ORIGINAL ARTICLE

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Health risk assessment of cadmium and lead in root vegetables from retail and private cultivation in the Silesian Province, south-west Poland

Ocena ryzyka zdrowotnego związanego z obecnością kadmu i ołowiu w warzywach korzeniowych pochodzących z handlu detalicznego i upraw prywatnych zlokalizowanych na terenie województwa śląskiego w Polsce

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Abstract

Introduction and Objective. Root vegetables are an essential part of a healthy diet, but they can also accumulate heavy metals, such as cadmium (Cd) and lead (Pb). The Silesian Province is one of the most polluted areas in Poland; as a result, concerns have been raised about the safety of locally produced food due to elevated concentrations of heavy metals in the region›s soils. The aim of the study is to determine the concentrations of toxic heavy metals (Cd and Pb) in root vegetables and assess the potential health risks associated with their consumption.

Materials and Method. The study included 114 samples of root vegetables (including carrots, parsley roots and potatoes) harvested in autumn 2025 and collected from commercial and private sources in the Silesian Province in south-west Poland. The Cd and Pb content of the samples was determined using a flameless electrothermal atomic absorption spectrometer (ET-AAS). Non-parametric tests were used for statistical analysis. Health risk assessment was performed using the hazard quotient (HQ) and margin of exposure (MoE).

Results. The permissible concentration of Cd was exceeded in 35 samples, while the permissible level of Pb was exceeded in samples. The exposure assessment indicated that HQ values for Cd exceeded 1 in some high-concentration carrot samples (Cd: 1.43). The low MoE values obtained for Pb, particularly under Scenario II, suggest that potential health concerns cannot be completely ruled out.

Conclusions. The study results indicate the need for regular monitoring of heavy metal content in vegetables, especially in industrialized regions.

Key words

environmental exposure, food safety, toxic metals, dietary exposure

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Streszczenie

Wprowadzenie i cel pracy. Warzywa korzeniowe są niezbędnym elementem zdrowej diety, ale mogą gromadzić metale ciężkie, takie jak kadm (Cd) i ołów (Pb). Województwo śląskie jest jednym z najbardziej zanieczyszczonych regionów w Polsce. W związku z tym pojawiły się obawy dotyczące bezpieczeństwa lokalnie produkowanej żywności ze względu na podwyższone stężenie metali ciężkich w glebach regionu. Celem badania było określenie stężeń toksycznych metali ciężkich (Cd i Pb) w warzywach korzeniowych i ocena potencjalnych zagrożeń dla zdrowia związanych z ich spożywaniem.

Materiał i metody. Badaniem objęto 114 próbek warzyw korzeniowych (w tym marchwi, korzeni pietruszki i ziemniaków) zebranych jesienią 2025 roku ze źródeł komercyjnych i prywatnych w województwie śląskim. Zawartość Cd i Pb w próbkach oznaczono za pomocą bezpłomieniowego elektrotermicznego spektrometru absorpcji atomowej (ET-AAS). Do analizy statystycznej wykorzystano testy nieparametryczne. Ocenę ryzyka dla zdrowia przeprowadzono z wykorzystaniem ilorazu zagrożenia (HQ) i marginesu narażenia (MoE).

Wyniki. Dopuszczalne stężenie Cd zostało przekroczone w trzydziestu pięciu próbkach, a dopuszczalny poziom Pb w pięciu. Ocena narażenia wykazała, że wartości HQ dla Cd przekroczyły 1 w niektórych próbkach marchwi o wysokim stężeniu (Cd: 1,43). Niskie wartości MoE uzyskane dla Pb, szczególnie w Scenariuszu II, sugerują, że nie można całkowicie wykluczyć potencjalnych zagrożeń dla zdrowia wynikających z obecności kadmu i ołowiu w badanych warzywach.

Wnioski. Wyniki badań wskazują na konieczność regularnego monitorowania zawartości metali ciężkich w warzywach, szczególnie w tych uprawianych w regionach uprzemysłowionych.

Słowa kluczowe

bezpieczeństwo żywności, metale toksyczne, narażenie na czynniki środowiskowe, narażenie drogą pokarmową

INTRODUCTION

Vegetables are an essential and irreplaceable part of a healthy diet. The World Health Organization (WHO) recommends consuming at least 400 g of fruit and vegetables daily, while global guidelines advise eating 5 portions of fruit and vegetables, 3 of which should be vegetables. These provide essential micronutrients such as copper, zinc, magnesium and potassium, as well as antioxidants and vitamins [1–4]. The health quality of vegetables is crucial due to their frequent consumption, and contamination with toxic heavy metals can pose a significant threat to human health. Particular attention is paid to heavy metals such as cadmium (Cd) and lead (Pb), as they are persistent and able to bioaccumulate in soil, posing a significant threat to consumers of agricultural products. Root vegetables are particularly susceptible to absorbing these elements from the soil, potentially exposing humans to toxic substances [5]. The bioavailability of heavy metals is significantly influenced by the physico-chemical properties of soil. Factors such as soil pH, organic matter content and texture can significantly affect metal mobility; for instance, acidic soils often increase the solubility of heavy metals, rendering them more accessible to plants. Conversely, higher levels of organic matter can bind metals, thereby reducing their bioavailability and subsequent uptake by plants [6, 7]. Different plant species have different capacities for heavy metal uptake, which are influenced by their root structure, growth habits and physiological mechanisms. Environmental factors, such as rainfall, temperature and humidity, can also affect the migration of heavy metals. For instance, heavy rainfall can cause metals to leach from the soil, thereby increasing their concentration in the soil solution and their uptake by plants. Conversely, dry conditions can limit metal mobility, reducing their availability for plant uptake. Seasonal changes can also affect plant growth and metal accumulation, with different growth stages potentially leading to different levels of metal uptake [8–10].

In the case of non-smokers, dietary intake, particularly of plant-based foods such as carrots and celery, is the main source of exposure to Cd. Renal and circulatory dysfunction, reproductive disorders, diabetes, cerebral infarction and other neurotoxic effects can be the result of exposure to Cd [11–13]. This element and its compounds has been classified into Group 1 by the International Agency for Research on Cancer (IARC) as carcinogenic to humans [14]. Pb and its compounds have been classified by the IARC as possibly carcinogenic to humans, with inorganic Pb compounds classified as Group 2A – probably carcinogenic to humans. Pb can affect the nervous system, which is particularly dangerous for foetuses, infants and children as it disrupts brain development and negatively impacts cognitive function [14, 15].

The Silesian Province is considered one of the most anthropogenically burdened areas in Poland, characterised by long-term emissions of pollutants from industry, transport and the energy sector. Consequently, the soils in the region may contain elevated concentrations of heavy metals, which raises legitimate concerns about the safety of locally produced food [16]. Consuming food contaminated with heavy metals is one of the main ways in which humans are exposed to these compounds, and long-term consumption of contaminated vegetables and other crops can lead to increased bioaccumulation of these elements in the body [4]. In this study, the hazard quotient (HQ) for Cd was calculated according to the Agency for Toxic Substances and Disease Registry›s (ATSDR) methodology, i.e. as the ratio of the estimated exposure dose to the reference dose. This was performed in order to assess the potential non-carcinogenic effects [17, 18]. For Pb, the margin of exposure (MoE) approach was used in accordance with the European Food Safety Authority (EFSA) assessment, which withdrew the previous Provisional Tolerable Weekly Intake (PTWI) value and indicated that it was impossible to establish a safe exposure level due to the potential for health effects at even low concentrations [19].

OBJECTIVE

The aim of the study is to determine the concentrations of the toxic metals Pb and Cd in 114 samples of root vegetables and assess the potential health risks associated with their consumption.

MATERIALS AND METHOD

Research material. The research material consisted of 114 samples of root vegetables, including 71 carrots, 15 parsley, and 28 potatoes, harvested in the autumn of 2025. Eighty-three of these samples came from 6 of the most popular retail chains, independent retailers, and local markets located in the Silesian Province, and 25 from individual crops belonging to residents of various cities in the Province. For 6 samples, data on the origin of the vegetables were not available.

[The study included samples of carrots, root parsley, and potatoes from home gardens and homegrown crops located in the Silesian Province, as well as from retail chains located in the same locations as the homegrown crops].

Sampling was conducted in 2 stages: first, the maximum number of available samples was obtained from homegrown crops, and corresponding samples purchased from retail stores were then selected. Samples that were damaged, spoiled, of unknown origin, or insufficient for laboratory analysis were excluded from the study. The geographic origin of vegetables purchased from retail chains was not a criterion for sample selection. The study was designed to compare the potential exposure of consumers consuming home-grown root vegetables with that associated with consuming vegetables available in retail stores. Therefore, store samples were classified regardless of the declared place of production, considering them to be representative of products actually available to consumers in the local market. Each sample was placed in a clean plastic bag and carefully labelled with information about the location and date of collection.

Preparation of the sample. The vegetable samples were prepared for analysis in the same way they are prepared for consumption, i.e. prepared by first cleaning them of any soil (if necessary), washing them, and then peeling and grating them on fine-mesh sieves. Next, approximately 1 gram of each vegetable was weighed into Teflon containers.

Chemical analysis of root vegetables. To each weighed sample, 9 mL of spectrally pure, 65% concentrated nitric acid (HNO_3) and 1 mL of 30% hydrogen peroxide (H_2O_2)

Table 1. Method description and measuring conditions of the spectrometer ET-AAS

Element	Cd	Pb
Analytical methods	ET-AAS	
Line [nm]	8	0
Calibration curve		
Calibration range [μg/L]	00–20.00	00–40.00
Calibration of failure criteria: R^2	≥ 0.995	
RSD for standards [%]	< 10%	
Calibration type	least squares	
Characteristics of the method		
R^2 value	995 – 1.000	998–0.999
Recovery [%]	90–107	81–109
RSD [%]	< 20%	
LOD [mg/kg]	003	03
LOQ [mg/kg]	005	05
Measuring conditions of the spectrometer		
Slit width [nm]	50	00
Lamp current [mA]	00	00
Background correction	deuterium	
Sample volume [μL]	00	00*
Gas flow (Ar 99,999%) [L/min]	3	
Spectrometer ambient temperature [°C]	10–35	
Air humidity [%]	3–30	

Table 2. Cadmium and lead cuvette programme

Element	Step	Cuvette program			
		Final temperature [°C]	Rise time [s]	Maintenance time [s]	Gas type
Cd	1	50	0	0	inert
	Injection				
	3	100	0	0	inert
	4	120	0	0	inert
	5	300	0	0	inert
	6	300	0	0	inactive
	7	1,800	0	0	inactive
	8	2,100	0	0	inert
Pb	1	50	0	0	inert
	Injection				
	3	100	0	0	inert
	4	120	0	0	inert
	5	600	0	0	inert
	6	600	0	0	inactive
	7	2,200	8	0	inactive
	8	2,200	0	0	inert

were added. All samples underwent a pressure-assisted mineralization process using microwave energy in a Milestone ETHOS UP Microwave Mineralizer. The Cd and Pb content of the mineralized root vegetable samples was determined using an electrothermal atomic absorption spectrometer (ET-AAS) without a flame. The spectrometers were calibrated using certified CPAchem standard solutions with the following serial numbers: 923783 and 1105278 for Cd, and 923785 and 1105277 for Pb. Tables 1 and 2 present the detailed sample mineralization programme and description of the method used, and the ET-AAS measurement conditions of the spectrometer.

Assessment of exposure. The study estimated the oral exposure of adult consumers to Cd and Pb contained in root vegetable samples. The health risk assessment was based on 2 scenarios: 1) assumed average concentrations of Cd and Pb in the selected vegetables, 2) considered maximum concentrations of Cd and Pb. The following formula was used to perform the necessary calculations:

$$ADD = (C \times IngR \times EF \times ED)/(BW \times AT)\ [mg/kg/day]$$

where:
ADD – Average Daily Dose, or the average potential daily dose of a heavy metal (mg/kg/day).
C – Concentration, or the concentration of the heavy metal determined in the tested sample (mg/g). To ensure consistency with the accepted form of the equation, where IngR is expressed in g/day, C units were converted to mg/g for the ADD calculations. This conversion (1 mg/kg = 0.001 mg/g) ensures consistent unit conversion throughout the equation without affecting the final ADD value; it merely guarantees the accuracy of the calculations› dimensions.
IngR – Ingestion Rate, or the daily intake of the selected root vegetable (g/day).
EF – Exposure Frequency, or the frequency of exposure (days).
ED – Exposure Duration, or the duration of exposure (years).
BW – Body Weight, or the average body weight (kg).
AT – Averaging Time, or the average exposure time (days).

The following parameters were used to calculate the average potential daily dose of heavy metals.
Scenario I – average concentration of Cd and Pb in tested root vegetables [mg/g].
Scenario II – maximum concentration of Cd and Pb in the tested root vegetable samples [mg/g].
IngR – Daily consumption of root vegetables (186 g/day);
EF – 365 days;
ED – 70 years;
BW – 80 kg;
AT – 25 550 days [3, 20].

The health risk assessment of adult consumers exposed to Cd orally through the consumption of select root vegetables was based on the estimation of the hazard quotient (HQ) using the following formula:

$$HQ = ADD/RfD$$

where: RfD (Reference Dose) is the reference dose for Cd, which is 0.001 mg/kg/day.

HQ values above 1 indicate that exposure exceeds the reference level and may be associated with an increased potential for adverse health effects [17, 18].

Due to the lack of an established Reference Dose (RfD) for Pb, the non-carcinogenic risk assessment for adults exposed to Pb orally from consuming selected root vegetables was

Table 3. Cadmium and lead content in tested root vegetables (mg/kg fw)

Vegetable Type	Quantity (pcs)	Cd			Pb		
		Concentration Range: (Min. – Max.)	Mean ± SD (Median)	Maximum level* (exceedances)	Concentration Range: (Min. – Max.)	Mean ± SD (Median)	Maximum level* (exceedances)
Carrot	71	<0.005 – 0.617	146 ± 0.158 (0.082)	10 (23)**	<0.05 – 0.128	096 ± 0.032 (0.107)	10 (3)**
Parsley root	15	006 – 0.361	081 ± 0.112 (0.035)	050 (7)**	<0.05 – 0.153	027 ± 0.053 (0.101)	10 (2)**
Potato	28	<0.005 – 0.351	073 ± 0.064 (0.068)	10 (5)**	<0.05 – 0.064	008 ± 0.020 (0.055)	10 (0)**
Individual crops	25	<0.005 – 0.351	110 ± 0.081 (0.083)	10 $^{c, p}$ / 0.05 ^{pr} (8)**	<0.05–0.107	070 ± 0.025 (0.061)	10 (1)**
Purchased	83	<0.005 – 0.617	125 ± 0.156 (0.063)	10 $^{c, p}$ / 0.05 ^{pr} (24)**	<0.05–0.153	092 ± 0.043 (0.079)	10 (4)**

*- Based on Commission Regulation (EU) 2023/915, issued on 25 April 2023, which establishes maximum levels of certain contaminants in food and repeals Regulation (EC) No. 1881/2006 [22],
**- Number of samples > maximum level, ^{c} – carrot, ^{p} – potato, ^{pr} – parsley root.

Table 4. Estimated oral exposure of adults to cadmium

Vegetable Type	Scenario I		Assessment of exposure	Scenario II		Assessment of exposure
	Cd [mg/kg fw]	ADD [mg/kg/day]	HQ	Cd [mg/kg fw]	ADD [mg/kg/day]	HQ
Carrot	138	00032085	32	617	001434525	**43**
Parsley root	081	000188325	19	361	000839325	84
Potato	073	000169725	17	351	000816075	82

Table 5. Results of MoE estimation for adults for Pb

Vegetable Type	Scenario I		Assessment of exposure		Scenario II		Assessment of exposure	
			MoE	MoE			MoE	MoE
	Pb [mg/kg fw]	ADD [mg/kg/day]	N	K	Pb [mg/kg fw]	ADD [mg/kg/day]	N	K
Carrot	007	000016275	71	17	128	0002976	12	04
Parsley root	027	000062775	04	89	153	000355725	77	22
Potato	008	0000186	87	65	064	0001488	23	08

N – Nephrotoxicity; K – Cardiotoxicity.

based on estimating the Margin of Exposure (MoE) using the following formula:

$$MoE = BMDL/ADD$$

where: BMDL (benchmark dose lower confidence limit)—the lower confidence interval of the reference dose, which, for the selected toxic effects, is:

- Nephrotoxicity – 0.63 μg/kg/day;
- Cardiotoxicity – 1.5 μg/kg/day.

The MoE approach allows for a comparative risk assessment. Lower MoE values indicate a smaller margin of safety and potentially greater public health significance, whereas higher values indicate a larger margin of safety. However, the MoE is not a safety threshold, but rather a tool for risk characterisation and substance prioritisation. [19, 21].

Statistical analysis. A statistical analysis was performed using Statistica software, version 13.3, from StatSoft Polska Sp. z o.o. Only results greater than the LOQ were included in the analysis. The normality of the variable distribution was assessed using the Shapiro-Wilk test. Due to the lack of normality of the variables: Cd and Pb concentrations in root vegetable samples, non-parametric tests were used for the subsequent statistical analysis. Specifically, the Mann-Whitney U tests (to compare concentrations in vegetables from individual crops and those purchased) and Kruskal-Wallis test and bilateral comparisons (using the Bonferroniego/Holm correction to adjust p) (to compare concentrations in carrot, parsley root and potato) were employed. To compare the differences in the number of vegetable samples purchased and those originating from individual crops in which Cd and Pb concentrations exceeded maximum permissible levels, a $\chi 2$ test was used.

RESULTS

Content of Cd and Pb in vegetable samples. Table 3 shows the concentration ranges, median and arithmetic means of the determined heavy metals (Pb and Cd) in 114 root vegetable samples. The concentration range for Cd was below the limit of quantification (LOQ) to 0.617 mg/kg fresh weight (fw), while the concentration range for Pb was below LOQ to 0.153 mg/kg fw. Cd concentrations below LOQ were observed in only 5 root vegetable samples (4.17%), while Pb concentrations below LOQ were recorded in 107 samples (89.17%). The highest Cd content was found in the shop-bought carrot sample – 0.617 mg/kg fw. The highest Pb concentration among all the root vegetable samples tested was found in the purchased parsley root – 0.153 mg/kg fw. According to Commission Regulation (EU) 2023/915 of 25 April 2023, on maximum levels of certain contaminants in food and the subsequent repeal of Regulation (EC) No. 1881/2006, the Cd concentration in 23 carrot samples (32.4%) exceeded the maximum permissible level. Cd concentrations above the maximum permissible level were detected in seven 7 (46.7%) of the parsley root samples tested. Five of the 28 potato samples tested exceeded the maximum permissible level (2 were from individual crops). Of the 71 carrot samples tested, 3 had Pb concentrations above 0.10 mg/kg fw. In the case of parsley, exceeded Pb limits were observed in 2 purchased vegetables. No Pb concentrations above the permissible levels were recorded in any of the tested potato samples. Cd concentrations above the maximum permissible level were detected in seven 7 (46.7%) of the parsley root samples tested. Cd and Pb concentrations above the maximum permissible level were recorded in both purchased vegetables and those from individual crops [22].

Health risk assessment. The exposure assessment indicated that HQ values for Cd exceeded 1 in some high-concentration carrot samples, suggesting potential concern related to chronic exposure (Tab. 4).

As the Pb concentrations in celeriac and beetroot were below the LOQ, MoE calculations were only performed for carrots, parsley root and potatoes. The calculated MoE values for both nephrotoxicity and cardiotoxicity were relatively low, decreasing further under Scenario II exposure conditions. These results suggest that potential health risks cannot be entirely excluded, particularly under higher exposure assumptions, given the limited margin between estimated exposure and the selected toxicological reference points (Tab. 5).

Results of statistical analysis. The concentrations of Cd in tested vegetables are presented in Figure 1. The analysis revealed differences in Cd concentrations among various vegetable species (Kruskal-Wallis test; $p < 0.05$). However, bilateral comparisons (using the Bonferroniego/Holm correction to adjust p) indicated that the differences were not statistically significant ($p > 0.013$).

No statistically significant differences were found between the concentration of Cd in purchased vegetables and those

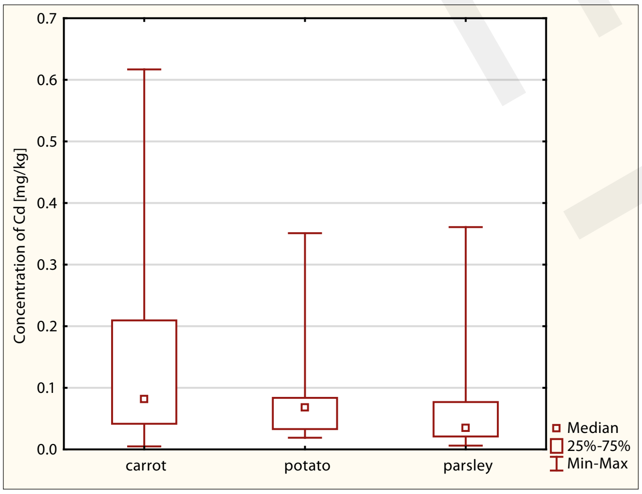

Figure 1. Concentration of Cd in the vegetables

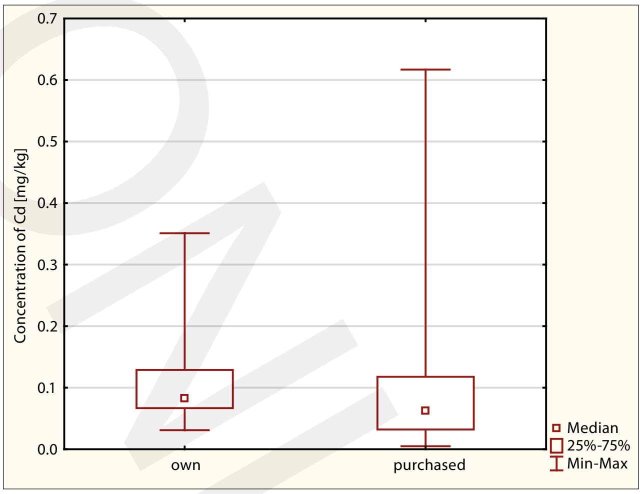

Figure. 2. A Comparison of Cd concentration in root vegetables that were either grown individually or purchased

from individual crops (Mann-Whitney U test; $p > 0.05$) (Fig. 2). The purchased vegetables had higher levels of Pb compared to those grown in home gardens, allotments, or fields. However, the number of samples tested was very small and the differences were not statistically significant ($p > 0.05$, Mann-Whitney U test). The number of samples with Cd and Pb concentrations exceeding the maximum permissible levels did not depend on the origin of the vegetables (own/purchased) ($p > 005$, $\chi2$ test).

DISCUSSION

When comparisons were made between some of the obtained results and those of other authors, it was found that the average Cd concentration in carrots was 0.146 mg/kg fw, whereas Zhou H et al. found an average concentration of 0.161 mg/kg fw [23]. In the study by Heshmati et al., the average Cd concentration in carrots was found to be 0.013 mg/kg fw [24]. In the current study, the average Cd concentration in parsley root was 0.081 mg/kg fw, whereas in the study by Plopeanu, G., the average Cd concentration was 0.028 mg/kg fw [25]. For the same root vegetable, Cozma A et al. found an average Cd concentration of 0.03 mg/kg fw [26]. The average Cd concentration in potato samples in the current study was 0.073 mg/kg fw, whereas in the study by Ćwieląg-Drabek et al., the average Cd concentration in potatoes was found to be 0.18 mg/kg fw [27]. Comparing the results obtained for Pb concentrations in selected root vegetables with those of other authors, the average Pb concentration in carrots was found to be 0.096 mg/kg fw. In the study by Heshmati et al., the average Pb concentration was found to be 0.029 mg/kg fw [24]; in the study by Cozma et al., the average Pb level in carrots was 0.02 mg/kg fw [26]; in a study by Ćwieląg-Drabek et al., the average concentration of this element in carrots was found to be 0.78 mg/kg fw [27]. In the current study, the average Pb concentration of parsley root was 0.027 mg/kg fw. In another study, the average level of this element was found to be 0.02 mg/kg fw [26], whereas in the current study, the average Pb concentration in potatoes was 0.008 mg/kg. In the study by Heshmati et al., the average level was 0.022 mg/kg fw, and in the study by Ćwieląg-Drabek et al., it was 0.20 mg/kg fw [24, 27].

The current study showed no statistically significant differences between the concentration of cadmium (Cd) in root vegetables cultivated privately and those purchased from shops (Mann–Whitney U test; $p > 0.05$). Higher levels of lead (Pb) were found in purchased vegetables than in vegetables cultivated privately (in allotment gardens, home gardens, and fields). Nevertheless, the observed differences were not statistically significant (Mann–Whitney U test; $p > 0.05$). The level of heavy metals in root vegetables depends on the migration of soil contaminants and the physico-chemical properties of the soil, which are largely influenced by anthropogenic sources [5, 28].

For the presented study, 25 samples of root vegetables were collected from our own crops in the Silesian Province, of which 25% exceeded the maximum permissible level of Cd. Upper Silesia is a region of Poland with the highest environmental concentration of heavy metals, which is historically associated with intensive industrial activity, including the smelting of non-ferrous metals and mining. As a result of many years of activity in these sectors, the natural environment of Upper Silesia has become contaminated with Cd and Pb, among others [29, 30]. Referring to the results of the current study and Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels of certain contaminants in food, which repealed Regulation (EC) No. 1881/2006, the permissible concentration of Cd was exceeded in 35 samples, while the permissible level of Pb was exceeded in 5 samples. [22]. Due to the high concentrations of Cd and Pb obtained in the tested samples, exposure to these elements in adult consumers was estimated by calculating HQ for Cd and MoE for Pb. The exposure assessment indicated that HQ values for Cd exceeded 1 in some high-concentration carrot samples, suggesting potential concern related to chronic exposure. However, it should be emphasized that the results obtained for Cd exposure estimation take into account average global vegetable consumption in adult populations (186 g/day), whereas the WHO recommends consuming at least 400 g of vegetables and fruit per day [1, 3]. Therefore, it can be expected that the HQ values for Cd would be higher and that the number of potential risk cases (HQ > 1) would be greater. This suggests the need to monitor Cd levels in root vegetables and to conduct a further assessment of consumer exposure. With respect to the obtained MoE estimation results, however, Pb exposure is associated with an acceptably low risk of nephrotoxicity and cardiotoxicity, even assuming maximum concentrations of this element in root vegetables. The risk of nephrotoxicity is estimated to be slightly higher. However, it should be emphasized that there is no threshold below which adverse effects of Pb exposure do not occur, therefore any concentration of lead in root vegetables is a potential threat, especially since lead compounds have the ability to accumulate in the human body [31]. It is also worth noting that the exposure scenarios considered the adult population only. A similar assessment based on HQ and MoE indicators for the paediatric population could indicate a higher risk of adverse health effects.

The key strength of the study lies in the large sample size (n=114), enhancing the reliability of the results and enabling a more accurate representation of contamination levels. Another significant advantage is the inclusion of 2 sources of vegetable origin – retail and homegrown – enabling a practical comparison relevant to consumers. The use of a precise and sensitive analytical method (ET-AAS) is also noteworthy, ensuring high-quality determinations as confirmed by the validation parameters (high R^2 values, adequate recoveries and low limits of quantification).

Another advantage of the study is the health risk assessment using HQ and MoE indicators, which allowed contamination levels to be described and interpreted in the context of potential health effects. Including 2 exposure scenarios (average and maximum) increased the comprehensiveness of the analysis and allowed both typical and worst-case exposure situations to be assessed.

Despite the numerous advantages of the study, it also has certain limitations which should be taken into consideration when interpreting the results. One such limitation is the lack of detailed characterization of the sample origins (e.g. soil analysis and the level of industrializtion of the location), which prevents more precise linking of metal concentrations to specific pollution sources. It is also worth noting that the exposure assessment averaged parameters such as body weight and vegetable consumption, which may not reflect the actual diversity of the population.

The study provides important and practical information on the health safety of root vegetables consumed in the most industrialised region of Poland, which is a valuable resource for those working in the field. The results, despite their numerous nutritional benefits, indicate that vegetables – especially those grown locally – may be a source of exposure to heavy metals, particularly cadmium, in highly industrialised areas.

The study also demonstrates that health risk assessment based on actual contaminant concentrations and realistic consumption scenarios is a valuable tool that supports the protection of public health. The results can be used as a basis for monitoring food quality, as well as for shaping dietary recommendations and food safety policies. The results also highlight the need for further research and environmental monitoring, particularly given the growing popularity of locally grown foods.

CONCLUSIONS

1) Cd and Pb were detected in root vegetables tested in the Silesian Province in south-west Poland. Some samples exceeded the permissible levels specified by EU law.
2) Cd exposure may represent a greater potential health concern than Pb exposure based on HQ and MoE estimates.
3) MoE values for Pb suggested a relatively low level of concern, although the absence of a safe exposure threshold for Pb should be considered when interpreting the obtained results.
4) The study results indicate the need for regular monitoring of heavy metal content in vegetables, especially in industrialized regions.
5) Future studies should include a larger number of samples of different vegetable species and additional environmental factors that influence the level of contamination in root vegetables.

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