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MANGANESE AND NICKEL IN BERRIES AND STONE FRUITS FROM REGIONS NEAR SMELTER IN KOSOVO: INSIGHTS FOR BIOCONCENTRATION FACTOR AND DAILY INTAKE RATE

S u m m a r y

Background. Heavy metal pollution is a significant risk to human, animal and plant health due to their toxicity and their accumulation in biological tissues. The aim of this study is to determine the concentrations of nickel (Ni) and manganese (Mn) in cherries, sour cherries, raspberries and blackberries grown in three different regions near a lead-zinc ore smelter. Nickel and manganese was determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The bioconcentration factor of nickel and manganese, which provides information on the intake and accumulation of metals in plant tissues, was also determined.

Results and conclusions. The highest concentration of Ni was measured in sour cherries (48.2 mg/kg d.w. or 7.04 mg/kg w.w.), and of Mn in raspberries (72.7 mg/kg d.w. or 12.5 mg/kg w.w.). In addition, in the region that was the furthest from the smelter, measurements showed the lowest Mn concentration in cherries and the lowest Ni concentration in raspberries. Furthermore, the daily intake rates (DIR) for Mn and Ni were higher in berries, but lower than tolerable daily limits. The bioconcentration factor (BCF) for manganese in stone fruits is lower than that of berries and much lower than that for Ni for both types of fruit. Stone fruits showed a greater ability to accumulate nickel, and berries displayed a greater ability to accumulate manganese. Statistical analysis of the results showed that the differences in the concentration of manganese between stone and berry fruits are statistically significant, while those of nickel are not statistically significant.

Keywords: fruit, nickel, manganese, bioconcentration factor, daily intake rate

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Introduction

Consuming a variety of fruit and vegetables provides a significant amount of minerals, vitamins (niacin, thiamine, ascorbic acid), phytochemicals (flavonoids, anthocyanins, rutin, lutein, ellagic acid), nutrients and dietary fibers [26]. Consuming various fruit is good for health and is necessary for the intake of essential micronutrients and dietary fiber. In this context, the US recommendations for 2015 ÷ 2020 are that fruit and vegetables should constitute half of each meal [31].

Fruit and fruit juices are products that are consumed by all age groups and are part of the daily diet. They can also be considered a source of important nutrients such as vitamins and minerals [13]. Fruit is divided into several groups: pome fruits (apple, pear, quince, rowan, medlar), stone fruits (sour cherry, plum, cherry, peach, apricot), berries (strawberry, blackberry, raspberry, mulberry), nuts (walnut, almond, hazelnut, chestnut), grainy fruits (grapes, currant, blueberry, cranberry) and southern, subtropical and tropical (lemon, orange, tangerine, banana, pineapple, avocado, kiwi, fig, pomegranate, carob, etc.) [10, 19].

Cherries are one of the most valued fruit among consumers due to their good external appearance and organoleptic quality. Carbohydrates are the main chemical compounds in cherries (12 ÷ 17 %), with dietary fiber representing 1.3 ÷ 2.1 % of the total compounds. The sugar content usually ranges from 11 to 15 % depending on climatic and agro-mechanical conditions. Five sugars (glucose, fructose, sorbitol, sucrose and maltose) are commonly found in sweet cherries, and glucose and fructose constitute ~ 90 % of the total fruit sugars [4]. They are an excellent source of vitamins and minerals, and have a beneficial effect on the entire organism. The main pigment is red anthocyanin, which acts as an antioxidant, and is one of the most important regulators of heart rhythm and the aging process. Cherries are a curative plant that is widely used in the Ayurvedic and Unani systems of medicine. In general, cherry fruits are widely used in the treatment of urinary system disorders, including urinary tract, to treat a number of diseases, such as urinary tract infections, nephrolithiasis, cystolithiasis, and various parts of the plant have been proven to be beneficial for diabetes, heart disease and skin diseases [1].

Blackberries and raspberries, commonly known as Rubus berries, are commercially grown worldwide in various climates. They have a short shelf life, which is the main limitation in their supply chains leading to higher post-harvest losses. Their susceptibility to microbial spoilage, fruit softening and increased oxidation of anthocyanins, phenols and flavonoids significantly affect market sales [28].

Globally, human health and the environment are currently at high risk from food contaminated with heavy metals and other related sources. Heavy metals enter the food chain through natural contamination or due to human activities; they usually accumulate in humans and animals through bioaccumulation effects, slowly causing toxicity and resulting in serious health problems. Long-term exposure to heavy metals can cause progressive neurological and muscular degeneration that can result in Parkinson's disease, muscular dystrophy, Alzheimer's disease and multiple sclerosis [8]. Moreover, the consumption of fruit contaminated with heavy metals can pose a serious health risk, highlighting the importance of controlling and determining the level of contamination to ensure their quality and safety [5].

Nickel is the 24th most abundant element in the Earth's crust and the 5th most abundant element by weight after iron, oxygen, magnesium and silicon [29]. Nickel (Ni) is a chemotoxic, immunotoxic, neurotoxic, genotoxic, nephrotoxic, hepatotoxic agent. It also causes reproductive and pulmonary toxicity. Acute Ni toxicity results in kidney disease, nausea and vomiting. Chronic exposure to Ni results in hepatic and renal toxicity, hypothermia, bronchitis and rhinitis [27]. In the scientific literature there are several *in vivo* studies related to Ni concentration in the human body. For example, a study conducted by Zeneli et al. [33]determined serum Ni concentrations in men (70 in number) between 31 and 64 years of age, who worked in a thermal power plant, and men aged 30 to 65 years of age (27 in number), who did not work in a thermal power plant (control subjects), in Kosovo as 2.76 ± 0.4 and 2.18 ± 0.2 μg/dm^3, respectively. In addition, *in vivo* study by Nisse et al. [25] was conducted on 2,000 adults (982 men and 1,018 women) in northern France. In this study, blood and urine samples were analyzed for the presence of Ni and other metals and metalloids. Nickel was detected in 99.95 % in the blood and 98.38 % in urine samples.

Manganese (Mn) pollution from industrial processes and mining contaminates water, creating a toxic environment. Chronic exposure to low levels of Mn can lead to behavioral, cognitive and motor dysfunctions, primarily affecting the central nervous system. Excess Mn accumulates in the basal ganglia, causing neurological problems similar to Parkinson's disease. Additionally, manganese exposure can result in hematological, nephrotoxic, endocrine and hepatotoxic effects. The inhalation of manganese dust can cause lung irritation and cardiovascular problems. Astrocytes in the central nervous system serve as reservoirs for manganese, which may contribute to the development of type II astrocytosis in Alzheimer's disease. Additionally, Mn also disrupts cholesterol metabolism, leading to liver and cardiovascular damage [9].

According to the WHO, the city of Mitrovica (Kosovo) and its surroundings are among the most polluted cities in Europe due to the proximity of a lead-zinc ore mine [22]. Heavy metal contamination in agricultural products, fruit and vegetables, as well as in animals, contributes to the consumption of products with a high content of heavy metals, which negatively affects human health.

This study determined the concentrations of the heavy metals Mn and Ni in stone fruits (cherries and sour cherries) and berry fruits (raspberries and blackberries) from three areas in Kosovo (Zvecan, Frasher and Polski) in the Mitrovica area, as well as provided a calculation of the bioconcentration factor and the daily intake rate of manganese and nickel from these fruits.

Materials and methods

Samples

Stone fruits (cherries and sour cherries) and berries (raspberries and blackberries) were examined in their technological and nutritional maturity (2023). An analysis of the soil on which these fruits were grown was also performed. Namely, this research was conducted in three areas in Kosovska Mitrovica region (42.883°N, 20.867°E) in Kosovo. Two areas, Zvecan (42°54'27"N, 20°50'25.01"E) and Frasher (42°34'59.88"N, 21°00'0.36"E), are located in the immediate vicinity of the lead and zinc smelter, while the third area, Polski (43°25' 00", 25°39'00"), is at a significantly greater distance from the smelter.

All samples for analysis were dried to constant mass in a drying oven (Drying Oven SLN 15, Wodzisław Śląski, Poland) for a period of 24 to 30 hours, depending on the type of fruit, and stored in sterile plastic cups.

Chemical analysis

The concentration of Mn and Ni in the selected fruit species was determined using an accredited method [23] based on microwave digestion and inductively coupled plasma mass spectrometry ICP-MS (model 7500cx, Agilent, USA) - flexible range method. More particularly, Mn and Ni in the soil were determined using the accredited methods [16, 17] with ICP-MS technique [18].

Data analysis

For the Daily Intake Rate (DIR), the metal content from each region in each fruit was calculated and multiplied by the respective consumption rate. Daily Intake Rate (DIR) was determined using the following equation 1 [7]:

$$DIR = C \times D \quad (1)$$

where: C is the concentration of heavy metals in fruit (mg/kg) in fresh fruit weight, while D is the daily fruit intake (kg/person/day of fresh fruit).

The bioconcentration factor (BCF) of heavy metals from soil to fruit is determined by calculating the ratio of the concentration of each heavy metal in the fruit and the concentration of the corresponding heavy metals in the corresponding soil. If the value of BCF is lower than 1, this means that the movement of heavy metals from the soil to fruit is lower, while if the BCF value is greater than 1, this indicates a greater intake of heavy metals from the soil into the fruits [3, 15].

The bioconcentration factor (BCF) is determined using the following equation 2:

$$\text{BCF} = \frac{C_{fruit}}{C_{\text{soil}}} \qquad (2)$$

where: C_{fruit} is the heavy metal concentration in dried fruit, while C_{soil} is the concentration of heavy metals in the soil.

Statistical analysis

Statistical data processing was performed using Microsoft Excel 2013. A statistical correlation was made using the Pearson correlation coefficient and Student's t-test on the concentration of Ni and Mn between stone fruits (cherries and sour cherries) and berry fruits (raspberries and blackberries) [20].

Results and discussion

The Mn and Ni contents in the dry weight (d.w.) of different types of examined fruit (cherries, sour cherries, raspberries and blackberries) grown in the three different regions around the city of Kosovska Mitrovica are given in Table 1. The average concentration of Mn in dry mass of cherries and sour cherries (in all three regions) is quite similar; moreover, a higher Mn concentration was observed in blackberries, while the highest Mn concentration was determined in raspberries. The highest concentration of Ni of 48.2 mg/kg d.w. was determined in sour cherries.

Table1. Heavy metals content in fruit grown in the study area (dry weight)
Tabela 1. Zawartość metali ciężkich w owocach uprawianych na badanym obszarze (masa sucha)

Regions / Region	Stone fruits / Owoce pestkowe				Berry fruits / Owoce jagodowe			
	Cherries / Wiśnie		Sour cherries / Wiśnie kwaśne		Raspberries / Maliny		Blackberries / Jeżyny	
	Mn (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Ni (mg/kg)
Zvecan	16.70	14.10	14.30	29.90	72.70	19.50	40.80	19.10
Frasher	12.30	39.00	13.70	48.20	65.00	23.80	33.60	24.80
Polski	9.55	15.40	11.90	13.30	58.60	8.52	24.60	14.10
Average value / Wartość średnia	12.85	22.83	13.33	30.47	65.43	17.27	33.00	19.33

For the determination of the content of Mn and Ni in the fruit, wet weight (w.w.), it was necessary to determine the water and dry matter content (presented in Table 2).

Table 2. Water and dry matter in fruit cultivated in the study area
Tabela 2. Zawartość wody i suchej masy w owocach uprawianych na badanym obszarze

Fruit / Owoce	Cherries / Wiśnie			Sour cherries / Wiśnie kwaśne			Raspberries / Maliny			Blackberries / Jeżyny		
Region / Region	Zvecan	Frasher	Polski	Zvecan	Frasher	Polski	Zvecan	Frasher	Polski	Zvecan	Frasher	Polski
Water / Woda [%]	87.5	87.7	89.0	86.3	85.4	84.0	82.8	86.0	85.8	81.8	79.1	82.1
Dry matter / Sucha masa [%]	12.5	12.3	11.0	13.7	14.6	16.0	17.2	14.0	14.2	18.2	20.9	17.9

The concentration of heavy metals in fresh fruits is calculated using the following formula 3:

$$C_{ww} = C_{dw}\left[\frac{100-W}{100}\right] \tag{3}$$

where: C_{ww} is the concentration of the metal in the fruit, wet weight; C_{dw} is the concentration of the metal in the fruit dry weight and W is the water content in %.

Figure 1 shows that the Mn content is several times higher in berry fruits than in stone fruits. The Mn content in cherries and sour cherries is in accordance with the research of Manea, and the Mn content in raspberries is in accordance with the research of Grembicka [14; 21]. In his research, Al Juhaimi determined higher concentrations of Mn in cherries and sour cherries, however, this certainly depends on the Mn content in the soil in which they are grown [2]. The dominant microminerals in blackberries from the study by Moraes were Mn and Cu [24]. The Mn content in blackberries from this study corresponds to the Mn content determined by Moraes et al. [24].

The highest concentration of Mn of 12.5 mg/kg w/w was determined in raspberries, and among all fruit samples, the lowest Mn concentrations were found in fruit from the Polski area, which is the furthest location from the smelter.

All types of fruit from the Frasher area have the highest Ni concentration, and fruit from the Polski area has the lowest Ni concentration. The Ni content in all types of fruit is higher than in previous studies [14, 21], but is within the permissible limits according to WHO [32].

The daily intake rate (DIR) for Mn and Ni when consuming cherries, sour cherries, raspberries and blackberries is given in Table 3. The daily consumption of fruit is proposed for Mn in berries 0.352 g/kg/day for adults and 1.5524 g/kg/day for children, Ni in adults and children 0.0006 g/kg/day) [11].

The daily intake rate of Mn and Ni is much lower for stone fruits (cherries and sour cherries) than for berries (raspberries and blackberries). The highest daily intake rate for Mn is found in raspberries and blackberries, but it is much lower than the upper tolerable daily intake limit for both adults and children (11 mg/day) [7]. Raspberries and blackberries have higher daily intake rates than cherries and sour cherries, and for Ni, it ranges between 0.0621 and 0.1768 mg/day.

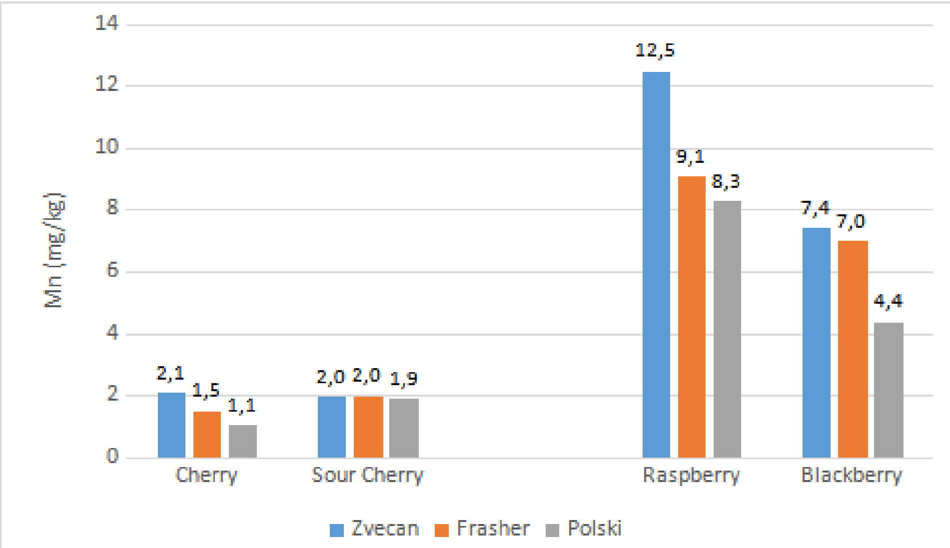

Figure 1. Content of Mn in fruit grown in the study area (wet weight)
Rycina 1. Zawartość Mn w owocach uprawianych na badanym obszarze (masa mokra)

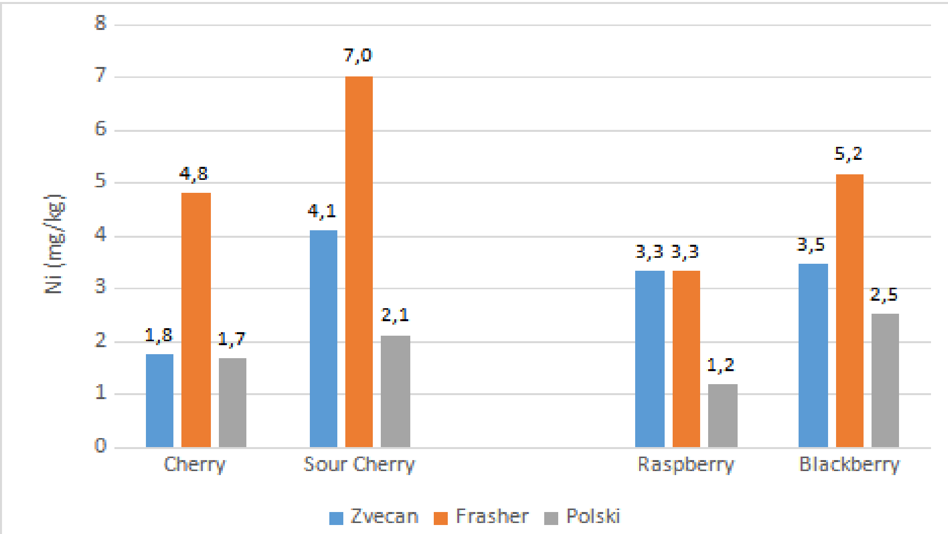

Figure 2. Content of Ni in fruit grown in the study area (wet weight)
Rycina 2. Zawartość Ni w owocach uprawianych na badanym obszarze (masa mokra)

Table 3. DIR for Mn and Ni in the analyzed fruit from different regions
Tabela 3. DIR dla Mn i Ni w analizowanych owocach z różnych regionów

Fruit / Owoc	Region / Region	DIR (mg/day)			
		Mn		Ni	
		Adults / Dorośli	Children / Dzieci	Adults / Dorośli	Children / Dzieci
Cherries / Wiśnie	Zvecan	0.001254		0.001056	
	Frasher	0.000906		0.002880	
	Polski	0.000630		0.001014	
Sour cherries / Wiśnie kwaśne	Zvecan	0.001176		0.002460	
	Frasher	0.001200		0.004224	
	Polski	0.001140		0.001278	
Raspberries / Maliny	Zvecan	0.308000	0.310669	0.082544	0.114367
	Frasher	0.224224	0.310669	0.082051	0.113685
	Polski	0.205005	0.284041	0.029814	0.041309
Blackberries / Jeżyny	Zvecan	0.183075	0.253656	0.085747	0.118805
	Frasher	0.172973	0.150214	0.127635	0.176843
	Polski	0.108416	0.150214	0.062093	0.086032

These values are still lower than the tolerable upper intake level of 300 μg /day for children given by the Food and Nutrition Board and Institute of Medicine [30].Various studies indicate highly variable dietary intake of nickel, but the typical daily intake of this metal from food ranges between 100 and 300 μg/day in most countries [6].

Table 4 presents the concentration of nickel and manganese in the soil on which the cherries, sour cherries, raspberries and blackberries analyzed in this research were grown.

Table 4. Concentration of Mn and Ni in soil
Tabela 4. Stężenie Mn i Ni w glebie

Heavy metals / Metale ciężkie (mg/kg)	Region / Region		
	Zvecan	Frasher	Polski
Mn	715	929	528
Ni	50.5	66.1	48.8

The Mn concentration in all three regions is significantly higher than the Ni concentration in the same soil. The Ni content in the soil, compared to the Mn content, seems to be very low, however, according to European regulations, it is high and very close to the prescribed Ni concentration in soil of 70 mg/kg [12]. The movement of metals from the soil into fruit depends on the type of metal and the type of fruit. The ability to extract metals from the soil and accumulate them in fruit is determined by the bioconcentration factor.

Table 5 presents the bioconcentration factor (BCF) in cherries, sour cherries, raspberries and blackberries grown in the Zvecan, Frasher and Polski regions.

If one compares the values of BCF for manganese and BCF for nickel, it can be concluded that BCF for nickel is much higher than BCF for manganese in all fruit. For example, as regards sour cherries, BCF for Ni in relation to BCF for Mn is as much as 27.95 times higher, and in cherries 21.94 times higher. In berries, this ratio is lower in relation to stone fruits; for instance, in raspberries, BCF for Ni is 3.27 times higher than in the case of BCF for Mn, while in blackberries 7.38 times higher.

Table 5. Bioconcentration factor (BCF) in the analyzed fruit
Tabela 5. Współczynnik biokoncentracji (BCF) w analizowanych owocach

Region / Region	Stone fruits / Owoce pestkowe				Berry fruits / Owoce jagodowe			
	Cherries / Wiśnie		Sour cherries / Wiśnie kwaśne		Raspberries / Maliny		Blackberries / Jeżyny	
	Mn	Ni	Mn	Ni	Mn	Ni	Mn	Ni
Zvecan	0.023	0.279	0.020	0.592	0.102	0.386	0.057	0.378
Frasher	0.013	0.590	0.015	0.729	0.070	0.360	0.036	0.375
Polski	0.018	0.316	0.023	0.273	0.111	0.175	0.047	0.289
Average value / Wartość średnia	0.018	0.395	0.019	0.531	0.094	0.307	0.047	0.347

This means that all analyzed fruit extracts more nickel from the soil than manganese. In addition, stone fruit extracts nickel from the soil and accumulates it much more than berries. If we compare the mean BCF value for Mn in stone fruit (0.0185) with the mean BCF value for Mn in berries (0.07), we can see that berries have a 3.78 times higher BCF for Mn extracted from the soil than stone fruits. The mean BCF value for Ni in stone fruits (0.463) is higher than the mean BCF value for Ni for berries (0.327), i.e. stone fruits extract Ni from the soil 1.42 times more than berry fruits.

Table 6 presents the correlation coefficients for the concentration of Mn and Ni between the analyzed fruit, wet weight. The results show a small positive correlation (0.0256) for Mn and a very large positive correlation for Ni (0.8390) between the analyzed stone and berry fruits.

Table 6. Correlation of Mn and Ni concentration between stone and berry fruits
Tabela 6. Korelacja stężenia Mn i Ni w owocach pestkowych i jagodowych

	Correlation coefficient / Współczynnik korelacji
Correlation of Mn between stone and berry fruits / Korelacja Mn pomiędzy owocami pestkowymi i jagodowymi	0.0256
Correlation of Ni between stone and berry fruits / Korelacja Ni pomiędzy owocami pestkowymi i jagodowymi	0.8390

Table 7 presents the results of a Student's t-test for the concentration of Mn and Ni in stone fruits (cherries and sour cherries) and berries (raspberries and blackberries).

Table 7. Student's t-test of Mn and Ni concentration between stone and berry fruits
Tabela 7. Test t-Studenta pomiaru stężenia Mn i Ni w owocach pestkowych i jagodowych

	Mn		Ni	
	Stone fruits / Owoce pestkowe	Berry fruits / Owoce jagodowe	Stone fruits / Owoce pestkowe	Berry fruits / Owoce jagodowe
Average values / Wartości średnie	1.7516667	8.1283333	3.5866667	3.1783333
Values of t-test / Wartości testu t	-5.7809734		0.4005642	
Obtained *p*-value / Otrzymane wartości *p*	0.0001775		0.6971651	
Critical value for t / Krytyczne wartości dla t	2.2281389		2.2281389	

Based on the results of the Student's t-test shown in Table 7, it can be seen that there is no difference between the concentration of manganese in stone and berry fruits (-5.7809734 < 0.0001775). The obtained p-value 2.2281389 > the marginal *p*-value (0.05) indicating that there is no statistically significant difference between the concentrations of manganese in the examined stone and berry fruits. Based on the statistical processing of the nickel results, the t-test values (0.4005642 < 0.6971651) show that there is no difference in Ni concentration between stone and berry fruits and there is no statistically significant difference, because the obtained *p*-value 2.2281389 > the marginal *p*-value (0.05).

Conclusions

1. The results show that the highest concentration of nickel was observed in sour cherries from the Frasher region (48.2 mg/kg d.w. or 7.04 mg/kg w.w.), while the lowest concentration was measured in raspberries from Polski (8.52 mg/kg d.w. or 1.21 mg/kg w.w.). Stone fruits have higher concentrations of nickel than berries in

almost all examined regions, and berries have higher concentrations of manganese in all regions. The highest concentration of manganese is found in raspberries from the Zvecan region (72.7 mg/kg d.w. or 12.5 mg/kg w.w.), while the lowest in cherries from Polski (9.55 mg/kg d.w. or 1.05 mg/kg w.w.).

2. The daily intake of Mn and Ni in berries is higher for both Mn and Ni than in stone fruits. Raspberries and blackberries have the highest daily intake for Mn, but it is still much lower than the upper tolerable daily intake limit for Mn.
3. The BCF values lead to the conclusion that all analyzed fruit has a greater ability to extract nickel from the soil than manganese. Berries have a greater ability to accumulate manganese compared to stone fruits [14]. However, the ability to extract manganese from the soil is greater in berries, 3.81 times more than in stone fruits. The manganese content in the soil is much higher than the nickel content, but since the manganese extraction ability of the analyzed fruit is low, there are no large differences between the concentrations of manganese and nickel in the analyzed fruit.
4. The t-test values show that there is statistically significant difference of manganese between stone and berry fruits (*p*-values < the marginal *p*-values) and no statistically significant difference of nickel between stone and berry fruits (*p*-values > the marginal *p*-values). A regular monitoring should be enforced in this area, as metal accumulation can be toxic to consumers when they are present in excess or can cause certain diseases when present in quantities not suitable for human health. The findings in this study are important for fruit safety assessment and risk management of heavy metals in fruit, as well as in other horticultural crops that are used in a human diet.

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MANGAN I NIKIEL W JAGODACH I OWOCACH PESTKOWYCH Z REGIONÓW W POBLIŻU HUTY W KOSOWIE: WNIOSKI DOTYCZĄCE WSPÓŁCZYNNIKA BIOKONCENTRACJI I DZIENNEGO POBIERANIA

S t r e s z c z e n i e

Wprowadzenie. Zanieczyszczenie metalami ciężkimi stanowi poważne ryzyko dla zdrowia ludzi, zwierząt i roślin ze względu na ich toksyczność i akumulację w tkankach biologicznych. Celem tego badania było określenie stężeń niklu (Ni) i manganu (Mn) w wiśniach, wiśniach kwaśnych, malinach i jeżynach uprawianych w trzech różnych regionach w pobliżu huty rudy ołowiu i cynku. Oznaczenie niklu i manganu przeprowadzono metodą spektrometrii masowej ze wzbudzeniem plazmą sprzężoną indukcyjnie (ICP-MS). Określono również współczynnik biokoncentracji niklu i manganu, który dostarcza informacji na temat pobierania i akumulacji metali w tkankach roślin.

Wyniki i wnioski. Najwyższe stężenie Ni zmierzono w wiśniach (48,2 mg/kg s.m. lub 7,04 mg/kg w.w.), a Mn w malinach (72,7 mg/kg s.m. lub 12,5 mg/kg w.w.). Ponadto w regionie najbardziej oddalonym od huty zmierzono najniższe stężenie Mn w wiśniach i najniższe stężenie Ni w malinach. Ponadto stwierdzono, że dzienne wskaźniki pobrania (DIR) Mn i Ni były wyższe w przypadku jagód, ale niższe niż te, które są dopuszczalnymi dziennymi limitami. Współczynnik biokoncentracji (BCF) dla manganu w owocach pestkowych jest niższy niż w przypadku jagód i jest znacznie niższy niż dla Ni dla obu rodzajów owoców. Owoce pestkowe wykazały większą zdolność do akumulacji niklu, a jagody większą zdolność do akumulacji manganu. Analiza statystyczna wyników wykazała, że różnice w stężeniu manganu pomiędzy owocami pestkowymi i jagodowymi są statystycznie istotne, natomiast w przypadku niklu nie są statystycznie istotne.

Słowa kluczowe: owoce, nikiel, mangan, współczynnik biokoncentracji, dzienna norma spożycia