Milenković K *et al.* (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 4, Article number 13959
DOI:10.15835/nbha52413959
Research Article

Elemental composition of *Rosa* L. fruits: Optimization and validation procedure of an ICP AES method

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Abstract

This study aimed to determine element profile of the rose species originating from Serbia. With respect to that, 52 fruit samples of six wild *Rosa* L. species (*R. agrestis* Savi, *R. canina* L., *R. corymbifera* Borkh., *R. dumalis* Bechst, *R. myriacantha* DC., and *R. spinosissima* L.) were assayed for element contents, after the optimization and validation of the inductively coupled plasma atomic emission spectrometric (ICP AES) method. The analytical performance of axial and radial views was evaluated using the Mg(II)/Mg(I) line ratio. Robust plasma conditions were achieved at the radio frequency (RF) power of 1150 W and nebulization gas flow (NBF) rate of 0.5 L min^{-1}. The matrix effect was below 13% and the recovery, using certified reference material (LGC7162 strawberry leaves), was between 85.7% and 109% with the exception of Fe (76.4%). *Rosa* fruits were found to be richer in minerals such as K (4710-9850 mg kg^{-1}), Ca (2650-5140 mg kg^{-1}), P (532-1610 mg kg^{-1}), Mg (402-1000 mg kg^{-1}), Na (11.2-39.1 mg kg^{-1}), Mn (6.8-64 mg kg^{-1}), Fe (9.9-30 mg kg^{-1}), and Zn (6.03-17.5 mg kg^{-1}). Also, the fruits were found to have a higher content of Si (15.2-51.6 mg kg^{-1}). Regarding toxic elements, the obtained results for Pb (0.035-0.0121 mg kg^{-1}) and Cd (0.0027-0.0492 mg kg^{-1}) are in accordance with the maximum levels in fruits established set by the Commission Regulation. The results of the present study indicate that the investigated *Rosa* species contain various minerals and could contribute to the daily dietary requirements for K, Ca, Mg, P, Na, Mn, Cu, Zn, and Fe, as well as be used in food and the food additive industry.

Keywords: ICP AES; macro elements; microelements; nutrition value; rosehip; validation

Received: 20 Jun 2024. Received in revised form: 08 Oct 2024. Accepted: 25 Oct 2024. Published online: 06 Nov 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

The genus *Rosa* L. (eng. Rose) includes many species that grow in natural habitats or are cultivated in Europe, the Middle East, and North America (Hummer and Janick, 2009). The fruits of rose contain many different groups of biologically active compounds, which are widely recognized as functional compounds with desirable health-promoting properties. Because of that, rose fruits have been used as a raw material or in the form of preparations in the medicine, pharmaceutical, and food industries, as well as in the chemical industry, for the green synthesis of new types of nanomaterials (Nađpal *et al.*, 2016; Jiménez *et al.*, 2017; Zhou *et al.*, 2023). Its fruits can be consumed either fresh or processed. Due to their biological activities, *Rosa* species fruits have been used as antioxidant, anti-inflammatory, anti-diabetic, antimicrobial, anticancer, analgesic, and cardioprotective agents (Mármol *et al.*, 2017; Koczka *et al.*, 2018; Langhans, 2018). The fruits of *Rosa canina*, the most popular *Rosa* species, is widely used in European countries in the food industry to produce marmalade, jam, syrup, compotes, wine, desserts, cookies, cakes, etc. Similarly, the fruits of *Rosa rugosa*, and *Rosa arvensis* are commonly used in jams, juices, preserves, jelly, and wine (Nađpal *et al.*, 2016). Also, in China, the fruits of *Rosa roxburghii* are processed and consumed in wine, juice, cake, yogurt, preserved fruit, and canned products (He *et al.*, 2016). Drying is one of the widely used methods of fruit preservation. Drying processes influence changes in phytochemical composition and reduction of antioxidant activity. Despite this, dried rosehip is a rich source of bioactive compounds with significant antioxidant activity, which could contribute to the synergistic effect of vitamin C, phenolics, and flavonoids (Nađpal *et al.*, 2016). The weight of a rosehip and its seed ranges from 1.25 g to 3.25 g with 71% constituting the pericarp and approximately 29% constituting the seed (Stoian-Dod *et al.*, 2023). Several studies, cited in the review work by Zhou *et al.* (2023), used rosehips as raw materials to generate functional foods, such as balsamic vinegar and fruit wines. Furthermore, rosehip vinegar was the most effective product for inhibiting pathogenic bacteria in beef and improving both safety and quality. Also, the addition of coating with rosehip oil can reduce color change, total acidity, and the production of ethylene in ripe fruits and extend the storage life of fruits, while the addition of rosehip powder can increase quail egg weight without any negative effects on production parameters. The fruit extract of *Rosa canina* can be considered an effective green corrosion inhibitor also (Zhou *et al.*, 2023).

Rosa species fruits are rich in vitamin C and contain vitamins A, B1, B2, B6, D, E, and K. Among the active ingredients, *Rosa* fruits contain carotenoids, sugars, mainly glucose and fructose, fatty acids (linoleic acid, α-linolenic acid, and oleic acid), and phenolic compounds (flavonoids, phenolic acids, tannins, and anthocyanins) (Ercisli, 2007; Rosu *et al.*, 2011; Najda and Buczkowska, 2013; Demir *et al.*, 2014; Nađpal *et al.*, 2016; Bhave *et al.*, 2017; Elmastas *et al.*, 2017; Jiménez *et al.*, 2017; Fascella *et al.*, 2019; Liaudanskas *et al.*, 2021; Fayaz *et al.*, 2024). Also, rosehips contain minerals, mainly P, K, Ca, Mg, Mn, and Zn (He *et al.*, 2016; Popović-Djordjević *et al.*, 2021 Benković-Lačić *et al.*, 2022; Sun *et al.*, 2022). Minerals play a significant role in determining the nutritional value of fruit as well as fruit storage quality (Lechaudel *et al.*, 2005). They are necessary for normal cellular functions because they protect the human body (Gharibzahedi and Jafari, 2017). On the other hand, long-term exposure of the human body to toxic metals taken from foods and beverages may cause significant health risks due to the absence of a mechanism for their removal from the body (Scutarașu and Trincă, 2023). Inductively coupled plasma atomic emission spectrometry (ICP AES) and inductively coupled plasma-mass spectrometry (ICP-MS) are commonly used techniques for determining elements (He *et al.*, 2016; Zeiner and Juranović Cindrić, 2018; Popović-Djordjević *et al.*, 2021; Benković-Lačić *et al.*, 2022; Sun *et al.*, 2022).

The literature includes many quantitative and qualitative descriptions of the phenolic profile of rose fruits (Ercisli, 2007; Rosu *et al.*, 2011; Najda and Buczkowska, 2013; Demir *et al.*, 2014; Bhave *et al.*, 2017; Elmastas *et al.*, 2017; Fascella *et al.*, 2019; Liaudanskas *et al.*, 2021). Additionally, or some studies tried to determine whether the harvest period had an impact on obtaining the maximum pharmacological effects of rose petals (Cendrowski *et al.*, 2017a; Cendrowski *et al.*, 2017b; Kieliszek *et al.*, 2018). Also, many results have been published on the chemical composition of *Rosa canina* (Demir and Ozcan, 2001; Ercisli, 2007; Sekeroglu *et al.*, 2008; Kazaz *et al.*, 2009; Levent *et al.*, 2010; Kizil *et al.*, 2018; Paunović *et al.*, 2019; Igual *et al.*, 2022; Al-Juhaimi *et al.*, 2023; Peña *et al.*, 2023), but there is no data based on the optimization and validation of an ICP AES method. The aim of this study was to develop and optimize the ICP AES method, which is a fast and effective quantitative technique for multielement analysis. The identification and quantification of minerals, as well as toxic elements, in the 52 fruit samples of six wild *Rosa* species (*Rosa agrestis* Savi, *Rosa canina* L., *Rosa corymbifera* Borkh., *Rosa dumalis* Bechst., *Rosa myriacantha* DC., and *Rosa spinosissima* L.) play a significant role in their use in the food industry and pharmacy.

Materials and Methods

Instrumentation

The inductively coupled plasma atomic emission spectrometer (Thermo Scientific, Cambridge, UK) was from the iCAP 6000 series. It was equipped with the sample introduction system, spray concentric nebulizer, and charge injection device (CID) detector. Argon, with a purity of 5.0, was used as a plasma gas. Alpha 1-2 LDplus freeze-dryer (CHRIST) was used for lyophilization of samples, and ETHOS EASY microwave digestion system (Milestone, Bergamo, Italy) was used for sample preparation. Deionized water was obtained using the MicroMed high purity water system (TKA Wasseraufbereitungssysteme GmbH).

Chemicals

The 65% nitric acid (Merck, Germany) and 30% hydrogen peroxide (Fluka, Switzerland) were used for sample preparation. Multielement standard solutions III (Ca (1000 ppm), Mg (400 ppm), K (200 ppm) and Na (1000 ppm)), IV (Be, Cd, Co, and Mn (10 ppm); Cr, Cu, and Ni (20 ppm); Al, As, Ba, Pb, and V (40 ppm); B, Fe, Se, Tl, Zn (100 ppm)) and individual standard solutions of Si, P, and Hg (1000 ppm) (TraceCERT, Fluka, Analytical, Switzerland) were used for ICP analysis. The MgII/MgI ratios were measured by using solutions containing 5 mg/L of Mg in water. Certified reference material (CRM), strawberry leaves (LGC7162), was used for the quality control of element determination. All plastic containers were rinsed with 20% v/v HNO_3 and washed with ultra-pure (0.05 μS cm^{-1}) deionized water before use.

Samples

Fifty-two fruit samples of six wild *Rosa* species: *R. myriacantha* (S1-S4), *R. dumalis* (S5-S8, S21-S24, S29-S32, S33-S36, S45-S48), *R. corymbifera* (S9-S12, S17-S20), *R. agrestis* (S13-S16, S49-S52), *R. spinosissima* L. (S25-S28), and *R. canina* (S37-S40, S41-S44) were collected during October 2022 and 2023 in Serbia. Due to the rugged terrain, four points were chosen at the location, with a minimum of 500 m distance among the selected rosehip bushes. An amount of nearly 300-500 g of rosehip was collected at every point. The fruit samples were stored at -20 °C until analysis. The specimens were deposited at the Herbarium of the Department of Biology and Ecology, Faculty of Sciences and Mathematics, University of Niš under the voucher number provided in Table 1.

Table 1. Characteristics of sampling localities of studied *Rosa* species

Sample	Species	Locality	Latitude(N)	Longitude(E)	Altitude (m a.s.l.)	Voucher No.
S1-S4	*R. myriacantha*	Seličevica, Donje Vlase	43°15'44.59"	21°54'51.44"	350	18602
S5-S8	*R. dumalis*	Gorica, Niš	43°18'19.45"	21°55'2.79"	230	18603
S21-S24		Vlasotince	42°57'56.39"	22° 7'25.08"	264	18604
S29-S32		Krupac, Pirot	43° 6'41.95"	22°40'29.13"	396	18605
S33-S36		Čiflik, Bela Palanka	43°13'27.56"	22°24'19.87"	331	18606
S45-S48		Smilovci, Dimitrovgrad	43° 4'52.25"	22°51'23.79"	734	18607
S9-S12	*R. corymbifera*	Crna Trava	42°48'38.02"	22°17'53.00"	980	18608
S17-S20		Vlasina, Vlasina Rid	42°44'25.37"	22°19'51.76"	1230	18609
S13-S16	*R. agrestis*	Seličevica, Donje Vlase	43°16'33.73"	21°54'42.06"	395	18610
S49-S52		Kamenički vis, Gornji Matejevac	43°21'38.74"	21°58'8.35"	349	18611
S25-S28	*R. spinosissima*	Rtanj	43°43'30.16"	21°55'16.16"	684	18612
S37-S40	*R. canina*	Senokos, Dimitrovgrad	43° 8'35.73"	22°55'27.27"	938	18613
S41-S48		Visočka Ržana, Pirot	43° 9'26.45"	22°48'59.04"	741	18614

Experimental procedure

Approximately 30-40 g of frozen fruit samples were dried by lyophilization. After complete drying, the samples were ground into a homogenized powder using a grinding mill. A closed type of Teflon digestion vessel was used for acid sample digestion. 0.35 g of each sample was accurately weighed directly into the digestion vessel. Then, 5 mL HNO_3 (conc.) and 3 mL H_2O_2 were added and digested at 190 °C under 1800 W. The mineralized samples were diluted to 25 mL with deionized water. Sample blanks and the CRM were prepared in the same way as the samples.

Operating instrument and plasma conditions

Before the element analyses were performed, it was necessary to obtain ICP operating conditions that could allow some possible changes in the nature or concentration of the matrix components without a significant change in the analyte signals. The plasma generated under those conditions is referred to as robust. Todoli and Mermet (1988), Mermet (1991), and Brenner and Zander (2000) showed that robust ICP conditions must be used to minimize matrix effects due to easily ionized elements, alkali earths, and mineral acids. According to the literature (Todoli and Mermet, 1988; Mermet, 1991; Brenner and Zander, 2000), Mg II (280.270 nm)/Mg I (285.213 nm) line emission ratio (Mg II/Mg I) higher than 10 corresponds to a local thermodynamic equilibrium in the plasma. In the present study, the effect of the radio frequency (RF) power and nebulization gas (argon) flow (NBF) rate on the Mg II/Mg I ratio was studied. Using a 27.12 MHz ICP, the RF power varied from 750 W to 1350 W with a step of 200 W, and the NBF rate was increased from 0.5 L min^{-1} to 1.5 L min^{-1} in intervals of 0.5 L min^{-1}. The optimum RF power and NBF rate were found under the following operating conditions of the instrument: flush pump rate 100 rpm, analysis pump rate 50 rpm, coolant gas flow rate 12 L min^{-1}, auxiliary gas flow rate 0.5 L min^{-1}, sample flow 0.5 mL min^{-1}, and sample uptake delay 30 s. By choosing the appropriate values of the RF power and NBF rate, it is possible to reduce the deviation of the analytical signal caused by the matrix of the samples. Also, as the plasma observation mode, axial or radial, may influence the magnitude of the matrix effect and the signal-to background ratio, both observation modes were considered.

Matrix effect (ME) and selection of analytical lines

For the matrix effect evaluation, the standard addition method was applied (Andrade *et al*., 2013). The slope of external calibration curves established from multi-elemental standards ($\text{slope}_{\text{cal}}$) was compared with the slope of standard addition curves ($\text{slope}_{\text{sam}}$) obtained from the *Rosa* species fruit samples spiked with calibration standards (using four calibration points: no analyte added, and three analyte additions with increasing concentrations), $\text{slope}_{\text{cal}}/\text{slope}_{\text{sam}}$. The *Rosa* samples were spiked at three levels with the addition of 12.5, 50, and 200 μg L^{-1} for Al, As, Ba, Pb, and V; 31.25, 125, and 500 μg L^{-1} for B, Fe, Se, Si, Zn, Hg, and Tl; 6.25, 25, and 100 μg L^{-1} for Cr, Cu, and Ni; 3.125, 12.5 and 50 μg L^{-1} for Be, Cd, Co, and Mn.

Analytic emission lines were evaluated according to the matrix effect as well as according to the following criteria: low interferences, high intensities, and signal-to-background ratios, keeping in mind that higher values of signal-to-background ratio and ratio $\text{slope}_{\text{cal}}/\text{slope}_{\text{sam}} \sim 1$ correspond to a better limit of detection, while lower values of the matrix effect produce higher accuracy due to interferences. Interferences in both axial and radial view modes were investigated. To uncover unexpected spectral and non-spectral interferences, four emission lines were chosen for each element.

Validation procedure

The validation procedure includes the selection of analytical wavelengths, linearity, precision, accuracy, and the detection and quantification limits of the studied elements (Gonzalez and Herrador, 2007). The linearity of the calibration curve on each analytical emission line was checked by the determination coefficient (R^2) and was accepted if $R^2 < 0.999$. The limit of detection (LOD) and limit of quantification (LOQ) were calculated as three and ten times the standard deviation of the ten independent prepared blank solutions, respectively. The precision was expressed as the relative standard deviation (%RSD) of three independent analyses, and the accuracy of the method was evaluated using certified reference material, strawberry leaves (LGC7162).

Results and Discussion

Operating instrument and plasma conditions

The effect of the RF power on the Mg(II)/Mg(I) ratio was evaluated by fixing the nebulization gas-flow rate at 0.5 L min^{-1}. The applied power varied from 750 W to 1350 W with a step of 200 W. Plasma robustness was improved in both views (axial and radial) when increasing the RF power (Figure 1). At a RF power of 1150 W, the standard deviation of a measurement was lower than at 1350 W, and this power was selected for further proceedings.

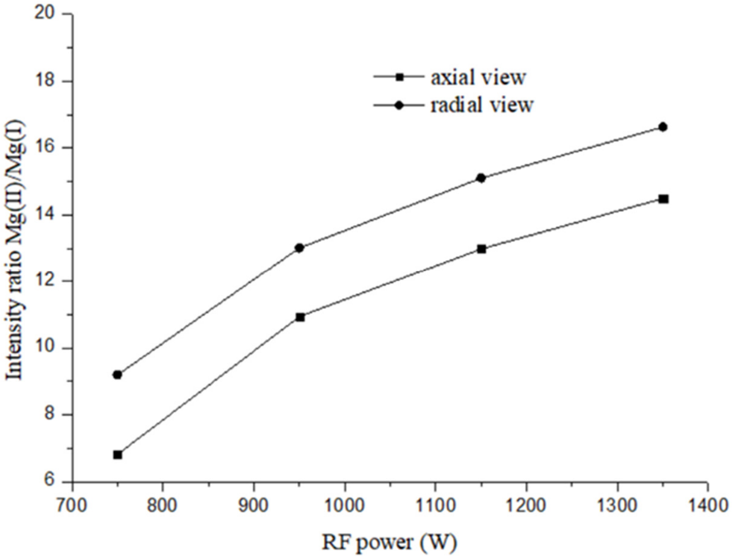

Figure 1. Effect of RF power on Mg(II)/Mg(I) ratios

The effect of the NBF rate on the Mg(II)/Mg(I) ratio was evaluated by fixing the RF power at 1150 W. The measurement was carried out in the 0.5-1.5 L min^{-1} range in intervals of 0.5 L min^{-1}. The highest MgII/MgI ratio was reached at the nebulization gas flow-rate at 0.5 L min^{-1} (Figure 2). Using a NBF rate higher than 0.5 L min^{-1}, Mg(II)/Mg(I) ratios were decreased for both views.

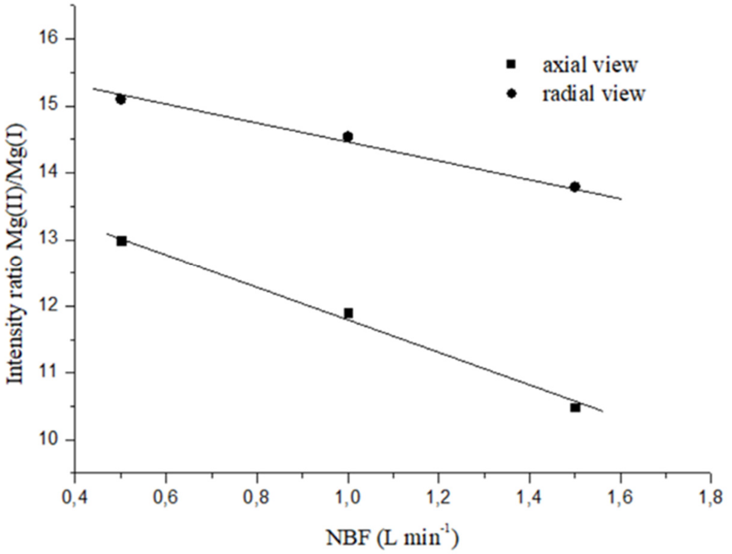

Figure 2. Effect of nebulization gas flow-rate power on Mg(II)/Mg(I) ratios (RF=1150 W)

The obtained results are in agreement with the literature data (Todoli and Mermet, 1988; Mermet, 1991; Brenner and Zander, 2000; Silva *et al.*, 2003), when plasma was operated at lower nebulization gas flow rates and a higher applied power.

Matrix effect (ME) and selection of analytical lines

Based on the evaluation of the matrix effect, high signal-to-background ratios at emission lines, and spectral interferences, the selection of analytical emission lines in both axial and radial plasma viewing modes is shown in Table 2. The slopes of both kinds of lines were statistically comparable, and the matrix effect was ≤ 13%, which indicates that the method of evaluation of the matrix effect generates reliable results.

Validation procedure

The linearity was obtained for the selected emission lines of the investigated elements over three days, and determination coefficients higher than 0.999 were obtained (Table 2). Also, the standard deviation of the slope, calculated according to the formula: $s_b(\%) = (s_b/b)\times 100$ (s_b - standard deviation of the slope and b - slope), was lower than 8% for all calibration lines (Bratinova *et al.*, 2009).

The obtained detection limits are comparable and lower to others obtained for metals in *Rosa* samples (Sekeroglu *et al.*, 2008; Igual *et al.*, 2022) or higher for Na (Igual *et al.*, 2022).

Table 2. Selected analytical emission wavelengths and characteristics of the ICP AES method

Element	**λ (nm)**	**Plasma view mode**	***LOD (ng g^{-1})**	***LOQ (ng g^{-1})**	***R^2**	***ME (%)**	**Linear range (µg g^{-1})**
Al	308.215	Axial	264	880	0.99940	3-13	0-0.4
As	189.042	Axial	181	605	1	6-11	0-0.4
B	249.678	Axial	109	363	1	4-11	0-1
Ba	455.403	Axial	4.9	16	0.99940	1-13	0-0.4
Be	313.042	Axial	2.6	8.6	0.99920	3-11	0-0.1
Ca	393.366	radial	12	41	0.99900	***	0-100
Cd	226.502	Axial	15	50	0.99960	1-11	0-0.1
Co	228.616	Axial	15	61	0.99980	1-9	0-0.1
Cr	283.563	Axial	46	154	0.99980	8-13	0-0.2
Cu	324.754	Axial	49	163	0.99940	6-10	0-0.2
Fe	259.940	Axial	38	126	0.99960	6-10	0-1
Hg	194.227	Axial	28	95	0.99960	4-12	0-0.5
K	766.490	radial	4.8**	16**	0.99900	***	0-10
Mg	279.553	radial	20	68	0.99940	***	0-50
Mn	257.611	Axial	9.1	30	0.99960	1-10	0-0.1
Na	589.592	radial	0.79**	2.6**	0.99920	***	0-50
Ni	221.647	Axial	24	79	0.99980	1-13	0-0.2
P	213.618	radial	241	803	1	***	0-100
Pb	220.353	Axial	116	387	0.99960	5-13	0-0.4
Se	196.090	Axial	0.31**	1.0**	0.99960	10-13	0-1
Si	251.611	Axial	101	336	0.99960	4-9	0-1
Tl	276.787	Axial	189	632	0.99920	3-11	0-1
V	309.311	Axial	32	107	0.99920	1-11	0-0.4
Zn	213.856	Axial	10.4	35	0.99960	2-10	0-0.25

*LOD-limit of detection; LOQ-limit of quantification; R^2-determination coefficient; ME-matrix effect; **µg/g; ***It was not necessary to optimize slope$_{cal}$/slope$_{sam}$ and matrix effect for the major elements Ca, K, Mg, Na and P because of their relatively high concentration in the samples

To evaluate if the element quantification method in the investigated samples is accurate, the CRM (strawberry leaves) was used. The recovery, between 85.7% and 109%, indicated that the values obtained approached the true values satisfactorily (Table 3). Also, in this way, the efficiency of the microwave digestion process was verified. A low recovery value was obtained only for Fe (76.4%), which was determined only by one method (Isotope Dilution Mass Spectrometry (IDMS)) in a single laboratory. Also, the obtained results (except for Fe) are in accordance with the published acceptable recovery percentages as a function of the analyte concentration (Gonzalez and Herrador, 2007).

The precision of the determination of element concentrations was in the interval of 2.5%-4.8% (Table 3). According to the Horwitz function (Horwitz, 1982; Wood, 1999; Thompson, 2004) and to the Association of Official Agricultural Chemists (AOAC) Peer Verified Methods (PVM) program (AOAC International, 2000) on the analyte level (Gonzalez and Herrador, 2007), the accuracy and precision of the method give satisfactory results, showing that the proposed method is robust and comparable with a reference value.

Table 3. Accuracy and precision of the proposed method using certified reference material

Element	**Accuracy**			**Precision RSD (%)*****
	Certified values* (mg kg^{-1})	**Found values* (mg kg^{-1})**	**Recovery (%)****	
As	0.28±0.07	0.24±0.02	85.7	4.8
Ba	107±10	100±9	93.5	4.2
Ca	1.53±0.07	1.48±0.09	96.7	3.4
Cd	0.17±0.04	0.18±0.01	105.9	3.3
Co	0.47±0.11	0.44±0.03	93.6	3.9
Cr	2.15±0.34	1.93±0.14	89.8	4.2
Cu	10	10.9±0.9	109	4.6
Fe	818±48	625±39	76.4	3.6
K	1.96±0.10	1.89±0.10	96.4	3.2
Mg	0.377±0.017	0.365±0.015	96.8	2.5
Mn	171±10	164±9	95.9	2.9
Ni	2.6±0.7	2.8±0.2	107.7	4.1
P	0.260±0.023	0.248±0.017	95.4	3.8
Pb	1.8±0.4	1.6±0.1	88.9	3.6
Zn	24±5	21±1	91.7	2.6

*c_{sr}±u, $u = \frac{3\times s}{\sqrt{n}}$, u-standard uncertainty, n=3

**[1-(found value-certified value)/certified value] ×100%

***RSD=s/c_{sr}×100%

Certified concentration values for Ca, K, Mg and P are given in g/100g; for Cu is given indicative value (has not been certified)

Macro and microelements determination

The quantification of macro and microelements is important because there has been an increase in their consumption as functional food. The content (mean value with their SDs for n=3) of macro and microelements are given in Table 4 and Table 5, respectively.

Table 4. Content (c_{sr} ± SD, mg kg^{-1}) of macroelements in studied *Rosa* species fruits

Sample	Na	RSD (%)	K	RSD (%)	Ca	RSD (%)	Mg	RSD (%)	P	RSD (%)
1	39±1	2.56	8210±120	1.46	4630±60	1.30	837±9	1.08	1310±20	1.53
2	19.5±0.8	4.10	8690±170	1.96	4110±60	1.46	804±8	1.00	1294±20	1.55
3	18.3±0.7	3.83	8480±140	1.65	4015±60	1.49	788±8	1.01	1266±30	2.37
4	26.1±0.5	1.92	8900±200	2.25	4030±80	1.99	740±20	2.70	1170±20	1.71
5	17.1±0.7	4.09	7590±80	1.05	4500±50	1.11	821±9	1.10	1275±30	2.36
6	18.3±0.6	3.28	9200±200	2.17	4750±60	1.26	970±20	2.06	1551±40	2.58
7	19.1±0.3	1.57	9200±200	2.17	4900±70	1.43	980±20	2.04	1407±30	2.13
8	20.1±0.2	1.00	8800±200	2.27	4800±60	1.25	960±20	2.08	1591±30	1.89
9	16.9±0.2	1.18	8800±200	2.27	4180±60	1.44	850±20	2.35	554±10	1.81
10	15.4±0.3	1.95	9850±270	2.74	3510±40	1.14	707±8	1.13	675±14	2.07
11	17.4±0.6	3.45	8570±170	1.98	3920±40	1.02	756±8	1.06	632±14	2.21
12	17.8±0.7	3.93	9000±250	2.78	3790±40	1.06	772±9	1.17	579±10	1.72
13	15.2±0.6	3.95	7280±180	2.47	5130±60	1.17	750±20	2.67	1563±35	2.24
14	16.3±0.4	2.45	7600±200	2.63	5500±60	1.09	790±20	2.53	1512±30	1.98
15	15.6±0.2	1.28	6540±160	2.45	5370±60	1.12	806±10	1.24	1543±35	2.26
16	15.1±0.3	1.99	5450±80	1.47	5000±60	1.20	700±20	2.86	1449±30	2.07
17	14.3±0.6	4.20	7010±140	2.00	2900±30	1.03	509±7	1.38	631±12	1.90
18	13.8±0.6	4.35	6900±100	1.45	2650±30	1.13	461±7	1.52	532±10	2.26
19	14.1±0.6	4.26	7590±150	1.98	2950±30	1.02	502±5	1.00	579±10	1.73
20	13.9±0.3	2.16	7500±140	1.87	2840±40	1.41	507±6	1.18	651±12	1.84
21	12.7±0.6	4.72	7200±100	1.39	2700±40	1.48	920±20	2.17	1360±20	1.47
22	13.3±0.6	4.51	6760±80	1.18	2660±40	1.50	900±20	2.22	1257±20	1.59
23	12.4±0.4	3.23	8000±200	2.50	2920±60	2.05	1000±20	2.00	1610±20	1.24
24	11.6±0.2	1.72	6730±90	1.34	2530±30	1.19	861±10	1.16	1380±20	1.45
25	11.8±0.3	2.54	4710±80	1.70	3190±50	1.57	419±6	1.43	662±15	2.26
26	11.6±0.4	3.45	4890±80	1.64	3530±70	1.98	444±6	1.35	654±7	1.07
27	11.8±0.2	1.69	5402±90	1.67	3840±50	1.30	488±7	1.43	692±20	2.89
28	11.2±0.4	3.57	4400±50	1.14	3490±50	1.43	402±6	1.49	670±20	2.99
29	19.7±0.5	2.54	5520±60	1.09	2890±30	1.04	419±6	1.43	720±20	2.78
30	18.5±0.2	1.08	5200±60	1.15	3000±30	1.00	415±6	1.45	669±15	2.24
31	15.3±0.5	3.27	7300±100	1.37	3460±40	1.16	500±10	2.00	920±20	2.17
32	14.6±0.4	2.74	6800±200	2.94	3700±50	1.35	490±20	4.08	876±20	2.28
33	14.8±0.4	2.70	6650±130	1.95	3610±90	2.49	520±10	1.92	794±10	1.26
34	15.6±0.3	1.92	6600±200	3.03	3110±40	1.29	460±10	2.17	808±10	1.24
35	13.1±0.6	4.58	6550±160	2.44	2830±30	1.07	419±5	1.19	914±20	2.19
36	12.8±0.5	3.91	6530±80	1.23	3570±50	1.40	490±9	1.84	930±20	2.15
37	12.3±0.3	2.44	6020±130	2.16	3550±50	1.41	470±5	1.06	1065±25	2.35
38	11.8±0.4	3.39	5900±200	3.39	3540±40	1.13	420±5	1.19	980±20	2.04
39	12.8±0.2	1.56	6460±140	2.17	4150±50	1.20	560±8	1.43	1106±20	1.81
40	13.2±0.6	4.55	6310±150	2.38	3870±90	2.33	507±7	1.38	1112±20	1.80
41	12.3±0.5	4.07	6680±150	2.24	3950±50	1.27	519±7	1.35	1122±20	1.78
42	12.2±0.5	4.10	6120±130	2.12	3660±70	1.91	461±5	1.08	1030±20	1.94
43	13.4±0.5	3.73	7330±130	1.77	4340±60	1.38	564±7	1.24	1236±20	1.62
44	12.5±0.4	3.20	6750±140	2.07	3400±40	1.18	457±5	1.09	1158±20	1.73
45	23.7±0.5	2.11	6900±100	1.45	3410±60	1.76	509±8	1.57	954±20	2.10
46	12.9±0.5	3.88	6750±140	2.07	3420±40	1.17	423±5	1.18	785±15	1.91
47	13.7±0.2	1.46	6640±150	2.26	3750±50	1.33	505±7	1.39	913±20	2.19
48	15.2±0.4	2.63	7400±200	2.70	3650±60	1.64	490±6	1.22	796±15	1.88

49	13.4±0.6	4.48	5002±70	1.40	5330±60	1.13	698±7	1.00	1156±20	1.73
50	11.7±0.3	2.56	5530±80	1.45	5140±60	1.17	735±8	1.09	1241±20	1.61
51	12.2±0.2	1.64	5690±90	1.58	5200±60	1.16	695±7	1.01	1206±20	1.66
52	12.3±0.4	3.25	5220±60	1.15	4590±50	1.09	619±8	1.29	1153±20	1.73

Table 5. Content (c_{sr} ± SD, mg kg^{-1}) of microelements in studied *Rosa* species fruits

Sample	Zn	RSD (%)	Fe	RSD (%)	Cu	RSD (%)	Mn	RSD (%)	Si	RSD (%)
1	9.1±0.2	2.2	30±1	3.33	7.4±0.1	1.35	64±1	1.56	52±1	1.92
2	9.6±0.2	2.08	23.7±0.2	0.84	7.1±0.1	1.41	55±1	1.82	41±1	2.44
3	8.6±0.1	1.16	25.7±0.5	1.95	5.63±0.07	1.24	59±2	3.39	46±1	2.17
4	30.9±0.4	1.29	21.9±0.3	1.37	7.32±0.08	1.09	57±1	1.75	40±1	2.50
5	10.6±0.2	1.89	13.0±0.2	1.54	3.67±0.06	1.63	84±2	2.38	17.6±0.3	1.7
6	10.3±0.2	1.94	22.1±0.3	1.36	5.5±0.2	3.64	80±1	1.25	24.8±0.3	1.21
7	11.8±0.1	0.85	24.9±0.3	1.2	4.55±0.05	1.10	71±1	1.41	29.0±0.4	1.38
8	12.7±0.2	1.57	18.9±0.2	1.06	5.87±0.07	1.19	100±2	2.00	23.8±0.3	1.26
9	9.9±0.2	2.02	16.6±0.2	1.20	4.22±0.05	1.18	50±1	2.00	21.1±0.3	1.42
10	11.9±0.2	1.68	19.4±0.2	1.03	6.47±0.07	1.08	33±1	3.03	20.0±0.3	1.50
11	10.4±0.1	0.96	17.3±0.2	1.16	4.96±0.08	1.61	42±1	2.38	22.1±0.3	1.36
12	9.5±0.1	1.05	14.5±0.2	1.38	5.35±0.07	1.31	31±1	3.22	19.3±0.3	1.55
13	8.8±0.1	1.14	21.3±0.3	1.41	5.39±0.07	1.30	7.6±0.1	1.32	29.4±0.4	1.36
14	9.9±0.1	1.01	16.1±0.08	0.5	6.65±0.08	1.20	8.9±0.1	1.12	30.0±0.4	1.33
15	11.2±0.2	1.79	14.9±0.2	1.34	5.81±0.07	1.20	8.1±0.2	2.47	44±1	2.27
16	9.8±0.1	1.02	34±1	2.94	12.0±0.2	1.67	8.2±0.2	2.44	26.9±0.3	1.12
17	6.4±0.1	1.56	14.5±0.3	2.07	4.94±0.05	1.01	11.0±0.2	1.82	18.2±0.3	1.65
18	7.9±0.1	1.27	14.0±0.4	2.86	3.8±0.1	2.63	10.6±0.3	2.83	16.1±0.3	1.86
19	10.3±0.2	1.94	13.8±0.2	1.45	5.00±0.06	1.20	9.3±0.2	2.15	19.0±0.3	1.58
20	8.9±0.1	1.12	16.9±0.2	1.18	3.90±0.04	1.03	9.5±0.2	2.11	15.2±0.4	2.63
21	10.9±0.2	1.83	13.1±0.2	1.53	5.13±0.07	1.36	62±1	1.61	30.4±0.2	0.66
22	17.5±0.2	1.14	13.6±0.2	1.47	4.05±0.05	1.23	59±1	1.69	25.7±0.2	0.78
23	23.9±0.3	1.26	11.7±0.1	0.85	5.51±0.06	1.09	94±1	1.06	30.4±0.3	0.99
24	10.1±0.2	1.98	14.3±0.2	1.4	4.56±0.05	1.10	76±1	1.32	24.7±0.2	0.81
25	8.4±0.1	1.19	26.3±0.4	1.52	5.05±0.07	1.39	17.6±0.4	2.27	46±1	2.17
26	8.3±0.1	1.20	23.0±0.4	1.74	4.26±0.07	1.64	20.7±0.3	1.45	34.6±0.4	1.16
27	11.4±0.1	0.87	24.0±0.2	0.83	5.56±0.07	1.26	21.9±0.2	0.91	34.2±0.6	1.75
28	18.2±0.4	2.2	24.5±0.2	0.82	4.44±0.06	1.35	18.5±0.2	1.08	40±1	2.50
29	27.7±0.4	1.44	19.6±0.4	2.04	4.9±0.2	4.08	8.5±0.2	2.35	39±1	2.56
30	5.1±0.1	1.96	16.8±0.3	1.79	4.03±0.05	1.24	9.5±0.2	2.11	44±1	2.27
31	9.1±0.1	1.10	19.9±0.2	1.00	4.98±0.05	1.00	7.7±0.1	0.26	40±1	2.50
32	6.7±0.1	1.49	23.3±0.3	1.29	4.13±0.06	1.45	9.2±0.2	2.17	40±1	2.50
33	12.6±0.1	0.79	19.9±0.2	1.01	8.21±0.09	1.10	9.9±0.1	1.01	41±1	2.44
34	6.5±0.1	1.54	14.1±0.3	2.13	3.38±0.04	1.18	7±0.1	1.43	32.7±0.6	1.83
35	6.9±0.1	1.45	17.9±0.3	1.68	4.07±0.05	1.23	6.9±0.2	2.9	31.3±0.4	1.28
36	6.1±0.1	1.64	16.7±0.3	1.8	4.51±0.06	1.33	6.8±0.2	2.94	38.4±0.5	1.30
37	8.5±0.1	1.18	16.5±0.2	1.21	3.92±0.05	1.28	11.3±0.2	1.77	18.1±0.2	1.10
38	7.9±0.1	1.27	23.4±0.4	1.71	2.85±0.08	2.81	13.2±0.3	2.27	15.3±0.2	1.31
39	11.9±0.2	1.68	19.4±0.3	1.55	3.82±0.05	1.31	14.6±0.2	1.37	16.7±0.3	1.80
40	10.3±0.1	0.97	13.8±0.3	2.17	2.98±0.03	1.01	13.4±0.3	2.24	19.2±0.4	2.08
41	8.9±0.1	1.12	22.1±0.3	1.36	3.28±0.04	1.22	13.7±0.2	1.46	21.5±0.2	0.93
42	7.3±0.1	1.37	13.1±0.1	0.76	2.97±0.05	1.68	12.0±0.1	0.83	17.3±0.3	1.73
43	9.6±0.1	1.04	15.6±0.2	1.28	3.58±0.04	1.12	14.8±0.2	1.35	17.7±0.4	2.26
44	6.2±0.1	1.61	12.2±0.1	0.82	3.22±0.04	1.24	11.6±0.2	1.72	17.9±0.2	1.12
45	6.1±0.1	1.64	16.8±0.2	1.19	3.61±0.05	1.39	8.0±0.1	1.25	35.4±0.4	1.13
46	6.0±0.1	1.67	9.9±0.2	2.02	2.92±0.05	1.71	7.6±0.2	2.63	27.0±0.4	1.48
47	8.4±0.1	1.19	17.7±0.2	1.13	3.34±0.04	1.20	10.9±0.1	0.92	45±1	2.22
48	14.4±0.2	1.39	19.7±0.2	1.02	3.22±0.04	1.24	8.2±0.1	1.22	29.8±0.3	1.01

49	18.9±0.2	1.06	14.0±0.2	1.43	3.51±0.04	1.14	8.5±0.1	1.17	30.5±0.4	1.31
50	8.7±0.1	1.15	15.6±0.2	1.28	3.69±0.05	1.36	8.4±0.1	1.19	34.0±0.2	0.59
51	6.9±0.1	1.45	25.3±0.3	1.19	3.31±0.04	1.21	7.7±0.1	1.30	31.5±0.2	0.63
52	7.9±0.1	1.27	15.1±0.4	2.65	4.43±0.07	1.58	6.9±0.1	1.15	28.8±0.4	1.39

Table 5. Continued

Sample	Ni	RSD (%)	V	RSD (%)	Cr	RSD (%)	Al	RSD (%)	Cd	RSD (%)
1	2.48±0.04	1.61	1.23±0.03	2.44	0.237±0.009	3.80	8.2±0.4	4.88	0.0084±0.0002	2.38
2	2.43±0.03	1.23	1.16±0.03	2.59	0.223±0.004	1.79	5.2±0.2	3.85	0.0116±0.0005	4.31
3	4.53±0.05	1.10	1.12±0.02	1.79	0.237±0.006	2.53	5.2±0.2	3.85	0.0072±0.0003	4.17
4	2.72±0.03	1.10	1.07±0.03	2.8	0.166±0.006	3.61	4.6±0.2	4.35	0.0112±0.0003	2.68
5	2.68±0.03	1.12	1.19±0.03	2.52	0.225±0.009	4.00	3.34±0.05	1.50	0.0084±0.0002	2.38
6	3.74±0.04	1.07	1.46±0.03	2.05	0.166±0.006	3.61	1.99±0.03	1.51	0.0111±0.0005	4.50
7	2.76±0.03	1.09	1.51±0.02	1.32	0.282±0.006	2.13	3.31±0.07	2.11	0.0109±0.0005	4.59
8	3.72±0.04	1.08	1.47±0.02	1.36	0.231±0.007	3.03	1.84±0.02	1.09	0.0159±0.0006	3.77
9	2.19±0.03	1.37	1.29±0.02	1.55	0.211±0.006	2.84	1.76±0.05	2.84	0.0085±0.0009	1.06
10	2.65±0.03	1.13	1.03±0.04	3.88	0.126±0.004	3.17	2.1±0.08	3.81	0.0182±0.0006	3.30
11	2.13±0.03	1.41	1.11±0.04	3.60	0.193±0.005	2.59	3.72±0.08	2.15	0.0069±0.0002	2.90
12	1.67±0.03	1.80	1.13±0.03	2.65	0.115±0.003	2.61	1.89±0.05	2.65	0.0070±0.0003	4.29
13	1.42±0.02	1.41	1.10±0.02	1.82	0.172±0.005	2.91	3.51±0.06	1.71	0.0034±0.0001	2.94
14	1.33±0.02	1.50	1.15±0.02	1.74	0.144±0.005	3.47	2.25±0.09	4.00	0.0090±0.0003	3.33
15	1.48±0.02	1.35	1.19±0.05	4.20	0.208±0.005	2.40	2.66±0.08	3.01	0.0049±0.0001	2.04
16	2.19±0.03	1.37	1.03±0.02	1.94	0.139±0.006	4.32	1.93±0.04	2.07	0.0042±0.0002	4.76
17	0.46±0.02	4.34	0.74±0.01	1.35	0.071±0.003	4.23	2.52±0.08	3.17	0.0041±0.0001	2.44
18	0.41±0.01	2.44	0.69±0.03	4.35	0.101±0.004	3.96	3.4±0.02	0.59	0.0041±0.0002	4.88
19	0.37±0.01	2.70	0.73±0.02	2.74	0.122±0.004	3.28	2.7±0.1	3.70	0.0028±0.0006	2.14
20	0.71±0.01	1.41	0.75±0.02	2.67	0.210±0.006	2.86	2.2±0.1	4.55	0.0145±0.0005	3.45
21	2.69±0.03	1.12	1.40±0.03	2.14	0.114±0.004	3.51	1.21±0.03	2.48	0.0041±0.0002	4.88
22	2.46±0.04	1.63	1.36±0.02	1.47	0.184±0.007	3.80	2.22±0.08	3.60	0.0022±0.0001	4.55
23	3.16±0.04	1.27	1.50±0.03	2.00	0.124±0.006	4.84	1.46±0.06	4.11	0.0084±0.0002	2.38
24	2.99±0.03	1.00	1.32±0.02	1.52	0.159±0.005	3.14	0.79±0.03	3.80	0.0046±0.0009	1.61

25	0.46±0.02	4.34	0.62±0.01	1.61	0.123±0.006	4.88	20.8±0.5	2.40	0.0137±0.0006	4.38
26	0.45±0.02	4.44	0.69±0.03	4.35	0.122±0.005	4.1	13.0±0.4	3.08	0.0136±0.0005	3.68
27	0.46±0.02	4.35	0.72±0.03	4.17	0.132±0.006	4.55	12.7±0.3	2.36	0.0139±0.0006	4.32
28	0.48±0.02	4.17	0.62±0.03	4.84	0.136±0.006	4.41	15.4±0.4	2.60	0.0413±0.0002	4.84
29	0.81±0.03	3.70	0.60±0.02	3.33	0.119±0.003	2.52	5.8±0.2	3.45	0.0467±0.0002	4.28
30	0.89±0.03	3.37	0.63±0.03	4.76	0.165±0.005	3.03	4.9±0.2	4.08	0.0225±0.0001	4.44
31	1.29±0.02	1.55	0.76±0.02	2.63	0.128±0.002	1.56	6.7±0.1	1.49	0.0209±0.0006	2.87
32	0.92±0.03	3.26	0.75±0.02	2.67	0.069±0.002	2.9	6.6±0.2	3.03	0.0027±0.0001	3.70
33	0.97±0.02	2.06	0.79±0.02	2.53	0.123±0.006	4.88	6.4±0.2	3.13	0.0035±0.0001	2.86
34	0.62±0.03	4.84	0.67±0.03	4.48	0.056±0.002	3.57	4.1±0.2	4.88	0.0073±0.0003	4.11
35	0.77±0.03	3.90	0.62±0.02	3.23	0.065±0.002	3.08	3.7±0.1	2.70	0.0043±0.0002	4.65
36	0.77±0.03	3.90	0.72±0.03	4.17	0.070±0.002	2.86	4.1±0.2	4.88	0.0425±0.0005	1.18
37	0.67±0.02	2.99	0.71±0.03	4.23	0.086±0.004	4.65	2.92±0.06	2.05	0.0048±0.0002	4.17
38	0.71±0.02	2.82	0.71±0.02	2.82	0.042±0.001	2.38	1.51±0.03	1.99	0.0045±0.0002	4.44
39	0.93±0.02	2.15	0.81±0.03	3.70	0.111±0.004	3.60	2.11±0.07	3.32	0.0492±0.0006	1.22
40	1.04±0.02	1.92	0.77±0.02	2.60	0.037±0.001	2.70	2.23±0.06	2.69	0.0501±0.0006	1.20
41	0.78±0.01	1.28	0.80±0.03	3.75	0.049±0.001	2.04	3.38±0.08	2.37	0.0340±0.0001	2.94
42	1.55±0.03	1.94	0.69±0.02	2.90	0.056±0.001	1.79	2.28±0.06	2.63	0.0207±0.0005	2.42
43	0.72±0.01	1.39	0.82±0.02	2.44	0.085±0.001	1.18	0.62±0.01	1.61	0.0137±0.0006	4.38
44	0.66±0.01	1.51	0.67±0.03	4.48	0.042±0.002	4.76	0.253±0.006	2.37	0.0217±0.0006	2.76
45	1.42±0.02	1.41	0.76±0.02	2.63	0.077±0.001	1.30	3.60±0.07	1.94	0.0049±0.0001	2.04
46	1.07±0.02	1.87	0.63±0.03	4.76	0.057±0.001	1.75	0.104±0.002	1.92	0.0027±0.0001	3.70
47	1.86±0.02	1.08	0.76±0.02	2.63	0.070±0.003	4.29	3.23±0.07	2.17	0.0218±0.0007	3.21
48	1.15±0.02	1.74	0.72±0.02	2.78	0.057±0.002	3.51	1.28±0.03	2.34	0.0358±0.0005	1.40
49	1.51±0.03	1.99	1.06±0.03	2.83	0.035±0.001	2.86	2.82±0.05	1.77	0.0361±0.0006	1.66
50	0.87±0.01	1.15	1.11±0.03	2.70	0.141±0.007	4.96	2.44±0.05	2.05	0.0432±0.0002	4.63
51	0.66±0.01	1.52	1.05±0.02	1.90	0.097±0.003	3.09	2.38±0.05	2.10	0.0145±0.0005	3.45
52	0.57±0.02	3.51	0.96±0.02	2.08	0.035±0.001	2.86	1.41±0.02	1.42	0.0138±0.0006	4.35

Table 5. Continued

Sample	Ba	RSD (%)	Pb	RSD (%)	Co	RSD (%)	B	RSD (%)
1	7.5±0.1	1.33	0.117±0.005	4.27	0.055±0.002	3.64	9.4±0.2	2.13
2	5.99±0.06	1.00	0.124±0.006	4.84	0.071±0.002	2.82	10.5±0.2	1.90
3	6.2±0.2	3.23	0.088±0.005	5.68	0.083±0.003	3.61	9.7±0.3	3.09
4	5.83±0.06	1.03	0.113±0.004	3.54	0.069±0.003	4.35	11.8±0.2	1.69
5	13.0±0.3	2.31	0.095±0.002	2.11	0.108±0.003	2.78	14.5±0.2	1.38
6	12.4±0.3	2.42	0.121±0.006	4.96	0.086±0.003	3.49	18.2±0.3	1.65
7	11.6±0.2	1.72	0.114±0.005	4.39	0.160±0.005	3.13	14.9±0.2	1.34
8	14.3±0.4	2.8	0.088±0.003	3.41	0.077±0.002	2.60	21.7±0.3	1.38
9	17.4±0.05	0.29	0.102±0.004	3.92	0.121±0.002	1.65	8.4±0.2	2.38
10	13.8±0.1	0.72	0.099±0.002	2.02	0.049±0.001	2.04	7.7±0.2	2.60
11	14.6±0.2	1.37	0.094±0.003	3.19	0.054±0.002	3.70	9.4±0.2	2.13
12	13.5±0.2	1.48	0.099±0.003	3.03	0.077±0.002	2.60	11.3±0.2	1.77
13	4.11±0.05	1.22	0.075±0.002	2.67	0.0204±0.0008	3.92	12.4±0.2	1.61
14	4.23±0.05	1.18	0.107±0.005	4.67	0.123±0.005	4.07	13.3±0.3	2.26
15	4.4±0.1	2.27	0.094±0.003	3.19	0.048±0.002	4.17	13.1±0.3	2.29
16	3.7±0.2	5.41	0.104±0.005	4.81	0.295±0.009	3.05	11.0±0.2	1.82
17	3.43±0.04	1.17	0.052±0.002	3.85	0.027±0.001	3.70	7.8±0.2	2.56
18	3.3±0.1	3.03	0.041±0.002	4.88	0.076±0.001	1.32	8.6±0.2	2.33
19	2.88±0.05	1.74	0.058±0.002	3.45	0.086±0.003	3.49	8.9±0.3	3.37
20	2.67±0.05	1.87	0.049±0.002	4.08	0.057±0.002	3.51	7.8±0.2	2.56
21	10.9±0.2	1.83	0.063±0.003	4.76	0.043±0.001	2.33	17.5±0.2	1.14
22	10.3±0.2	1.94	0.056±0.002	3.57	0.048±0.002	4.17	13.7±0.2	1.46
23	13.9±0.2	1.44	0.061±0.002	3.28	0.075±0.003	4.00	15.9±0.3	1.89
24	11.9±0.2	1.68	0.056±0.002	3.57	0.0145±0.0005	3.45	12.2±0.2	1.64
25	0.289±0.008	2.77	0.078±0.003	3.85	0.0137±0.0006	4.38	6.1±0.1	1.64
26	0.321±0.007	2.18	0.054±0.002	3.70	n.d.*	-	6.9±0.2	2.90
27	0.299±0.005	1.67	0.063±0.002	3.17	0.0281±0.0006	2.14	7.6±0.2	2.63
28	0.363±0.007	1.93	0.063±0.002	3.17	0.045±0.002	4.44	6.3±0.1	1.59
29	2.65±0.05	1.89	0.071±0.002	2.82	0.123±0.005	4.07	6.6±0.1	1.52
30	2.75±0.07	2.55	0.057±0.002	3.51	0.024±0.001	4.17	6.8±0.2	2.94
31	2.24±0.05	2.23	0.062±0.003	4.84	0.049±0.001	2.04	7.7±0.1	1.30
32	2.93±0.05	1.71	0.073±0.002	2.74	0.055±0.002	3.64	8.3±0.2	2.41
33	3.09±0.05	1.62	0.103±0.003	2.91	0.045±0.001	2.22	8.6±0.2	2.33
34	2.37±0.05	2.11	0.035±0.001	2.86	0.0356±0.0006	1.69	7.9±0.2	2.53
35	2.10±0.04	1.90	0.058±0.002	3.45	0.053±0.002	3.77	7.0±0.2	2.86
36	2.09±0.04	1.91	0.056±0.002	3.57	0.0284±0.0005	1.76	6.9±0.1	1.45
37	2.65±0.03	1.13	0.053±0.002	3.77	n.d.	-	9.8±0.2	2.04
38	2.77±0.07	2.53	0.049±0.002	4.08	n.d.	-	8.3±0.2	2.41
39	3.31±0.04	1.21	0.051±0.002	3.92	0.0138±0.0006	4.35	10.1±0.2	1.98
40	3.09±0.09	2.91	0.055±0.002	3.64	n.d.	-	13.3±0.3	2.26
41	3.16±0.05	1.58	0.053±0.002	3.77	0.072±0.003	4.17	9.3±0.2	2.15
42	2.73±0.03	1.10	0.047±0.001	2.13	n.d.	-	9.0±0.2	2.22
43	3.3±0.05	1.52	0.058±0.002	3.45	n.d.	-	10.9±0.2	1.83
44	2.58±0.04	1.55	0.051±0.002	3.92	n.d.	-	8.9±0.1	1.12
45	2.39±0.04	1.67	0.072±0.003	4.17	n.d.	-	8.6±0.1	1.16
46	2.47±0.04	1.62	0.048±0.002	4.17	n.d.	-	7.1±0.1	1.41
47	3.33±0.05	1.50	0.057±0.002	3.51	n.d.	-	8.7±0.2	2.30
48	2.31±0.04	1.73	0.055±0.002	3.64	n.d.	-	9.5±0.2	2.11

49	2.19±0.04	1.83	0.071±0.002	2.82	n.d.	-	12.0±0.2	1.67
50	2.29±0.03	1.31	0.057±0.002	3.51	n.d.	-	11.9±0.2	1.68
51	2.19±0.03	1.37	0.065±0.002	3.08	n.d.	-	13.4±0.2	1.49
52	1.93±0.05	2.59	0.063±0.003	4.76	n.d.	-	11.1±0.2	1.80

*n.d. – not detected

The *Rosa* fruit samples generally contained the highest amounts of K (4710-9850 mg kg^{-1}), Ca (2650-5140 mg kg^{-1}), and P (532-1610 mg kg^{-1}), followed by Mg (402-1000 mg kg^{-1}) and Na (11.2-39.1 mg kg^{-1}). The fruits of the analyzed samples are rich in macroelements compared to the previous studies (Demir and Ozcan, 2001; Levent *et al.*, 2010; Rosu *et al.*, 2011; Fan *et al.*, 2014; Kizil *et al.*, 2018; Paunović *et al.*, 2019; Smanalieva *et al.*, 2020) or the their content is in accordance with the literature data (Gharibzahedi and Jafari, 2017; Cendrowski *et al.*, 2017a; Kieliszek *et al.*, 2018; Popović-Djordjević *et al.*, 2021) or lower than that reported by other authors ((He *et al.*, 2016; Popović-Djordjević *et al.*, 2021; Benković-Lačić *et al.*, 2022; Sun *et al.*, 2022). The World Health Organization (2012) recommends consumption of less than 2 g of Na per day and more than 3.5 g of K per day, resulting in a Na/K ratio of ≤1.0, which is believed to be optimal for preserving cardiovascular health. Looking for the relation between Na and K in all sample studies, this ratio was favorable, being much lower than 1 in all samples. This is important for people who want to change their dietary patterns and increase vegetable/fruit consumption, because recent studies have reported that the Na/K ratio is associated with blood pressure (Jackson *et al.*, 2018; Higo *et al.*, 2019; Kogure *et al.*, 2021). Also, the Ca/Mg ratio was favorable to Ca in all samples. Mg is also one of the major elements important for human health. Popović-Đorđević and associates (2021) found that the tested wild rosehips were a much better source of Mg than the cultivated ones. The same authors (Popović-Đorđević *et al.*, 2021) reported that the contents of P in the rosehip studied was significantly higher in cultivated than in wild rosehip seed samples, but they didn't find any significant differences in P contents between cultivated and wild rosehip mesocarp samples. In addition, P, as an essential nutrient, is important for bones and teeth, as well as for repairing cells and tissues.

Among the microelements, the most abundant were Mn (6.8-64 mg kg^{-1}), Si (15.2-51.6 mg kg^{-1}), and Fe (9.9-30 mg kg^{-1}), followed by Zn (6.03-17.5 mg kg^{-1}), B (6.1-16.7 mg kg^{-1}), Al (0.79-15.4 mg kg^{-1}), Ba (0.289-14.6 mg kg^{-1}), and Cu (2.85-12 mg kg^{-1}). Mn is a mineral important for human health. It is necessary for normal brain and nerve function, and it also plays a role in calcium absorption and blood sugar regulation (Godswill *et al.*, 2020). Fe is a biologically essential element with numerous health benefits, including the prevention of anaemia, strengthening of the immune system, and the preservation of gastrointestinal processes. The body requires Fe for the synthesis of haemoglobin and myoglobin, and for the formation of iron-containing enzymes involved in the electron transfer and oxidation-reductions (McDowell, 2003). Zn is a metal that is a cofactor to more than 300 enzymes. It helps the immune system and the metabolism function (Rink and Gabriel, 2000). A deficiency of Zn leads to chronic diseases, such as cancer, diabetes, depression, Alzheimer's disease, and other age-related diseases (Chasapis *et al.*, 2012). Cu is an essential micronutrient that plays an important role in a lot of biological processes, including mitochondrial respiration, antioxidant defense, and biocompound synthesis (Chen *et al.*, 2022). Si and B are the elements that have been reported as essential, but their specific biochemical or physiological functions are still unconfirmed (Godswill *et al.*, 2020). According to the literature data (Martin, 2013), Si has been suggested to play a role in the structural integrity of nails, hair, and skin, bone mineralization, immune system health, and the reduction of the risk of atherosclerosis. Recent findings have considered B to be possibly essential for animal and human health. Some experiments on humans and animals have resulted in noticeable improvement of immunity, antioxidative effects, growth, and embryonic development (Khaliq *et al.*, 2018). Al is considered a potentially toxic metal, which may even be related to various neurological diseases (Exley, 2013). Ba has never been considered an essential nutrient for humans. High concentrations of Ba result in an increased risk to public health (Peana *et al.*, 2021). Ingesting high doses of Ba for a long time can damage the kidneys and is associated with alterations in cardiac rhythms (Dallas and Williams, 2001).

The content of Mn, Fe, Zn, and Cu in the fruits of the rose species were in accordance with the literature data (Sekeroglu *et al.*, 2008; Kazaz *et al.*, 2009; Levent *et al.*, 2010; Kizil *et al.*, 2018; Benković-Lačić *et al.*, 2022; Al-Juhaimi *et al.*, 2023), lower (Igual *et al.*, 2022; Sun *et al.*, 2022) or higher (Demir and Ozcan, 2001; Popović-Djordjević *et al.*, 2021) than the literature data. The content of B was in accordance with the data found in Kazaz *et al.* (2009), He *et al.* (2016), Paunović *et al.* (2019), Popović-Đorđević *et al.* (2021), and Al-Juhaimi *et al.* (2023), while the content of Al and Ba was in accordance with the literature data (He *et al.*, 2016) or higher than the results obtained by Paunović *et al.* (2019). In addition, Zeiner and Juranović Cindrić (2018) found a very high content of Al (8 mg g^{-1}) in rosehip samples from Croatia, which can be explained by the impact of bedrock composition on Al content in rosehips. On the other hand, there is no literature data for Si content in *Rosa* species fruits.

Other microelements, quantified in the *Rosa* species fruits, were: Ni (0.37-3.74 mg kg^{-1}), V (0.62-1.51 mg kg^{-1}), Co (nd-0.292 mg kg^{-1}), Cr (0.011-0.23 mg kg^{-1}), Pb (0.035-0.121 mg kg^{-1}), and Cd (0.0027-0.0492 mg kg^{-1}).

Ni is an essential micronutrient for plants and some animals, while there is no data indicating its essential role for humans. Plant food, rather than animal food, is a major source of nickel exposure for humans. Allergic contact dermatitis is the most frequent effect of Ni in the general population (EFSA, 2015). Researchers have shown that most of the toxic effects of V compounds result in local irritation of the eyes and respiratory tract rather than any systemic toxic manifestations (Mukherjee *et al.*, 2004). Co, as a metal constituent of vitamin B12, has a biological role, but excessive exposure has been shown to induce various adverse health effects such as neurological, cardiovascular, and endocrine symptoms (Leyssens *et al.*, 2017). For many years, Cr has been proposed to be an essential element, but the results of new studies indicate that Cr can only be considered to have pharmacologically beneficial effects associated with glucose metabolism and diabetes and not an essential element (Vincent, 2017). Also, the European Food Safety Authority (2014) concluded that chromium is not an essential element for humans.

The contents of Ni and Cr in the studied samples was in accordance with the literature data (Kizil *et al.*, 2018; Paunović *et al.*, 2019; Benković-Lačić *et al.*, 2022), or the contents of Ni was lower (Zeiner and Juranović Cindrić, 2018), while the contents of Co and V was higher (Levent *et al.*, 2010; He *et al.*, 2016; Paunović *et al.*, 2019) or lower (Benković-Lačić *et al.*, 2022) than the data found in the literature.

Cd is an element that can be found in lower concentrations in food, which is also the main source of Cd exposure in humans. Also, Cd is recognized as a human carcinogen, and this classification was based on animal data and epidemiology (Nordberg *et al.*, 2018). Pb is a harmful environmental pollutant that affects respiratory, nervous, digestive, cardiovascular, and urinary systems (Boskabady *et al.*, 2018). The content of Cd and Pb was in accordance with the findings of Sekeroglu *et al.* (2008), Levent *et al.* (2010), and Paunović *et al.* (2019) Zeiner and Juranović Cindrić (2018), who found a very high contents of Pb (3.3-15 mg kg^{-1}) in rosehip samples. Also, Kalinovic *et al.* (2019), reported that *Rosa* spp. accumulated toxic elements in lower concentrations in fruits than in other parts of the plant (branches, leaves, and roots), even when grown in contaminated soil. In addition, the obtained results were in accordance with the maximum levels of Cd (0.05 mg kg^{-1}, w.w.) and Pb (0.1 mg kg^{-1}, w.w.) in fruits established by the Commission Regulation (2023).

As, Be, Hg, and Tl were not detected in the analyzed samples.

The difference in the element compositions of the fruits could be caused by the species, variety, ecological factors, fruit size, harvest time, and storage conditions (Ercisli, 2007; Demir and Ozcan, 2001).

Many countries have developed recommendations for intake of micronutrients in the normal diet. Also, the Institute of Medicine in the USA published editions of the Dietary Reference Intakes (DRIs), which are defined as the intakes of each micronutrient that meet the requirements of almost all (97%–98%) people in the group. According to the U.S. National Academy of Sciences, Institute of Medicine (National Academies, 1997; National Academies, 2001; National Academies, 2011; National Academies, 2019), recommended a daily intake for adults (31-50 years) of K, Na, Ca, Mg, P, Mn, Cu, Zn, and Fe are 3400/2600 mg day^{-1} (males/females), 1500 mg day^{-1} (males and females), 1000 mg day^{-1} (males and females), 420/320 mg day^{-1} (males/females), 700 mg day^{-1} (males and females), 2.3/1,8 mg day^{-1} (males/females), 0.9 mg day^{-1} (males and females), 11/8 mg day^{-1} (males/females), and 8 mg day^{-1} (males/females), respectively. A serving of 100 g of *Rosa* fruits covers 13.0-29.0% for males and 17.0-38.0% for females, 0.08-0.26% for males and females, 25.3-55.0% for males and females, 9.6-23.8% for males and 12.6-31.2% for females, 7.9-23.0% for males and females, 29.6-435% for males and 37.8-100% for females, 31.7-100% for males and females, 4.6-28.1% for males and 6.4-38.6% for females, and 12.4-42,5% for males and females of the daily recommended of K, Ca, Mg, P, Na, Mn, Cu, Zn, and Fe intake, respectively. Based on the obtained results, the analyzed fruit samples contain various minerals and could contribute to the daily dietary requirements.

Conclusions

The optimization and validation of ICP AES method permits an accurate and precise analysis of 19 elements in fruit samples of six wild *Rosa* species. The method gave good precision values, below 5%, and an average recovery between 85.7% and 109%, with the exception of Fe (76.4%) for strawberry leaves as a CRM. Applied to the analyzed samples, this validated method could help to quantify minerals as well as toxic elements. The most abundant elements in the analyzed rose fruit samples were K, Ca, P, Mg, Na, Mn, Fe, Zn, and Si. The content of Cd and Pb was below the EU Commission recommended maximum levels of these metals in fruits. Also, the Na/K ratio, much below 1.0, is favorable and very important in terms of human health. Additionally, with respect to their mineral content, the fruits of the studied rose species samples could contribute to the daily dietary requirements.

Authors' Contributions

Conceptualization: AP; Writing - original draft: AP and ST; Methodology: AP and BZ; Investigation: KM; Data curation: KM and DM; Formal analysis JM and DK; Supervision: AP and ST; Validation: JM and SP; Visualization: JM; Writing - review and editing: AP and ST. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research was supported by the Ministry of Science, Technological Development, and Innovation of Republic of Serbia (grant numbers: 451-03-47/2023-01/200124, 451-03-65/2024-03/200124 and 451-03-66/2024-03/200124).

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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