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Mineral composition and bioactive potential of red raspberry fruits, juice, and jam

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Abstract

Raspberries are highly valued by consumers due to their nutraceutical properties, which have been associated with various health benefits. The aim of this study was to evaluate the differences in quality characteristics of fresh raspberry fruits and final products (jam and juice) collected from plantations under different agroecological conditions (three localities). The total phenolic content in raspberry fruits and products was quantified by the Folin-Ciocalteu method and the total anthocyanin content by the pH-differential method. In the same samples, eight elements (phosphate, iron, manganese, zinc, calcium, potassium, magnesium, and sodium) were determined using atomic absorption spectrophotometry. The productivity of red raspberry (*Rubus idaeus* L.) cultivar 'Willamette' was studied by examining the variation in the number of floricanes per espalier meter and per unit area as well as the variation in yield per cane and per unit area. The results showed that the highest yield was observed in the L2 locality (660.00 g per cane and 14,840 kg ha^{-1} of total area), while the lowest yield was recorded in the L3 one (519.67 g per cane and 11,779 kg ha^{-1} of total area). The amount of macro- and microelements in the soil and raspberry fruits varied between the localities with a higher nutrient content obtained in the L2 locality. The antioxidant capacity and total anthocyanin and phenolic content of the raspberry fruits were influenced by the cultivation area with the highest values of anthocyanins (63.45 mg cyn-3-glu 100 g^{-1} FW) and phenols (630.00 mg GAE 100 g^{-1} FW) observed in the L2 locality. The study also revealed that the processing of raspberry fruits into juice and jam had minimal effects on the antioxidant capacity and phenolic content. The findings highlight that 'Willamette' raspberries are a valuable source of bioactive compounds and minerals that contribute to their nutritional value and potential health benefits.
Further research and optimisation of processing techniques are necessary to effectively preserve and enhance the bioactive compounds in processed raspberry products.

Keywords: *Rubus idaeus*, locality, fruit products, quality traits.

Introduction

From an economic perspective, the red raspberry (*Rubus idaeus* L.) is of great importance among small fruits in Serbia (Karaklajić-Stajić et al., 2012). Serbia stands out as one of the leading raspberry-producing countries worldwide due to favourable climate and soil conditions for the intensive cultivation of this fruit. Most of the raspberries produced in Serbia are exported frozen (95%), and only a small amount is exported fresh. According to the Statistical Office of the Republic of Serbia (www.stat.gov.rs), in 2022, raspberry production in Serbia reached 109,748 tons, and the total area was 21,861 hectares. The main raspberry growing regions in Serbia are Western and Central Serbia with prominent cultivation areas including Arilje-Ivanjica and Valjevo. The large production area of Kopaonik in Central Serbia also contributes significantly to raspberry cultivation (Kljajić, 2017). The most common raspberry cultivar grown is 'Willamette' accounting for more than 90% of plantations, followed by 'Meeker' with 3–5%. The dominance of 'Willamette' can be attributed to its

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adaptability to the agro-ecological conditions of Serbia's primary raspberry growing region and favourable fruit processing characteristics.

There is global increasing interest worldwide in the consuming of fresh raspberry fruits due to the presence of chemical compounds with antioxidant properties that provide various health benefits to the human body, as highlighted by Dragišić-Maksimović et al. (2017). Among other bioactive compounds, phenols have been widely studied for their significant antioxidant, antibacterial, antiviral, antimutagenic, antiproliferative, anticancer, anti-inflammatory, and vasodilatory properties, as noted by Olas (2018). According to Stojanov et al. (2019), the amount of phytochemicals found in raspberry fruits depends primarily on the specific fruit species and cultivars determined by genetic factors. Factors such as environmental conditions, cultivation technology, and physiological elements also contribute to the amount of these beneficial compounds. Seasonal variations in climatic parameters in recent years have become a determining factor in shaping agricultural production, especially in terms of precipitation patterns during the vegetative period. Global warming contributes to a dynamic hydrologic cycle characterised by increased total precipitation and more frequent intense rainfalls (Jovovic et al., 2021). Various factors such as environment, species, cultivar, altitude, and cultivation technology have a significant influence on the fruit quality (Roobha et al., 2011). At present, a large part of the Serbia's raspberry production is exported frozen. However, there is a need to increase the share of processed raspberry products such as raspberry juice and jam, as they are in high demand among consumers (Zhang et al., 2021).

The studies provide the evidence that the consumption of foods rich in antioxidants decreased the risk of developing chronic health conditions including cancer and coronary heart disease (Griffiths et al., 2016). The health benefits can be attributed in part to the presence of constituents such as vitamins C and E, phenols, carotenoids, lycopene, selenium, and dietary fibre (Elhadi et al., 2019). By promoting processed raspberry products, Serbia can take advantage on the demand for functional foods that provide these health benefits. Processed raspberry products have a higher value compared to frozen raspberry fruits increasing profitability for farmers and processors. Additionally, processed products have a longer shelf life and are more easily transported, allowing to reach a wider domestic and international market. This strategy is in line with the global trend of growing consumer demand for healthy and convenient food. Red raspberry fruits are widely recognised as a rich source of anthocyanins, which are natural pigments responsible for the bright colours of many flowers, fruits, and vegetables (Shahidi, Naczk, 2004). There is also growing interest in their potential health benefits associated with anthocyanins, particularly their ability to fight chronic and degenerative diseases such as heart disease and cancer (Leong et al., 2017).

According to Beekwilder et al. (2005), fresh raspberry fruits have a limited shelf life and are usually available during the summer season; therefore, many raspberry fruits are marketed as frozen fruits, jams, and sauces. The impact of processing on the antioxidant capacity of raspberry fruits can vary due to different production practices and possible effects of various processing steps. Findings on the impact of processing on antioxidant capacity have been contradictory.

A study of Mäkilä (2017) showed that the total antioxidant capacity of raspberry fruits increases twofold during the jam making due to the formation of aglycones from phenols during acid hydrolysis. However, other studies have reported a decrease of approximately 13% (w/w) in the antioxidant capacity of raspberry jam compared to that of fresh raspberry fruits (Kim, Padilla-Zakour, 2004). Andersen et al. (2003) indicated that the modern food industry faces the challenge of creating products that combine convenience, freshness, and healthy nutrition. To evaluate the potential health benefits of raspberry-based products such as juice and jam, it is necessary to determine the total anthocyanin and phenolic content, antioxidant capacity, and macro- and microelements in the final products. These analyses can provide valuable insights into the health-promoting properties of raspberry-supplemented juice and jam, allowing consumers to make informed purchasing decisions.

The objective of this study was to assess the influence of agroecological conditions on the main chemical properties of fresh red raspberry fruits as well as juice and jam with a focus on natural antioxidants and nutrients on consumer acceptability.

Material and methods

Plant material and experimental design. The experiment was conducted with the red raspberry (*Rubus idaeus* L.) primocane-fruiting cultivar 'Willamette' in private plantations located in three different cultivation areas: Stupčevići (L1), Bukovica (L2), and Milićevo Selo (L3), in the raspberry growing area Arilje-Ivanjica in Western Serbia. The plantations were established in 2008, and the experiment was carried out during two consecutive years, 2018 and 2019, i.e., 9–10 years after planting. The total area of each plantation was 0.25 ha. The plants were spaced 0.25 m within rows and 2.2 m apart and tested as a three-wire trellis. I-trellis (i.e., espalier) consisted of posts (spaced 5–6 m apart) and three horizontal wires at 0.7, 1.4, and 2.1 meters above the ground. A randomised complete block design with 15 m of I-trellis (i.e., espalier) was used per each treatment (localities for fresh fruits and for type of final products) with four replicates (n = 60 m). The cultivation area treatment included three localities (L1, L2, and L3) and two raspberry products (juice and jam).

Soil properties and weather conditions. The data about agroclimatic conditions for all experimental localities are presented in Table 1. The meteorological data were obtained from the Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs).

Table 1. Agroclimatic data of the three experimental localities (L) in Western Serbia

	Stupčevići (L1)	Bukovica (L2)	Milićevo selo (L3)
Altitude (m)	358	453	327
Latitude (N)	43°42′	43°36′	43°47′
Longitude (E)	20°06′	20°11′	20°05′
Region of city	Arilje	Ivanjica	Požega
Mean annual (2018–2019) rainfall mm	710.9	554.5	673.7
Mean growing season (2018–2019) temperature °C	14.9	15.9	15.7
Mean long-term growing season (1965–2019) temperature °C	15.3	16.3	15.9

The soil in the raspberry plantation in the Stupčevići (L1) locality is a silty clay loam, and the soils of Bukovica (L2) and Milićevo Selo (L3) ones are classified as silty clay and clay loam, respectively, according to the classification of the World Reference Base for Soil Resources (WRB, 2022). The mechanical and chemical characteristics and the amount of important nutrients in the soils of different cultivation areas are presented in Tables 2, 3, and 4. According to Stojanov et al. (2019), the soil is suitable for red raspberry planting if soil pH is 6.0 in N_{KCl} and contains 1.74–2.91% organic matter, 8–10 mg Al-P_2O_5 100 g^{-1}, and 18–20 mg Al-K_2O 100 g^{-1} of dry soil, respectively.

In the agroenvironmental conditions of Serbia, raspberries grow best in warm pre-mountainous areas with a high air humidity during the growing season, especially at the fruit maturation stage (Karaklajić-Stajić et al., 2022).

Table 2. Mechanical properties of soil in the three localities (L) of raspberry plantations

Depth 30 cm	Fine sand, 2–0.2 mm	Coarse sand, 0.2–0.02 mm	Dust, 0.02–0.002 mm	Clay, <0.002 mm	Physical sand, >0.02 mm	Physical clay, <0.02 mm
L1	8.20	26.10	48.20	17.50	34.30	65.70
L2	13.84	34.16	37.20	14.80	48.00	52.00
L3	2.53	48.27	30.80	18.40	50.80	49.20

Table 3. Chemical properties of soil in the three localities (L) of raspberry plantations

Depth 30 cm	pH in KCl 0.01 mol L^{-1}	$CaCO_3$ %	Organic matter %	N_{tot} %	Content of available soil P mg 100 g^{-1} dry soil	Content of available soil K mg 100 g^{-1} dry soil
L1	4.30	0.00	3.62	0.18	8.80	35.30
L2	4.63	0.00	4.45	0.22	10.74	21.00
L3	6.43	1.55	1.00	0.05	14.51	14.70

Table 4. Soil macro- and microelements content in the three localities (L) of raspberry plantations

Depth 30 cm	Macroelements %		Microelements ppm			
	Ca	Mg	Fe	Mn	Cu	Zn
L1	0.440	0.076	58.10	1,854.01	16.80	76.51
L2	1,074.02	0.159	29.40	836.03	8.01	56.30
L3	1,467.00	0.136	16.51	584.72	11.41	57.72

Processing techniques. Raspberry jam was prepared according to a traditional recipe, by cooking 1500 g of fresh raspberry fruits with 750 g of sugar for 30 min. The mixture was heated under stirring until the jam reached the appropriate density. Raspberry juice was prepared by pressing the raspberry fruits and filtering through a cheesecloth. After that, the raspberry juice was heated at 90°C for 3 min. The total anthocyanin and phenolic content, antioxidant capacity, and macro- and microelements were analysed over 24 h in the jam and juice.

Determination of productivity and fruit quality. Generative characteristics were studied by counting the number of floricanes per espalier meter and per hectare. Yield per floricanes (g) was measured using a digital balance FCB 6 K (Kern & Sohn GmbH, Germany) after each harvest, and yield per hectare (t) was calculated as the product of the yield per floricane and the number of floricanes per hectare.

To determine the amount of minerals, raspberry fruit samples were collected from all studied treatments at the commercial maturity stage on 20 June 2018 and 25 June 2019. Raspberry fruits were randomly sampled from five floricanes in four replicates (n = 20). Fruits were picked from different parts of the floricanes to avoid the effect of fruit position. After harvesting, the raspberry fruits were stored at +5°C and analysed within 24 h. Part of fresh raspberry fruits was cooked to make raspberry jam and juice.

The total phenolic content was estimated by the Folin-Ciocalteu method with slight modifications (Waterman, Mole, 1994). The results were expressed as gallic acid equivalents per 100 g of fresh weight (mg GAE 100 g^{-1} FW). The total anthocyanin content of aqueous extracts was determined using the pH differential method (Torre, Barritt, 1977; Liu et al., 2002). The pigment content was calculated in milligrams of cyanidin-3-glucoside per 100 g of fresh weight (mg cyn-3-glu 100 g^{-1} FW). The antioxidant capacity of jam and juice on the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical was performed according to the procedure described by Brand-Williams et al. (1995) with slight modifications. All analyses were performed in triplicate. The scavenging activity was calculated as mmol Trolox g^{-1} FW.

To determine the amount of minerals, all samples were homogenised, accurately weighed (10 g), and heated at 105 ± 5°C for gravimetric measurements of dry matter. The content of phosphate (PO_4), iron (Fe), manganese (Mn), zinc (Zn), calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) was determined according to Morais et al. (2017) in triplicate by atomic absorption spectrophotometry PinAAcle 500 (Perkin-Elmer, USA). The content of macro- (Ca and Mg) and microelements (Cu, Mn, Zn, and Fe) in fresh raspberry fruits was expressed as % and ppm, respectively, and in raspberry products as mg L^{-1} of dry matter.

Statistical analysis. The data were presented as the mean ± standard error (SE) of the mean. Differences between the means were compared by the Duncan's multiple range test for one- and two-way analysis of variance (ANOVA) using the statistical package MSTAT-C (Michigan State University, USA). The differences at $p \leq 0.05$ were considered significant.

Results and discussion

Productivity parameters of raspberry fruits. The data presented in Table 5 indicates that agroecological conditions had a significant influence on the yield parameters but did not significantly affect other generative potential traits. The highest yield per cane and per unit area was found in the L2 locality and the lowest in the L3 one. The average total yield per cane and the total area in the three localities ranged from 519.67 to 660.00 g and from 11,779.33 to 14,840.00 kg ha^{-1}, respectively. That is, the yield in the L2 locality was by 13% higher than that in the L1 and by 21% higher than that in the L3 ones, both in terms of yield per cane and per unit area. It is important to emphasise that the final yield of blackberries and raspberries can be calculated by multiplying the yield per individual cane by the total number of floricanes per unit area (Thexton, Bajcz, 2021).

Table 5. Productivity of raspberries grown in the three localities (L)

Treatment	Number of floricanes per espalier meter	Total number of floricanes per ha	Yield	
			per cane g	per total area kg ha^{-1}
Cultivation area				
L1	5.5 ± 0.03 a	22.000 ± 98.70 a	593.33 ± 8.82 b	12,945.67 ± 49.10 b
L2	5.7 ± 0.02 a	22.800 ± 78.80 a	660.00 ±10.07 a	14,840.00 ± 115.90 a
L3	5.3 ± 0.03 a	21.900 ± 84.60 a	519.67 ± 7.96 c	11,779.33 ± 98.73 c
ANOVA	ns	ns	*	*

Note. Values within each column followed by the same small letter are not significantly different at $p \leq 0.05$ by LSD test; * – significant at $p \leq 0.05$ according to LSD test; ns – not significant.

Previous studies involving *Rubus* spp. revealed that nitrogen (N) and K play a major role, while phosphorus (P) and Ca are less important in improving the fruit yield and quality (Mditshwa et al., 2017). It is determined that yield is affected by soil fertility and water availability in the previous year of primocane development (Dean et al., 2000). In the case of the studied raspberry cultivar 'Willamette', the highest generative parameters were observed in the L2 locality. In terms of the agrochemical properties, the soil of the studied localities is characterised by acidity, medium humus, high N, medium P, and sufficient K content. In the L1 locality, the soil has the least favourable mechanical composition for raspberry cultivation, is highly acidic, and has little available P, which may affect the studied parameters of raspberry productivity.

The amount of macro- and microelements in the soil in all localities indicates the significant influence of the soil mechanical composition, chemical reaction, and organic matter content on the nutrient availability. The optimal Ca content in the soil of the raspberry plantation was found in the L3 locality, while its low amount was found in the L1 one. Due to the positive influence of the geological substrate, a sufficient amount of Mg was observed in all localities. In terms of microelements, the increased content of Fe and Mn was found in the L1 locality, while their content in the other two localities corresponded to the average values. The content of Cu and Zn was within the average values in the L1 locality and slightly higher in the L2 and L3 ones. The yield values obtained in the present study for the 'Willamette' were similar to the results reported by Poledica et al. (2012) and Leposavić et al. (2017) for the same cultivar in different cultivation areas of Western Serbia.

Fruit quality characteristics. The data presented in Table 6 indicate that the cultivation area had a significant influence on the total anthocyanin and phenolic content as well as the antioxidant capacity in red raspberry fruits. The highest values of these parameters were found in the raspberry fruits sampled from the L2 locality, while the lowest values were found in the fruits from the L3 one. It is widely recognised that genetic factors play a significant role in determining quality aspects including bioactive compounds. This is due to the variation in the

Table 6. Total anthocyanin and total phenolic content and the antioxidant activity in fresh raspberry fruits from the three localities (L)

Treatment	Total anthocyanins mg cyn-3-glu 100 g^{-1} FW	Total phenols mg GAE 100 g^{-1} FW	Antioxidant capacity mmol Trolox g^{-1} FW
Cultivation area (A)			
L1	35.90 ± 3.45 b	546.48 ± 10.45 b	2.41 ± 0.07 b
L2	63.45 ± 4.02 a	630.00 ± 14.07 a	2.68 ± 0.09 a
L3	33.95 ± 1.95 c	328.18 ± 13.21 c	1.92 ± 0.07 b
ANOVA	*	*	*

Explanation under Table 5

amounts of these compounds between different cultivars (Skrovankova et al., 2015). However, in addition to the cultivar itself, various other factors such as cultivation area, cultivation technology, rainfall, average growing temperature (Hargreaves et al., 2008; Maro et al., 2013), and light levels (Polat et al., 2020) can also affect the total antioxidant capacity of fruits. In the present study, the dominant influence of agroecological conditions on the quality of raspberry fruits was confirmed exceeding the influence of genotype. This conclusion is supported by the significant differences between the average values of the chemical parameters of the studied fruits.

Raspberry fruits are recognised for their mineral-rich composition (Pereira et al., 2018). Among the macro- and microelements studied, the raspberry fruits from the L2 locality had the highest Ca content, while the fruits from the L1 one had the highest Fe content (Table 7). Regarding the lowest values, no consistent pattern or correlation with the cultivation area was found. The differences of Mg in raspberry fruits were less pronounced than the variations in Ca ranging from 34.17% (L1) to 68.49% (L2). It should be noted that significant differences in the content of Mg and Ca in raspberry fruits were determined depending on the cultivation area.

Table 7. Content of macro- and microelements in fresh raspberry fruits from the three localities (L)

Treatment	Macroelements %		Microelements ppm			
Cultivation area (A)	Ca	Mg	Fe	Mn	Cu	Zn
L1	34.17 ± 0.60 b	30.64 ± 1.18 b	6.89 ± 0.40 a	2.59 ± 0.13 b	0.57 ± 0.02 c	2.35 ± 0.11 a
L2	68.49 ± 1.46 a	42.26 ± 0.74 a	2.51 ± 0.12 c	2.65 ± 0.11 b	0.93 ± 0.01 a	2.33 ± 0.09 a
L3	35.84 ± 1.04 b	30.20 ± 0.96 b	4.60 ± 0.29 b	3.40 ± 0.18 a	0.74 ± 0.02 b	2.15 ± 0.04 b
ANOVA	*	*	*	*	*	ns

Explanation under Table 5

In the human body, Mg is an indispensable cofactor for many enzymes with a particular attention on those involved in energy metabolism. Its significance includes facilitating protein synthesis and maintaining cellular balance making it an essential element (Franken et al., 2022). Calcium ions are important for the blood coagulation process and the maintenance of osmotic pressure. They are involved in cell growth and development, act as enzyme compounds, and affect metabolism and immunity (Gins et al., 2018). According to Jeong et al. (2008), the primary elements of raspberry fruits composition are K, P, and Ca. This study focused on determining the amount of microelements including Fe, Mn, Cu, and Zn in raspberry fruits. The results revealed that the highest content of Fe and Zn was found in raspberry fruits in L1, Mn in L2, and Cu in L2 localities. A study conducted by Dragišić-Maksimović et al. (2017) also identified primary elements such as K, Mg, Ca, Fe, Zn, and Mn in red raspberry fruits of the 'Willamette'. There is evidence that Zn and other heavy metals have antimicrobial effects (Daglia et al., 2011). In addition, the three main micronutrients, Zn, selenium (Se), and Fe, have received increasing attention for their antioxidant protection. Over the past two decades, a significant body of evidence has accumulated to support the role of these elements as cellular antioxidants (Zhang et al., 2021). One way in which Zn acts as an antioxidant is by inducing the production of metallothioneins, small molecule amino acid residues that are synthesised in various tissues including the liver, intestine, and kidney, in response to Zn stimulation.

Quality of raspberry products. The findings regarding the total anthocyanin and phenolic content and the antioxidant capacity in the raspberry juice and jam are presented in Table 8. The results indicate a significant influence of agroecological conditions on all studied parameters related to fruit quality. However, the type of final product (juice or jam) had no significant effect on the antioxidant capacity values alone. The total anthocyanin content in the raspberry products ranged from 9.60 to 42.45 mg cyn-3-glu 100 g^{-1} FW. The highest values of total anthocyanin content were found in the raspberry fruits from the L1 locality, while the lowest were found in the samples from the L2 one. When comparing the two types of raspberry products, the juice had a significantly higher total anthocyanin content compared to the jam. A similar trend was found for the total phenolic content, although the difference between the juice and jam was smaller at approximately 7% compared to the difference in the total anthocyanin content, which was approximately 17%. This suggests that the jam processing had a minor impact on the total phenolic content, as indicated by similar findings in other studies on jams from various berries, including raspberries (Amakura et al., 2000).

Table 8. Total anthocyanin and total phenolic content and the antioxidant activity in raspberry fruit products from the three localities (L)

Treatment	Total anthocyanins mg cyn-3-glu 100 g^{-1} FW	Total phenols mg GAE 100 g^{-1} FW	Antioxidant capacity mmol Trolox g^{-1} FW
Cultivation area (A)			
L1	42.45 ± 4.05 a	670.55 ± 5.50 a	2.39 ± 0.45 b
L2	26.78 ± 2.58 b	620.27 ± 4.15 c	2.35 ± 0.30 b
L3	29.99 ± 3.01 b	639.76 ± 4.60 b	2.49 ± 0.25 a
Final product (B)			
Juice	56.55 ± 5.78 a	658.06 ± 6.25 a	2.41 ± 0.40 a
Jam	9.60 ± 3.22 b	628.99 ± 5.77 b	2.41 ± 0.35 a
ANOVA			
A	*	*	*
B	*	*	ns
A × B	ns	ns	ns

Explanation under Table 5

The antioxidant capacity of raspberry juice and jam ranged from 2.35 to 2.49 mmol Trolox g^{-1} FW in the three experimental localities. Both raspberry juice and jam had a similar antioxidant capacity with the highest values in the L1 and L2 localities. These values were approximately by 6% higher compared to other treatments of this experiment. Similar to the results of the present study, the antioxidant capacity of some popular tomato products had been reported to be higher than their fresh equivalents (Re et al., 2002). This indicates that processing can enhance the antioxidant properties of raspberry fruits similar to the effects of tomato products. The processing of raspberry fruits into juice and jam did not significantly affect their antioxidant properties, except for minor variations between different localities. These findings are consistent with previous study on raspberry jam (Kim, Padilla-Zakour, 2004), which also indicated that processing has minimal effects on the antioxidant capacity. Despite the presence of some content of anthocyanins in processed raspberry products, the preservation of these bioactive compounds and their health benefits remain a challenge for the food industry. Optimisation of processing techniques and conditions is necessary to maintain and enhance the bioactive compounds in processed raspberry products.

The raspberry fruits have been found to be a source of biologically active compounds and minerals that have beneficial effects on human health (Pereira et al., 2018; Eremeeva et al., 2019). Minerals, classified as micronutrients, are the essential components of nutrition and play various physiological roles in the body. They are involved in various biochemical processes and contribute to overall health and well-being. Raspberries can be a natural source of these important minerals, which further increase the nutritional value of these fruits.

Mineral elements have antioxidant properties and play an essential role in various physiological processes including redox reactions, metabolism of carbohydrates, proteins, vitamins, and fats, bone tissue formation, regulation of heat and gas exchange, hematopoiesis, growth, respiration, immunobiological reactions, and water-salt and acid-base balance (Nile, Park, 2014). However, the influence of locality on the Ca and Mg content in raspberry fruits was not determined, although significant differences were observed based on the product type (Table 9).

Table 9. Content of macro- and microelements in raspberry fruit products from the three localities (L)

Treatment	Macroelements mg L^{-1}		Microelements mg L^{-1}			
Cultivation area (A)	Ca	Mg	Fe	Mn	Cu	Zn
L1	240.27 ± 41.35 a	218.94 ± 37.16 a	4.20 ± 0.84 a	13.48 ± 2.38 a	0.43 ± 0.08 a	1.41 ± 0.27 a
L2	236.68 ± 41.05 a	215.21 ± 31.50 a	4.42 ± 0.83 a	13.60 ± 2.75 a	0.41 ± 0.07 a	1.42 ± 0.26 a
L3	239.32 ± 36.76 a	227.57 ± 37.99 a	4.14 ± 0.81 a	13.84 ± 2.49 a	0.38 ± 0.06 b	1.43 ± 0.2 a
Final product (B)						
Juice	211.45 ± 29.28 b	187.99 ± 24.18 b	3.63 ± 0.66 b	12.04 ± 1.93 b	0.36 ± 0.05 b	1.22 ± 0.20 a
Jam	266.06 ± 30.54 a	253.15 ± 27.07 a	4.87 ± 0.57 a	15.24 ± 1.94 a	0.46 ± 0.05 a	1.61 ± 0.19 b
ANOVA						
A	ns	ns	ns	ns	*	ns
B	*	*	*	*	*	*
A × B	ns	ns	ns	ns	ns	ns

Explanation under Table 5

The raspberry jam had a higher content of Ca (266.06 mg L^{-1}) and Mg (253.15 mg L^{-1}) compared to the raspberry juice. The composition of macro- and microelements of the raspberry jam prepared from the red raspberry cultivar 'Willamette' fruits was analysed. The findings of this study are consistent with the results reported by Plessi et al. (2007), who also investigated the nutrient composition of the raspberry jam obtained from four different raspberry cultivars ('Glen Moy', 'Heritage', 'Scepter', and 'September'). It was found a higher content of Fe and Zn in the raspberry jam. However, contrary to their results, this study revealed a lower content of Mn and Ca in the 'Willamette' raspberry jam.

Conclusion

The agroecological conditions within three experimental localities (L) of the raspberry cultivation areas in Western Serbia have a significant influence on the yield, secondary metabolites, and essential biogenic elements content as well as the antioxidant capacity of fresh raspberry fruits.

The results of this study emphasise that soils exhibiting a predominant composition of fine sand and enriched with organic matter, nitrogen, potassium, and magnesium have a positive effect on generative parameters of raspberries, especially the yield. Also, in these localities, raspberry fruits had the highest total anthocyanin and phenolic content. Conversely, the determination of the Ca and Mg as well as Fe, Mn, Cu, and Zn content showed different trends in the three experimental localities.

This study revealed that raspberry juice has a higher content of secondary metabolites and antioxidant capacity, while raspberry jam is superior in terms of mineral composition.

These findings have significant implications for various stakeholders including raspberry growers, processors, and consumers. Providing valuable results, these findings indirectly contribute to increasing the economic viability of raspberry production in Serbia.

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