzel, 2014) and the adequate concentration of this nutrient in the soil. In this regard, Neilsen and Kappel (1996) also reported K concentrations in leaves of 'Bing' higher than the international standard, probably due to the lower cumulative load obtained in said study (1775 to 14 445 kg ha^{-1} cumulative in 4 yr), which generates an increase in the concentration of nutrients in the plant tissue associated with a lower extraction in the fruit produced (Mengel and Kirkby, 2001; Marschner, 2012).

The N concentration obtained in this study was higher than that reported by Hrotkó et al. (2014) for 'Petrus' and 'Rita' on different rootstocks, probably due to the low organic matter content of the soil used by these authors (less than 1%). Similarly, Kolega et al. (2024) also reported lower N and Ca concentrations in 'Lapins' on different rootstocks for substrate cultivation; however, substrate cultivation does not generate the same nutrient uptake conditions as soil cultivation.

As for the nutrient concentration values reported by Jiménez et al. (2007) for 'Stark Hardy Giant' and 'Van' on different rootstocks, the present study generally obtained higher values of N, K, and Fe, but lower values of P, Ca, Mg, and Mn, despite the yield ranges reported by Jiménez et al. (2007) were lower than those obtained in this study, which may lead to higher concentrations of nutrients with low to moderate mobility within the plant, such as Ca and Mn (Marschner, 2012). A lower concentration of N and K was expected in this study compared to that reported by Jiménez et al. (2007), given the higher fruit production obtained. However, the soil of this study was in conditions with better chemical fertility, and the fertilization program used was high in K.

Regarding the effect of rootstock on nutrient concentration differences in different cherry cultivars obtained, several authors have reported similar results in other cultivars on some of the rootstocks evaluated (Neilsen and Kappel, 1996; Jiménez et al., 2007; Hrotkó et al., 2014; Kolega et al., 2024). Hrotkó et al. (2014) suggested that rootstock has the ability to generate a selective quantitative absorption of nutrients, as well as to affect their transport within the plant, which affects the nutrient concentration obtained in the leaves. In turn, rootstock may present greater extraction of some nutrients when grown under limiting conditions (Kolega et al., 2024). On the other hand, the most vigorous rootstocks may present nutrient concentrations in leaves below the normal standard for the species, especially when exposed to unfavorable soil conditions (Kolega et al., 2024). Coincidently with what was obtained in this study for 'Santina' on different rootstocks, Hrotkó et al. (2014) reported a higher concentration of K in leaves with 'Gisela 6'. However, these authors also reported the lowest concentration of Ca and Mg in cherry leaves when 'Gisela 6' rootstock was used, which was not obtained in this study. For their part, Jiménez et al. (2007) reported a lower concentration of Mn in the leaves of 'Van' when 'Maxma 14' rootstock was used, which was also obtained in this study for 'Regina'. In this study, a lower concentration of some nutrients would have been expected when using rootstock of greater comparative vigor such as 'Maxma 14', as has been pointed out by Kolega et al. (2024), however this effect was only observed for the concentration of P in 'Santina' on 'Maxma 14' rootstock.

For the effect of cherry cultivar on the same rootstock, differences were found in the concentration of some nutrients in both rootstocks evaluated. Coincidentally, 'Regina' presented the highest concentration of K and the lowest concentration of Fe in both rootstocks, 'Gisela 6' and 'Maxma 14'. Jiménez et al. (2007) also reported higher concentrations of K and a lower concentration of Fe in 'Van' compared to 'Stark Hardy Giant' when they were grown on the 'Maxma 14' rootstock. The greatest number of differences between cultivars evaluated in this study were observed in 'Gisela 6' rootstock, probably due to its lower root exploratory capacity compared to 'Maxma 14', which makes it more dependent on the fertilization used and less dependent on the chemical fertility of the soil within the arable profile. It has been reported that there are nutritional differences between genotypes (Mengel and Kirkby, 2001; Marschner, 2012). The greatest contrasts in nutritional concentration in leaves were obtained between 'Santina' and 'Regina', mainly on 'Gisela 6'. In general, 'Regina' presented lower concentrations of P, Fe and Cu, and higher concentrations of K in leaves than 'Santina', which should be considered for the purposes of nutritional diagnosis and planning of fertilization programs for these cultivars in commercial orchards, mainly when any value obtained is outside the international reference range used for the crop.

CONCLUSIONS

The use of different cherry rootstocks ('Gisela 6' and 'Maxma 14' hybrids) had scarce results in fruit quality attributes but a greater effect on the concentration of nutrients in the leaves of the three sweet cherry cultivars evaluated ('Sweet Aryana', 'Santina', and 'Regina'). In sequence, the use of different cherry cultivars on the same rootstock also had little effect on the quality attributes evaluated, but did affect the concentration of some nutrients in the leaves. These differences in concentration in leaves of the same cultivar on different rootstocks, or of different cultivars on the same rootstock, should be considered for nutritional assessment purposes and in the development and planning of well-designed useful fertilization programs.

Author contributions

Conceptualization: J.H., J.D. Methodology: J.H., J.D. Software: J.H. Validation: J.H. Formal analysis: J.H. Investigation: J.H., J.D. Resources: J.H., J.D. Data curation: J.H. Writing-original draft: J.H. Writing-review & editing: J.H. Visualization: J.H. Supervision: J.H. Project administration: J.H., J.D. Funding acquisition: J.D. All co-authors reviewed the final version and approved the manuscript before submission.

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References

Agrometeorología INIA. 2025. Red agrometeorológica INIA. Instituto de Investigaciones Agropecuarias (INIA), Chile. Available at https://agrometeorologia.cl (accessed 11 October 2025).

Bais, H.P., Park, S.W., Weir, T.L., Callaway, R.M., Vivanco, J.M. 2004. How plants communicate using the underground information superhighway. Trends in Plant Science 9:26-32. doi:10.1016/j.tplants.2003.11.008.

Bianchi, D., Grossi, D., Di Lorenzo, G.S., Ying, Y.Z., Rustioni, L., Brancadoro, L. 2020. Phenotyping of the "G series" *Vitis* hybrids: First screening of the mineral composition. Scientia Horticulturae 264:109155. doi:10.1016/j.scienta.2019.109155.

CIREN. 2025. Catastro frutícola de Chile. Centro de Información de Recursos Naturales (CIREN), Santiago, Chile. Available at https://www.ciren.cl/proyectos/catastros/catastro-fruticola (accessed 11 October 2025).

Dubey, A.K., Sharma, R.M. 2016. Effect of rootstocks on tree growth, yield, quality and leaf mineral composition of lemon (*Citrus limon* (L.) Burm.) Scientia Horticulturae 200:131-136. doi:10.1016/j.scienta.2016.01.013.

Escribano, S., Biasi, W.V., Lerud, R., Slaughter, D.C., Mitcham, E.J. 2017. Non-destructive prediction of soluble solids and dry matter content using NIR spectroscopy and its relationship with sensory quality in sweet cherries. Postharvest Biology and Technology 128:112-120. doi:10.1016/j.postharvbio.2017.01.016.

Facteau, T.J., Chesnut, N.E., Rowe, K.E. 1996. Tree fruit size and yield of 'Bing' sweet cherry as influenced by rootstock, replant area, and training system. Scientia Horticulturae 67:13-26. doi:10.1016/S0304-4238(96)00943-0.

Hirzel, J. 2014. Diagnóstico nutricional y principios de fertilización en frutales y vides. Segunda edición aumentada y corregida. Colección Libros INIA N°31. Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile.

Hirzel, J., Díaz, J. 2025. Relationship between mineral content and fruit quality attributes firmness, size and weight of three sweet cherry cultivars. Chilean Journal of Agricultural Research 85:623-634. doi:10.4067/S0718-58392025000400623.

Hirzel, J., Moya, V., Balbontín, C. 2023. Characterization of fruit quality attributes and nutritional composition of ten blueberry cultivars. Israel Journal of Plant Sciences 70:91-103. doi:10.1163/22238980-bja10073.

Hirzel, J., Muñoz, V., Moya-Elizondo, E., Balbontín, C., Uribe, H. 2024. Nitrogen rate affects fruit production and leaf nutrient concentration of nine pot-grown blueberry cultivars. Journal of Plant Nutrition 48(5):827-838. doi:10.1080/01904167.2024.2415469.

Holzapfel, B.P., Gregson, A., Lewis, J., Falivene, S., Simpson, J.E. 2022. Assessing nutrient status and removal of hazelnut cultivars in Australian climates. Acta Horticulturae 1333:107-114. doi:10.17660/ActaHortic.2022.1333.15.

Hrotkó, K., Magyar, L., Borsos, G., Gyeviki, M. 2014. Rootstock effect on nutrient concentration of sweet cherry leaves. Journal of Plant Nutrition 37:1395-1409. doi:10.1080/01904167.2014.911317.

Hrotkó, K., Németh-Csigai, K., Magyar, L., Ficzek, G. 2023. Growth and productivity of sweet cherry varieties on Hungarian clonal *Prunus mahaleb* (L.) rootstocks. Horticulturae 9:198. doi:10.3390/horticulturae9020198.

Jiménez, S., Garín, A., Albás, E.S., Betrán, J.A., Gogorcena, Y., Moreno, M.A. 2004a. Effect of several rootstocks on the fruit quality of 'Sunburst' sweet cherry. Acta Horticulturae 658:353-358. doi:10.55730/1300-011X.3059.

Jiménez, S., Garín, A., Albás, E.S., Betrán, J.A., Gogorcena, Y., Moreno, M.A. 2004b. Flower and leaf analysis for nutritional prognosis of sweet cherry tree, Influence of different rootstocks. Journal of Plant Nutrition 27:701-712. doi:10.1081/PLN-120030376.

Jiménez, S., Pinochet, J., Gogorcena, Y., Betrán, J.A., Moreno, M.A. 2007. Influence of different vigour cherry rootstocks on leaves and shoots mineral composition. Scientia Horticulturae 112:73-79. doi:10.1016/j.scienta.2006.12.010.

Kolega, Š., Kos, T., Zorica, M., Marcelić, Š., Fruk, G. 2024. Substrate properties, vegetative growth, chlorophyll content Index and leaf mineral content of sweet cherry maiden trees as affected by rootstock and plant growth-promoting rhizobacteria. Sustainability 17:158. doi:10.3390/su17010158.

Kurešová, G., Neumannová, A., Raimanová, I. 2018. Differences in macronutrient uptake by apple rootstocks M9, M7 and MM106. Acta Horticulturae 1217:99-102. doi:10.17660/ActaHortic.2018.1217.12.

Li, M., Guo, Z., Jia, N., Yuan, J., Han, B., Yin, Y., et al. 2019. Evaluation of eight rootstocks on the growth and berry quality of 'Marselan' grapevines. Scientia Horticulturae 248:58-61. doi:10.1016/j.scienta.2018.12.050.

Ložienė, K., Labokas, J., Paškevičius, A., Abrutienė, G., Rimantas, P., Švedienė, J., et al. 2016. Variation in the content of total phenolics, anthocyanins and antimicrobial effects in two fractions of blueberries different cultivars. Botanica Lithuanica 22:78-86. doi:10.1515/botlit-2016-0008.

Mahmud, K.P., Field, S.K., Rogiers, S.Y., Nielsen, S., Guisard, Y., Holzapfel, B.P. 2023. Rootstocks alter the seasonal dynamics and vertical distribution of new root growth of *Vitis vinifera* cv. Shiraz grapevines. Agronomy 13(9):2355. doi:10.3390/agronomy13092355.

Marschner, H. 2012. Mineral nutrition of higher plants. Vol. 89. 651 p. Academic Press, London, UK.

Mengel, K., Kirkby, E.A. 2001. Principles of plant nutrition. Kluwer Academic Publishers, Dordrecht, The Netherland.

Mimmo, T., Pii, Y., Valentinuzzi, F., Astolfi, S., Lehto, N., Robinson, B., et al. 2018. Nutrient availability in the rhizosphere: A review. Acta Horticulturae 1217:13-27. doi:10.17660/ActaHortic.2018.1217.2.

Moreno, M.A., Adrada, R., Aparicio, J., Betrán, J.A. 2001. Performance of 'Sunburst' sweet cherry grafted on different rootstocks. Journal Horticultural Science and Biotechnology 76:167-173. doi:10.1080/14620316.2001.11511345.

Neilsen, G., Kappel, F. 1996. 'Bing' Sweet cherry leaf nutrition is affected by rootstock. HortScience 31:1169-1172. doi:10.21273/HORTSCI.31.7.1169.

Pachnowska, K., Ochmian, I. 2018. Influence of rootstock on nutrients and heavy metals in leaves and berries of the vine cultivar 'Regent' grown in North-Western Poland. Journal of Applied Botany and Food Quality 91:180-186. doi:10.5073/JABFQ.2018.091.024.

Pino, S., Palma, M., Sepúlveda, Á., Sánchez-Contreras, J., Moya, M., Yuri, J.A. 2023. Effect of rain cover on tree physiology and fruit condition and quality of 'Rainier', 'Bing' and 'Sweetheart' sweet cherry trees. Horticulturae 9:109. doi:10.3390/horticulturae9010109.

Quiroz, M.P., Blanco, V., Zoffoli, J.P., Ayala, M. 2023. Study of mineral composition and quality of fruit using vascular restrictions in branches of sweet cherry. Plants 12:1922. doi:10.3390/plants12101922.

Sadzawka, A., Carrasco, M.A., Demanet, R., Flores, H., Grez, R., Mora, M.L. 2007. Métodos de análisis de tejidos vegetales. Serie Actas INIA N°40. 2ª ed. Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile.

Sadzawka, A., Carrasco, M.A., Grez, R., Mora, M., Flores, H., Neaman, A. 2006. Métodos de análisis recomendados para los suelos de Chile. Revisión 2006. Serie Actas INIA N°34. Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile.

Salvadores, Y., Bastías, R.M. 2023. Environmental factors and physiological responses of sweet cherry production under protective cover systems: A review. Chilean Journal of Agricultural Research 83:484-498. doi:10.4067/S0718-58392023000400484.

Sarkhosh, A., Shahkoomahally, S., Asis, C., McConchie, C. 2021. Influence of rootstocks on scion leaf mineral content in mango tree (*Mangifera indica* L.) Horticulture, Environment, and Biotechnology 62:725-735. doi:10.1007/s13580-021-00355-w.

Scofield, C., Stanley, J., Schurmann, M., Hutton, M., Breen, K., Tustin, D.S. 2022. The relationship between light availability and fruit quality of sweet cherries grown on narrow row, planar canopy systems. Acta Horticulturae 1346:279-286. doi:10.17660/ActaHortic.2022.1346.35.

Shahkoomahally, S., Chaparro, J., Beckman, T., Sarkhosh, A. 2020. Influence of rootstocks on leaf mineral content in the subtropical peach cv. UFSun. HortScience 55(4):496-502. doi:10.21273/HORTSCI14626-19.

USDA. 2014. Keys to soil taxonomy. 12th ed. United States Department of Agriculture (USDA), Washington D.C., USA.

Yahmed, J.B., Ghrab, M., Benmoussa, H., Mimoun, M.B. 2020. Nutritional status of stone fruit trees on dwarfing and vigorous rootstocks under warm Mediterranean conditions. Acta Horticulturae 1281:339-345. doi:10.17660/ActaHortic.2020.1281.45.