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Food Additives & Contaminants: Part B
Surveillance

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tfab20

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To cite this article: Milana Lazović, Vladimir Tomović, Ivana Vasiljević, Isidora Kecojević, Mila Tomović, Aleksandra Martinović, Tanja Žugić Petrović, Bojana Danilović, Dragan Vujadinović, Igor Tomašević, Milenko Smiljanić & Vesna Đorđević (2023): Cadmium, lead, mercury and arsenic in fresh vegetables and vegetable products intended for human consumption in the Republic of Serbia, 2015–2017, Food Additives & Contaminants: Part B, DOI: 10.1080/19393210.2023.2169359

To link to this article: https://doi.org/10.1080/19393210.2023.2169359

Published online: 07 Feb 2023.

FOOD ADDITIVES & CONTAMINANTS: PART B
https://doi.org/10.1080/19393210.2023.2169359

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ARTICLE

Cadmium, lead, mercury and arsenic in fresh vegetables and vegetable products intended for human consumption in the Republic of Serbia, 2015–2017

Milana Lazović[a,b], Vladimir Tomović[a], Ivana Vasiljević[b], Isidora Kecojević[b], Mila Tomović[c], Aleksandra Martinović[d], Tanja Žugić Petrović[e], Bojana Danilović[f], Dragan Vujadinović[g], Igor Tomašević[h], Milenko Smiljanić[g], and Vesna Đorđević[i]

[a]Faculty of Technology Novi Sad, University of Novi Sad, Novi Sad, Republic of Serbia; [b]A BIO TECH LAB d.o.o., Sremska Kamenica, Republic of Serbia; [c]Technical School "Pavle Savić", Novi Sad, Republic of Serbia; [d]Faculty for Food Technology, Food Safety and Ecology, University of Donja Gorica, Podgorica, Montenegro; [e]Faculty of Science, Department of Biology and Ecology, University of Kragujevac, Kragujevac, Republic of Serbia; [f]Faculty of Technology, University of Niš, Leskovac, Republic of Serbia; [g]Faculty of Technology Zvornik, University of East Sarajevo, Zvornik, Bosnia and Herzegovina; [h]Faculty of Agriculture, University of Belgrade, Belgrade, Republic of Serbia; [i]Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

ABSTRACT

The concentrations of cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As) were determined in 455 samples of 27 species of vegetables and 28 different processed vegetables collected during the period from January 2015 to December 2017. Vegetables (n = 387) and vegetable products (n = 68) originated from 31 countries, including Serbia. The samples were analysed by inductively coupled plasma – optical emission spectrometry (ICP-OES). The concentrations of Cd, Pb, Hg and As in the vegetables and vegetable products were compared to the maximum levels set by the European Union and the Serbian legislation. The concentration of mercury was less than the limit of detection in each analysed sample. One or multiple measurable toxic metals (Cd, Pb and/or As) were found in 250 samples (54.9%; n = 455). According to the Regulations which were valid until the end of August 2021, the maximum levels of Cd, Pb and As were exceeded in 19 samples (4.2% of the samples of vegetable and vegetable products; n = 455), i.e. in 13 samples of vegetables: Cd in three, Pb in nine and As in one sample and in 6 samples of vegetables products: Cd in three, Pb in one and As in two samples. Regarding the new EU and Serbian legislation which is valid since September 2021 the maximum levels of Cd and Pb for vegetables and vegetable products were exceeded in 118 samples (25.9% of the samples of vegetable and vegetable products; n = 455), i.e. in 95 samples of vegetables: Cd in 67 and Pb in 28 samples and in 23 samples of vegetable products: Cd in 20 and Pb in 3 samples.

ARTICLE HISTORY
Received 22 July 2022
Accepted 12 January 2023

KEYWORDS
Vegetables; vegetables products; cadmium; lead; mercury; arsenic; maximum levels

Introduction

Food, especially cereals and vegetables, water and air are the major source of exposure to toxic metals like cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As). Their accumulation in the human body can lead to harmful effects over time (EFSA 2022). The EFSA panel on contaminants in the food chain (CONTAM) established a tolerable weekly intake (TWI) for Cd, Pb, inorganic Hg and As of 2.5, 25, 4 and 15 μg kg^{-1} body weight, respectively (EFSA, 2009a, 2009b, 2010, 2012).

The contamination of Cd, Pb, Hg and As in vegetables has been reported in numerous studies. Data from available literature on their levels in vegetables and vegetable products from various countries are shown in Table 1. The transfer of metallic contaminants from soil and water to plant tissues or direct atmospheric deposition onto plant surfaces has also been widely studied in terms of health risk (Chao et al., 2010; Chen et al. 2013; Gebrekidan et al. 2013; Guo et al. 2013; Ismail et al. 2014; Antisari et al. 2015; Li et al. 2015; Pirsaheb et al. 2016; Sharma et al. 2016; Gan et al. 2017; Zhong et al. 2018; Hussain et al. 2019; Khan et al. 2019; Tumanyan et al. 2019; Bayissa and Gebeyehu 2021; Guadie et al. 2021; Gupta et al. 2022). Additionally in several chapters and review papers (Manzoor et al. 2018; Hussain et al. 2019; Zwolak et al. 2019; Manwani et al. 2022) information on the content of toxic metals in vegetables is summarised, as well as factors affecting the accumulation of toxic metals in vegetables and their toxic effects on plant and human health. It was evident that heavy metals were found in several vegetables in different regions of the world. After reviewing the above mentioned studies it may be concluded that monitoring and assessment of toxic metal content in vegetables from the market as well

CONTACT Vladimir Tomović tomovic@uns.ac.rs

Table 1. Literature data of mean levels or ranges of Cd, Pb, Hg and as in vegetables and vegetable product samples from various countries (nm = not mentioned).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Turnips	Nm	Saudi Arabia	1.24 mg kg^{-1} dw	4.37 mg kg^{-1} dw	0.022 mg kg^{-1} dw		Ali and Al-Qahtani (2012)
Carrot	Nm		1.21 mg kg^{-1} dw	1.64 mg kg^{-1} dw	0.018 mg kg^{-1} dw		
Sweet potatoes	Nm		1.27 mg kg^{-1} dw	3.17 mg kg^{-1} dw	0.031 mg kg^{-1} dw		
Onions	Nm		0.94 mg kg^{-1} dw	4.38 mg kg^{-1} dw	0.021 mg kg^{-1} dw		
Potatoes	Nm		1.15 mg kg^{-1} dw	3.01 mg kg^{-1} dw	0.014 mg kg^{-1} dw		
Parsley	Nm		1.11 mg kg^{-1} dw	1.79 mg kg^{-1} dw	0.030 mg kg^{-1} dw		
Jews mallow	Nm		1.08 mg kg^{-1} dw	3.62 mg kg^{-1} dw	0.020 mg kg^{-1} dw		
Spinach	Nm		3.89 mg kg^{-1} dw	4.14 mg kg^{-1} dw	0.011 mg kg^{-1} dw		
Arugula	Nm		2.67 mg kg^{-1} dw	3.62 mg kg^{-1} dw	0.018 mg kg^{-1} dw		
Cabbage	Nm		1.10 mg kg^{-1} dw	3.49 mg kg^{-1} dw	0.018 mg kg^{-1} dw		
Cucumber	Nm		1.13 mg kg^{-1} dw	4.14 mg kg^{-1} dw	0.014 mg kg^{-1} dw		
Tomato	Nm		1.18 mg kg^{-1} dw	3.49 mg kg^{-1} dw	0.022 mg kg^{-1} dw		
Beans	Nm		1.65 mg kg^{-1} dw	1.51 mg kg^{-1} dw	< lod		
Haricot	Nm		1.03 mg kg^{-1} dw	2.90 mg kg^{-1} dw	< lod		
Kidney bean	Nm		1.90 mg kg^{-1} dw	0.88 mg kg^{-1} dw	< lod		
Peas	Nm		2.12 mg kg^{-1} dw	2.82 mg kg^{-1} dw	0.026 mg kg^{-1} dw		
Turnips	Nm		1.29 mg kg^{-1} dw	2.94 mg kg^{-1} dw	0.036 mg kg^{-1} dw		
Carrot	Nm		1.25 mg kg^{-1} dw	1.52 mg kg^{-1} dw	0.002 mg kg^{-1} dw		
Sweet potatoes	Nm		1.54 mg kg^{-1} dw	1.54 mg kg^{-1} dw	0.001 mg kg^{-1} dw		
Onions	Nm		1.13 mg kg^{-1} dw	3.15 mg kg^{-1} dw	0.030 mg kg^{-1} dw		
Potatoes	Nm		0.97 mg kg^{-1} dw	5.32 mg kg^{-1} dw	0.017 mg kg^{-1} dw		
Parsley	Nm		1.07 mg kg^{-1} dw	2.20 mg kg^{-1} dw	0.046 mg kg^{-1} dw		
Jews mallow	Nm		1.07 mg kg^{-1} dw	3.49 mg kg^{-1} dw	0.027 mg kg^{-1} dw		
Spinach	Nm		3.95 mg kg^{-1} dw	2.85 mg kg^{-1} dw	0.022 mg kg^{-1} dw		
Arugula	Nm		2.97 mg kg^{-1} dw	4.67 mg kg^{-1} dw	0.019 mg kg^{-1} dw		
Cabbage	Nm		1.09 mg kg^{-1} dw	2.75 mg kg^{-1} dw	0.010 mg kg^{-1} dw		
Cucumber	Nm		1.18 mg kg^{-1} dw	6.70 mg kg^{-1} dw	0.030 mg kg^{-1} dw		
Tomato	Nm		1.85 mg kg^{-1} dw	2.62 mg kg^{-1} dw	0.023 mg kg^{-1} dw		
Beans	Nm		1.47 mg kg^{-1} dw	2.19 mg kg^{-1} dw	0.013 mg kg^{-1} dw		
Haricot	Nm		1.09 mg kg^{-1} dw	3.13 mg kg^{-1} dw	0.013 mg kg^{-1} dw		
Kidney bean	Nm		2.20 mg kg^{-1} dw	2.50 mg kg^{-1} dw	0.018 mg kg^{-1} dw		
Peas	Nm		1.28 mg kg^{-1} dw	3.96 mg kg^{-1} dw	0.019 mg kg^{-1} dw		
Cabbage	6	Ghana (Tamale metropolis)	0.04–0.07 mg kg^{-1} ww	<0.05 mg kg^{-1} ww			Ametepey et al. (2018)
Carrot	6		0.04–0.07 mg kg^{-1} ww	<0.05 mg kg^{-1} ww			
Green pepper	6		0.01–0.06 mg kg^{-1} ww	<0.05 mg kg^{-1} ww			
Onion	6		0.03–0.06 mg kg^{-1} ww	<0.05 mg kg^{-1} ww			
Tomatoes	6		0.03–0.07 mg kg^{-1} ww	<0.05 mg kg^{-1} ww			
Tomato	Nm	Italy (Bologna city)	0.20[1] mg kg^{-1} dw and < lod[2]	0.28[1] and 0.40[2] mg kg^{-1} dw	< lod[1,2]	< lod[1,2]	Antisari et al. (2015)
Zucchini	Nm		< lod[1,2]	0.16[1] and 0.16[2] mg kg^{-1} dw	< lod[1,2]	< lod[1,2]	
Tomato	1	Ethiopia (Koka Ejersa area)	0.33 mg kg^{-1} dw	1.80 mg kg^{-1} dw	3.23 mg kg^{-1} dw	0.93 mg kg^{-1} dw	Bayissa and Gebeyehu (2021)
Cabbage	1		1.00 mg kg^{-1} dw	6.70 mg kg^{-1} dw	4.36 mg kg^{-1} dw	6.36 mg kg^{-1} dw	
Tomato	1	Ethiopia (Koka Negewo area)	0.50 mg kg^{-1} dw	2.63 mg kg^{-1} dw	3.26 mg kg^{-1} dw	1.03 mg kg^{-1} dw	

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Cabbage	1	China (Jiangsu province)	1.03 mg kg^{-1} dw	7.26 mg kg^{-1} dw	1.16 mg kg^{-1} dw	6.76 mg kg^{-1} dw	Cao et al. (2010)
Leafy vegetables	Nm		0.001–0.099 mg kg^{-1} ww	0.015–0.293 mg kg^{-1} ww	0.003–0.007 mg kg^{-1} ww		
Chinese cabbage	Nm		0.007–0.037 mg kg^{-1} ww	0.035–0.290 mg kg^{-1} ww	0.001–0.003 mg kg^{-1} ww		
Green cabbage	Nm		0.012–0.025 mg kg^{-1} ww	0.047–0.160 mg kg^{-1} ww	0.001–0.005 mg kg^{-1} ww		
Leek	Nm		0.003–0.091 mg kg^{-1} ww	0.019–0.230 mg kg^{-1} ww	0.001–0.007 mg kg^{-1} ww		
Water spinach	Nm		0.004–0.042 mg kg^{-1} ww	0.079–0.184 mg kg^{-1} ww	0.001–0.002 mg kg^{-1} ww		
Hort/lettuce	Nm		0.001–0.099 mg kg^{-1} ww	0.015–0.192 mg kg^{-1} ww	0.001–0.002 mg kg^{-1} ww		
Solanaceae vegetables	Nm		0.001–0.015 mg kg^{-1} ww	0.001–0.202 mg kg^{-1} ww	0.001–0.007 mg kg^{-1} ww		
Sendt/capsicum	Nm		0.003–0.008 mg kg^{-1} ww	0.006–0.015 mg kg^{-1} ww	0.001–0.002 mg kg^{-1} ww		
Solanum melon./ aubergine	Nm		0.003–0.014 mg kg^{-1} ww	0.007–0.017 mg kg^{-1} ww	0.001 mg kg^{-1} ww		
Roem/towel gourd	Nm		0.001–0.006 mg kg^{-1} ww	0.002–0.008 mg kg^{-1} ww	0.001 mg kg^{-1} ww		
Savi/cowpea	Nm		0.001–0.006 mg kg^{-1} ww	0.006–0.049 mg kg^{-1} ww	0.001 mg kg^{-1} ww		
Greenhouse leaf vegetables	9	China (Nanjing city)	53.1[3] µg kg^{-1} ww	61.8[3] µg kg^{-1} ww	1.7[3] µg kg^{-1} ww	7.7[3] µg kg^{-1} ww	Chen et al. (2013)
	26		120.9[4] µg kg^{-1} ww	97.5[4] µg kg^{-1} ww	3.3[4] µg kg^{-1} ww	15.4[4] µg kg^{-1} ww	
	9		117[5] µg kg^{-1} ww	47.9[5] µg kg^{-1} ww	2.9[5] µg kg^{-1} ww	20.4[5] µg kg^{-1} ww	
	21		21.2[6] µg kg^{-1} ww	38.3[6] µg kg^{-1} ww	2.2[6] µg kg^{-1} ww	9.6[6] µg kg^{-1} ww	
Greenhouse fruit vegetables	18		13.6[3] µg kg^{-1} ww	21.8[3] µg kg^{-1} ww	0.3[3] µg kg^{-1} ww	2.1[3] µg kg^{-1} ww	
	6		12.1[4] µg kg^{-1} ww	65.5[4] µg kg^{-1} ww	0.6[4] µg kg^{-1} ww	4.4[4] µg kg^{-1} ww	
	2		15.6[6] µg kg^{-1} ww	6.6 [6]µg kg^{-1} ww	0.5[6] µg kg^{-1} ww	2.3[6] µg kg^{-1} ww	
Cabbage	27	China (Huainan city)	18.6 µg kg^{-1} ww	0.107 mg kg^{-1} ww	1.12 µg kg^{-1} ww	0.032 mg kg^{-1} ww	Cheng et al. (2017)
Celery	9		9.18 µg kg^{-1} ww	0.040 mg kg^{-1} ww	1.08 µg kg^{-1} ww	0.010 mg kg^{-1} ww	
Cauliflower	9		1.83 µg kg^{-1} ww	0.008 mg kg^{-1} ww	0.550 µg kg^{-1} ww	0.003 mg kg^{-1} ww	
Water convolvulus	27		21.9 µg kg^{-1} ww	0.173 mg kg^{-1} ww	4.61 µg kg^{-1} ww	0.063 mg kg^{-1} ww	
Spinach	9		21.4 µg kg^{-1} ww	0.309 mg kg^{-1} ww	2.41 µg kg^{-1} ww	0.049 mg kg^{-1} ww	
Green pepper	27		8.03 µg kg^{-1} ww	0.012 mg kg^{-1} ww	1.00 µg kg^{-1} ww	0.005 mg kg^{-1} ww	
Cucumber	9		2.85 µg kg^{-1} ww	0.006 mg kg^{-1} ww	0.332 µg kg^{-1} ww	0.006 mg kg^{-1} ww	
Tomato	9		9.59 µg kg^{-1} ww	0.002 mg kg^{-1} ww	0.184 µg kg^{-1} ww	0.002 mg kg^{-1} ww	
Eggplant	27		15.3 µg kg^{-1} ww	0.011 mg kg^{-1} ww	1.53 µg kg^{-1} ww	0.021 mg kg^{-1} ww	
Cowpea	18		3.39 µg kg^{-1} ww	0.025 mg kg^{-1} ww	1.49 µg kg^{-1} ww	0.010 mg kg^{-1} ww	
Watermelon	Nm	Libya (Misurata area)	0.03 mg kg^{-1} dw	0.5 mg kg^{-1} dw			Elbagermi et al. (2012)
Melon	Nm		0.03 mg kg^{-1} dw	0.25 mg kg^{-1} dw			
Tomato	Nm		0.250 mg kg^{-1} dw	0.511 mg kg^{-1} dw			
Onion	Nm		0.02 mg kg^{-1} dw	0.14 mg kg^{-1} dw			
Potato	Nm		0.02 mg kg^{-1} dw	0.02 mg kg^{-1} dw			
Green pepper	Nm		0.07 mg kg^{-1} dw	0.47 mg kg^{-1} dw			
Carrot	Nm		0.12 mg kg^{-1} dw	0.21 mg kg^{-1} dw			
Cucumber	Nm		0.20 mg kg^{-1} dw	0.10 mg kg^{-1} dw			
Spinach	Nm		0.27 mg kg^{-1} dw	0.32 mg kg^{-1} dw			
Lettuce (open-grown)	20	The Netherlands	11 µg kg^{-1} ww	12 µg kg^{-1} ww			Ellen et al. (1990)
Lettuce (greenhouse)	21		12 µg kg^{-1} ww	13 µg kg^{-1} ww			

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Spinach (open-grown)	17		21 µg kg^{-1} ww	51 µg kg^{-1} ww			
Spinach (greenhouse)	21		32 µg kg^{-1} ww	30 µg kg^{-1} ww			
Endive (open-grown)	20		24 µg kg^{-1} ww	21 µg kg^{-1} ww			
Endive (greenhouse)	21		24 µg kg^{-1} ww	14 µg kg^{-1} ww			
Beetroot/Onion	19/22		9 µg kg^{-1} ww	<20 µg kg^{-1} ww			
Celeriac	22		95 µg kg^{-1} ww	<20 µg kg^{-1} ww			
Swedish turnip	22		9 µg kg^{-1} ww	<20 µg kg^{-1} ww			
Supermarket		China (Beijing city)					Fang et al. (2014)
Tomato, cucumber, green bean, chilli, wax gourd	Nm		0.02–0.08 mg kg^{-1} ww	0.01–0.57 mg kg^{-1} ww		<0.23–50 µg kg^{-1} ww	
Celery (cabbage), spinach	Nm		0.03–0.06 mg kg^{-1} ww	<0.06–30 µg kg^{-1} ww		0.03–0.04 mg kg^{-1} ww	
Potato, radish	Nm		<0.23 µg kg^{-1}–0.02 mg kg^{-1} ww	0.01–0.02 mg kg^{-1} ww		<0.23 µg kg^{-1} ww	
Traditional agri-product market							
Tomato, cucumber, green bean, chilli, wax gourd	Nm		0.01–0.03 mg kg^{-1} ww	0.03–0.10 mg kg^{-1} ww		<0.23–10 µg kg^{-1} ww	
Celery (cabbage), spinach	Nm		0.01–0.05 mg kg^{-1} ww	0.04–0.13 mg kg^{-1} ww		<0.23–30 µg kg^{-1} ww	
Potato, radish	Nm		0.04–0.09 mg kg^{-1} ww	0.01–0.14 mg kg^{-1} ww		0.01–0.03 mg kg^{-1} ww	
Cabbage	Nm	Northern Ethiopia (Wukro town – Lealay farm)	0.20 mg kg^{-1} dw	2.80 mg kg^{-1} dw			Gebrekidan et al. (2013)
Green pepper	Nm		0.32 mg kg^{-1} dw	2.07 mg kg^{-1} dw			
Letuce	Nm		0.30 mg kg^{-1} dw	1.55 mg kg^{-1} dw			
Swiss chard	Nm		0.23 mg kg^{-1} dw	2.53 mg kg^{-1} dw			
Tomato	Nm		0.22 mg kg^{-1} dw	3.25 mg kg^{-1} dw			
Cabbage	Nm	Northern Ethiopia (Wukro town – Tahtay farm)	0.18 mg kg^{-1} dw	3.82 mg kg^{-1} dw			
Green pepper	Nm		0.18 mg kg^{-1} dw	5.85 mg kg^{-1} dw			
Onion	Nm		0.20 mg kg^{-1} dw	4.90 mg kg^{-1} dw			
Potato	Nm		0.18 mg kg^{-1} dw	2.58 mg kg^{-1} dw			
Swiss chard	Nm		0.38 mg kg^{-1} dw	2.50 mg kg^{-1} dw			
Tomato	Nm		0.18 mg kg^{-1} dw	3.78 mg kg^{-1} dw			
Flowering cabbage	Nm	China (Dongguan city)	34.8 µg kg^{-1} ww	22.1 µg kg^{-1} ww	1.43 µg kg^{-1} ww	5.81 µg kg^{-1} ww	Guo et al. (2013)
Lettuce	Nm		32.6 µg kg^{-1} ww	21.2 µg kg^{-1} ww	0.71 µg kg^{-1} ww	7.61 µg kg^{-1} ww	
Welsh onion	Nm		6.12 µg kg^{-1} ww	22.6 µg kg^{-1} ww	0.95 µg kg^{-1} ww	4.02 µg kg^{-1} ww	
Eggplant	Nm		16.6 µg kg^{-1} ww	9.11 µg kg^{-1} ww	< lod	2.57 µg kg^{-1} ww	
Chard	2	Brazil (São Paulo state)	0.05 mg kg^{-1} ww	0.58 mg kg^{-1} ww			Guerra et al. (2012)
Watercress	2		0.10 mg kg^{-1} ww	0.86 mg kg^{-1} ww			
Iceberg lettuce	2		0.03 mg kg^{-1} ww	0.41 mg kg^{-1} ww			
Crisphead lettuce	2		0.08 mg kg^{-1} ww	0.48 mg kg^{-1} ww			
Smooth lettuce	2		0.07 mg kg^{-1} ww	1.24 mg kg^{-1} ww			
Coriander	2		0.16 mg kg^{-1} ww	1.66 mg kg^{-1} ww			
Cabbage	2		0.12 mg kg^{-1} ww	0.93 mg kg^{-1} ww			

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Broccoli	2		0.08 mg kg^{-1} ww	0.36 mg kg^{-1} ww			
Cauliflower	2		0.08 mg kg^{-1} ww	0.49 mg kg^{-1} ww			
Endive	2		0.07 mg kg^{-1} ww	0.07 mg kg^{-1} ww			
Spinach	2		0.13 mg kg^{-1} ww	1.05 mg kg^{-1} ww			
Sweetcorn	2		0.08 mg kg^{-1} ww	0.16 mg kg^{-1} ww			
White cabbage	2		0.04 mg kg^{-1} ww	0.60 mg kg^{-1} ww			
Purple cabbage	2		0.06 mg kg^{-1} ww	0.63 mg kg^{-1} ww			
Rocket	2		0.07 mg kg^{-1} ww	0.76 mg kg^{-1} ww			
Parsley	2		0.18 mg kg^{-1} ww	1.02 mg kg^{-1} ww			
Celery	2		0.05 mg kg^{-1} ww	0.47 mg kg^{-1} ww			
"Seca" squash	2		0.04 mg kg^{-1} ww	0.25 mg kg^{-1} ww			
"Italian" pumpkin	2		0.04 mg kg^{-1} ww	0.30 mg kg^{-1} ww			
"Japanese" pumpkin	2		0.16 mg kg^{-1} ww	0.90 mg kg^{-1} ww			
"Moranga" pumpkin	2		0.06 mg kg^{-1} ww	0.56 mg kg^{-1} ww			
"Paulista" squash	2		0.05 mg kg^{-1} ww	0.50 mg kg^{-1} ww			
"Italian" zucchini	2		0.04 mg kg^{-1} ww	0.51 mg kg^{-1} ww			
"Paulista" zucchini	2		0.04 mg kg^{-1} ww	0.59 mg kg^{-1} ww			
Yellow sweet potato	3		0.11 mg kg^{-1} ww	0.43 mg kg^{-1} ww			
White sweet potato	3		0.14 mg kg^{-1} ww	0.46 mg kg^{-1} ww			
Pink sweet potato	5		0.12 mg kg^{-1} ww	0.52 mg kg^{-1} ww			
Eggplant	2		0.04 mg kg^{-1} ww	0.44 mg kg^{-1} ww			
Beet	3		0.09 mg kg^{-1} ww	0.58 mg kg^{-1} ww			
Yam	2		0.06 mg kg^{-1} ww	0.72 mg kg^{-1} ww			
Carrot	3		0.03 mg kg^{-1} ww	0.38 mg kg^{-1} ww			
Chayote	2		0.09 mg kg^{-1} ww	0.31 mg kg^{-1} ww			
Jilo	2		0.06 mg kg^{-1} ww	0.28 mg kg^{-1} ww			
Cassava 1	2		0.13 mg kg^{-1} ww	< lod			
Cassava 2	2		0.10 mg kg^{-1} ww	0.98 mg kg^{-1} ww			
Arracacha	4		0.09 mg kg^{-1} ww	1.18 mg kg^{-1} ww			
"Caipira" cucumber	2		0.02 mg kg^{-1} ww	0.30 mg kg^{-1} ww			
"Comum" cucumber	2		0.02 mg kg^{-1} ww	0.25 mg kg^{-1} ww			
"Japanese" cucumber	2		0.02 mg kg^{-1} ww	0.37 mg kg^{-1} ww			
Green pepper	2		0.04 mg kg^{-1} ww	0.29 mg kg^{-1} ww			
Red pepper	2		0.05 mg kg^{-1} ww	0.25 mg kg^{-1} ww			
Okra	5		0.08 mg kg^{-1} ww	1.31 mg kg^{-1} ww			
"Andrea" tomato cv.	2		0.03 mg kg^{-1} ww	0.17 mg kg^{-1} ww			
"Caqui" tomato cv.	2		0.04 mg kg^{-1} ww	0.20 mg kg^{-1} ww			
"Long life" tomato cv.	2		0.03 mg kg^{-1} ww	0.21 mg kg^{-1} ww			
"Rasteiro" tomato cv.	2		0.02 mg kg^{-1} ww	0.19 mg kg^{-1} ww			
Green bean	4		0.07 mg kg^{-1} ww	0.75 mg kg^{-1} ww			
Chinese garlic	3		0.12 mg kg^{-1} ww	1.94 mg kg^{-1} ww			
National garlic	3		0.09 mg kg^{-1} ww	2.50 mg kg^{-1} ww			
"Ágata" potato cv.	3		0.09 mg kg^{-1} ww	0.99 mg kg^{-1} ww			
"Asterix" potato cv.	2		0.09 mg kg^{-1} ww	1.02 mg kg^{-1} ww			
"Caesar" potato cv.	2		0.11 mg kg^{-1} ww	0.48 mg kg^{-1} ww			
"Monalisa" potato cv.	2		0.12 mg kg^{-1} ww	0.77 mg kg^{-1} ww			
Onion	3		0.02 mg kg^{-1} ww	0.49 mg kg^{-1} ww			

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Bean 1	3		0.01 mg kg^{-1} ww	0.26 mg kg^{-1} ww			
Bean 2	3		0.002 mg kg^{-1} ww	0.70 mg kg^{-1} ww			
Coriander	7	India (Jhansi district)	0.14–0.44 mg kg^{-1} dw	0.71–12.52 mg kg^{-1} dw			Gupta et al. (2022)
Onion	7		0.01–0.30 mg kg^{-1} dw	0.19–2.21 mg kg^{-1} dw			
Tomato	7		0.02–0.35 mg kg^{-1} dw	0.03–2.30 mg kg^{-1} dw			
Brinjal	3	Bangladesh (industrial area)	0.39 mg kg^{-1} ww	2.58 mg kg^{-1} ww		0.35 mg kg^{-1} ww	Haque et al. (2021)
Malabar spinach	3		0.27 mg kg^{-1} ww	1.44 mg kg^{-1} ww		0.17 mg kg^{-1} ww	
Pointed gourd	3		0.24 mg kg^{-1} ww	2.87 mg kg^{-1} ww		0.22 mg kg^{-1} ww	
Potato	3		0.34 mg kg^{-1} ww	1.33 mg kg^{-1} ww		0.28 mg kg^{-1} ww	
Tomato	3		0.37 mg kg^{-1} ww	2.19 mg kg^{-1} ww		0.17 mg kg^{-1} ww	
Bottle gourd	3		0.46 mg kg^{-1} ww	2.27 mg kg^{-1} ww		0.43 mg kg^{-1} ww	
Yardlong bean	3		0.18 mg kg^{-1} ww	1.25 mg kg^{-1} ww		0.24 mg kg^{-1} ww	
Pumpkin	3		0.49 mg kg^{-1} ww	1.23 mg kg^{-1} ww		0.32 mg kg^{-1} ww	
Red amaranth	3		0.26 mg kg^{-1} ww	2.17 mg kg^{-1} ww		0.19 mg kg^{-1} ww	
Green amaranth	3		0.34 mg kg^{-1} ww	2.70 mg kg^{-1} ww		0.36 mg kg^{-1} ww	
Brinjal	3	Bangladesh (non-industrial area)	0.14 mg kg^{-1} ww	0.94 mg kg^{-1} ww		0.18 mg kg^{-1} ww	
Malabar spinach	3		0.08 mg kg^{-1} ww	0.36 mg kg^{-1} ww		0.12 mg kg^{-1} ww	
Pointed gourd	3		0.12 mg kg^{-1} ww	1.02 mg kg^{-1} ww		0.12 mg kg^{-1} ww	
Potato	3		0.14 mg kg^{-1} ww	0.11 mg kg^{-1} ww		0.13 mg kg^{-1} ww	
Tomato	3		0.17 mg kg^{-1} ww	0.67 mg kg^{-1} ww		0.08 mg kg^{-1} ww	
Bottle gourd	3		0.22 mg kg^{-1} ww	0.85 mg kg^{-1} ww		0.23 mg kg^{-1} ww	
Yardlong bean	3		0.09 mg kg^{-1} ww	0.45 mg kg^{-1} ww		0.14 mg kg^{-1} ww	
Pumpkin	3		0.21 mg kg^{-1} ww	0.33 mg kg^{-1} ww		0.19 mg kg^{-1} ww	
Red amaranth	3		0.11 mg kg^{-1} ww	0.75 mg kg^{-1} ww		0.09 mg kg^{-1} ww	
Green amaranth	3		0.15 mg kg^{-1} ww	0.87 mg kg^{-1} ww		0.19 mg kg^{-1} ww	
Brinjal	3	Bangladesh (Savar city, market)	0.22 mg kg^{-1} ww	< lod	Bangladesh (Faridpur – arsenic prone region)	0.36 mg kg^{-1} ww	
Malabar spinach	3		2.01 mg kg^{-1} ww	< lod		0.68 mg kg^{-1} ww	
Pointed gourd	3		0.26 mg kg^{-1} ww	0.35 mg kg^{-1} ww		0.48 mg kg^{-1} ww	
Potato	3		0.50 mg kg^{-1} ww	0.62 mg kg^{-1} ww		0.15 mg kg^{-1} ww	
Tomato	3		0.35 mg kg^{-1} ww	2.03 mg kg^{-1} ww		0.59 mg kg^{-1} ww	
Bottle gourd	3		0.37 mg kg^{-1} ww	1.94 mg kg^{-1} ww		0.18 mg kg^{-1} ww	
Yardlong bean	3		0.60 mg kg^{-1} ww	0.91 mg kg^{-1} ww		1.56 mg kg^{-1} ww	
Pumpkin	3		0.42 mg kg^{-1} ww	1.34 mg kg^{-1} ww		0.18 mg kg^{-1} ww	
Red amaranth	3		0.75 mg kg^{-1} ww	0.41 mg kg^{-1} ww		0.12 mg kg^{-1} ww	
Green amaranth	3		1.11 mg kg^{-1} ww	0.69 mg kg^{-1} ww		0.25 mg kg^{-1} ww	
Brinjal	3				Bangladesh (Singair – arsenic prone region)	0.26 mg kg^{-1} ww	
Malabar spinach	3					0.65 mg kg^{-1} ww	
Pointed gourd	3					0.37 mg kg^{-1} ww	
Potato	3					0.11 mg kg^{-1} ww	
Tomato	3					0.51 mg kg^{-1} ww	
Bottle gourd	3					0.12 mg kg^{-1} ww	
Yardlong bean	3					0.95 mg kg^{-1} ww	

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Pumpkin	3					0.14 mg kg^{-1} ww	
Red amaranth	3					0.16 mg kg^{-1} ww	
Green amaranth	3					0.51 mg kg^{-1} ww	
Vegetables	343	China (Zhejiang province)	<0.001–0.393 mg kg^{-1} ww	<0.005–0.270 mg kg^{-1} ww	<0.005–0.032 mg kg^{-1} ww	<0.005–0.160 mg kg^{-1} ww	Huang et al. (2014)
Tomato	6	Bangladesh (Dhaka city)	0.04–0.06 mg kg^{-1} ww	0.17–0.31 mg kg^{-1} ww		0.01–0.02 mg kg^{-1} ww	Islam and Hoque (2014)
Bottle gourd	6		0.03–0.05 mg kg^{-1} ww	0.52–0.94 mg kg^{-1} ww		0.01–0.02 mg kg^{-1} ww	
Brinjal	6		0.17–0.30 mg kg^{-1} ww	0.06–0.10 mg kg^{-1} ww		0.03–0.04 mg kg^{-1} ww	
Pumpkin	6		0.01–0.01 mg kg^{-1} ww	0.19–0.34 mg kg^{-1} ww		0.02–0.03 mg kg^{-1} ww	
Green amaranth	6		0.10–0.18 mg kg^{-1} ww	1.93–3.45 mg kg^{-1} ww		0.14–0.24 mg kg^{-1} ww	
Red amaranth	6		0.60–1.05 mg kg^{-1} ww	1.51–2.70 mg kg^{-1} ww		0.11–0.19 mg kg^{-1} ww	
Chilli	6		0.23–0.41 mg kg^{-1} ww	0.13–0.23 mg kg^{-1} ww		0.01–0.01 mg kg^{-1} ww	
Chickpea, lentil, bean.	60	Iran (Markazi	<0.05 µg kg^{-1} dw	562 µg kg^{-1} dw	35.5 µg kg^{-1} dw	<1 µg kg^{-1} dw	Karimi et al.
Potato	30	province)	27.5 µg kg^{-1} dw	470 µg kg^{-1} dw	17.5 µg kg^{-1} dw	<1 µg kg^{-1} dw	(2021)
Dill	10	Iran (Guilan province)	0.44 mg kg^{-1} ww	0.83 mg kg^{-1} ww			Naghipour et al. (2018)
Radish leaves	9		0.6 mg kg^{-1} ww	1.11 mg kg^{-1} ww			
Radish	10		2.57 mg kg^{-1} ww	1.58 mg kg^{-1} ww			
Parsley	9		0.34 mg kg^{-1} ww	0.58 mg kg^{-1} ww			
Spinach	11		0.23 mg kg^{-1} ww	0.94 mg kg^{-1} ww			
Spring onion	10		0.20 mg kg^{-1} ww	0.58 mg kg^{-1} ww			
Leek	10		0.37 mg kg^{-1} ww	1.27 mg kg^{-1} ww			
Fenugreek	10		0.29 mg kg^{-1} ww	1 mg kg^{-1} ww			
Mint	10		0.2 mg kg^{-1} ww	1.80 mg kg^{-1} ww			
Coriander	11		0.26 mg kg^{-1} ww	1.29 mg kg^{-1} ww			
Watermelon	3	Nigeria (Lagos state)	0.004 mg kg^{-1} ww	1.760 mg kg^{-1} ww	< lod		Ogunkunle et al. (2014)
Smooth amaranth	3		0.078 mg kg^{-1} ww	<0.001 mg kg^{-1} ww	< lod		
Cabbage	3		0.061 mg kg^{-1} ww	1.840 mg kg^{-1} ww	< lod		
Lettuce	3		0.089 mg kg^{-1} ww	1.930 mg kg^{-1} ww	< lod		
Cabbage (20), carrot (19), cauliflower (24), green onion (19), lettuce (21), onion (20), parsley (23), rocket (19), spinach (18) and potato (21)	204	Jordan	0.004–0.060 mg kg^{-1} ww	0.072–0.289 mg kg^{-1} ww		0.009–0.275 mg kg^{-1} ww	Osaili et al. (2016)
Beetroot (fresh)	4	Poland	0.022–0.670 mg kg^{-1} dw	0.056–0.135 mg kg^{-1} dw			Rusin et al. (2021)
Beetroot (frozen)	3		0.010–0.054 mg kg^{-1} dw	0.173–0.173 mg kg^{-1} dw			
Beetroot (processed)	16		0.004–0.056 mg kg^{-1} dw	0.001–0.020 mg kg^{-1} dw			
Beetroot (dried)	5		0.021–0.072 mg kg^{-1} dw	0.003–0.513 mg kg^{-1} dw			
Carrot (fresh)	12		0.024–0.062 mg kg^{-1} dw	0.020–0.041 mg kg^{-1} dw			
Carrot (frozen)	13		0.010–0.113 mg kg^{-1} dw	0.008–0.117 mg kg^{-1} dw			

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Carrot (processed)	4		0.004–0.054 mg kg^{-1} dw	0.004–0.034 mg kg^{-1} dw			
Carrot (dried)	7		0.086–0.331 mg kg^{-1} dw	0.090–0.348 mg kg^{-1} dw			
Celery (fresh)	21		0.002–0.712 mg kg^{-1} dw	0.003–0.074 mg kg^{-1} dw			
Celery (frozen)	5		0.026–0.062 mg kg^{-1} dw	0.048–0.080 mg kg^{-1} dw			
Celery (processed)	9		0.012–0.073 mg kg^{-1} dw	0.002–0.010 mg kg^{-1} dw			
Celery (dried)	4		–	0.259 mg kg^{-1} dw			
Tomato (fresh)	10		0.001–0.006 mg kg^{-1} dw	0.003–0.052 mg kg^{-1} dw			
Tomato (frozen)	4		0.015–0.024 mg kg^{-1} dw	0.050–0.537 mg kg^{-1} dw			
Tomato (processed)	6		0.006–0.067 mg kg^{-1} dw	0.031–0.031 mg kg^{-1} dw			
Tomato (dried)	5		0.032–0.285 mg kg^{-1} dw	0.028–0.133 mg kg^{-1} dw			
Palak	3	India (Varanasi city – production sites)	0.98 mg kg^{-1} dw	1.00 mg kg^{-1} dw			Sharma et al. (2009)
Lady's finger	3		0.90 mg kg^{-1} dw	0.88 mg kg^{-1} dw			
Cauliflower	3		1.26 mg kg^{-1} dw	1.02 mg kg^{-1} dw			
Palak	3	India (Varanasi city – market sites)	1.96 mg kg^{-1} dw	1.44 mg kg^{-1} dw			
Lady's finger	3		1.41 mg kg^{-1} dw	1.03 mg kg^{-1} dw			
Cauliflower	3		2.57 mg kg^{-1} dw	1.56 mg kg^{-1} dw			
Chinese cabbage	46	China (Beijing city)	0.001–0.049 mg kg^{-1} ww	0.003–0.370 mg kg^{-1} ww		0.001–0.19 mg kg^{-1} ww	Song et al. (2009)
Cabbage	27		0.002–0.020 mg kg^{-1} ww	<0.001–0.268 mg kg^{-1} ww		<0.001–0.077 mg kg^{-1} ww	
Rape	15		0.008–0.058 mg kg^{-1} ww	0.008–0.220 mg kg^{-1} ww		0.004–0.071 mg kg^{-1} ww	
Bok choy	13		0.012–0.034 mg kg^{-1} ww	0.013–0.350 mg kg^{-1} ww		0.003–0.223 mg kg^{-1} ww	
Cauliflower	11		0.004–0.021 mg kg^{-1} ww	0.001–0.139 mg kg^{-1} ww		<0.001–0.032 mg kg^{-1} ww	
Celery	8		0.006–0.017 mg kg^{-1} ww	0.008–0.116 mg kg^{-1} ww		0.002–0.020 mg kg^{-1} ww	
Spinach	7		0.011–0.023 mg kg^{-1} ww	0.008–0.061 mg kg^{-1} ww		0.002–0.030 mg kg^{-1} ww	
Leek	2		0.002–0.009 mg kg^{-1} ww	–		0.008–0.014 mg kg^{-1} ww	
Tomato	28		0.001–0.016 mg kg^{-1} ww	0.001–0.231 mg kg^{-1} ww		0.001–0.138 mg kg^{-1} ww	
Cucumber	27		<0.001–0.015 mg kg^{-1} ww	0.002–0.123 mg kg^{-1} ww		0.002–0.126 mg kg^{-1} ww	
Capsicum	24		0.003–0.046 mg kg^{-1} ww	<0.001–0.447 mg kg^{-1} ww		0.001–0.116 mg kg^{-1} ww	
Kinder bean	21		<0.001–0.015 mg kg^{-1} ww	<0.001–0.324 mg kg^{-1} ww		0.001–0.202 mg kg^{-1} ww	
Eggplant	18		0.004–0.062 mg kg^{-1} ww	0.012–0.367 mg kg^{-1} ww		0.004–0.075 mg kg^{-1} ww	
Wax gourd	15		0.001–0.013 mg kg^{-1} ww	0.002–0.068 mg kg^{-1} ww		<0.001–0.007 mg kg^{-1} ww	
Radish	29		0.002–0.037 mg kg^{-1} ww	0.001–0.440 mg kg^{-1} ww		0.004–0.479 mg kg^{-1} ww	
Scallion	20		<0.001–0.038 mg kg^{-1} ww	0.002–0.261 mg kg^{-1} ww		0.004–0.138 mg kg^{-1} ww	
Potato	7		0.006–0.033 mg kg^{-1} ww	0.003–0.286 mg kg^{-1} ww		0.001–0.038 mg kg^{-1} ww	
Garlic	7		0.004–0.015 mg kg^{-1} ww	0.007–0.655 mg kg^{-1} ww		0.001–0.310 mg kg^{-1} ww	
Lotus root	1		0.010 mg kg^{-1}) ww	–		0.028 mg kg^{-1} ww	
Other vegetables	86		<0.001–0.101 mg kg^{-1} ww	<0.001–0.218 mg kg^{-1} ww		<0.001–0.127 mg kg^{-1} ww	
Leafy vegetables	183		<0.001–0.101 mg kg^{-1} ww	<0.001–0.370 mg kg^{-1} ww		<0.001–0.223 mg kg^{-1} ww	
Gourd and fruit vegetables	152		<0.001–0.062 mg kg^{-1} ww	<0.001–0.447 mg kg^{-1} ww		<0.001–0.202 mg kg^{-1} ww	
Stem and root vegetables	81		<0.001–0.038 mg kg^{-1} ww	<0.001–0.655 mg kg^{-1} ww		0.001–0.479 mg kg^{-1} ww	
Local-produced vegetable	330		<0.001–0.101 mg kg^{-1} ww	<0.001–0.655 mg kg^{-1} ww		<0.001–0.479 mg kg^{-1} ww	
Non-locally vegetables	86		<0.001–0.049 mg kg^{-1} ww	<0.001–0.286 mg kg^{-1} ww		<0.001–0.310 mg kg^{-1} ww	
Open-field vegetable	236		<0.001–0.062 mg kg^{-1} ww	<0.001–0.447 mg kg^{-1} ww		<0.001–0.479 mg kg^{-1} ww	

(*Continued*)

Table 1. (Continued).

Vegetables (common name)	N	Country of origin	Cd	Pb	Hg	As	Reference
Greenhouse vegetable	180		<0.001–0.101 mg kg^{-1} ww	<0.001–0.655 mg kg^{-1} ww		<0.001–0.138 mg kg^{-1} ww	
All vegetables	416		<0.001–0.101 mg kg^{-1} ww	<0.001–0.655 mg kg^{-1} ww		<0.001–0.479 mg kg^{-1} ww	
Beets	8–10	Russia (southern)	0.02 mg kg^{-1} ww	0.21 mg kg^{-1} ww	0.005 mg kg^{-1} ww	0.08 mg kg^{-1} ww	Tumanyan et al. (2019)
Carrots	8–10		0.01 mg kg^{-1} ww	0.19 mg kg^{-1} ww	0.002 mg kg^{-1} ww	0.05 mg kg^{-1} ww	
Potatoes	8–10		0.02 mg kg^{-1} ww	0.2 mg kg^{-1} ww	0.002 mg kg^{-1} ww	0.05 mg kg^{-1} ww	
Onion bulbs	8–10		0.01 mg kg^{-1} ww	0.18 mg kg^{-1} ww	0.001 mg kg^{-1} ww	0.02 mg kg^{-1} ww	
Cucumber	30	Iran (Gonbad city)	0.09 mg kg^{-1} ww	1.47 mg kg^{-1} ww			Zafarzadeh et al. (2018)
Tomato	30		0.03 mg kg^{-1} ww	0.5 mg kg^{-1} ww			
Cucumber	30	Iran (Gorgan city)	0.12 mg kg^{-1} ww	1.4 mg kg^{-1} ww			
Tomato	30		0.08 mg kg^{-1} ww	0.7 mg kg^{-1} ww			
Melon, kale, solanaceous legumes		China	0.019 mg kg^{-1} ww (n = 8625)	0.052 mg kg^{-1} ww (n = 8389)	0.003 mg kg^{-1} ww (n = 5692)		Zhong et al. (2018)
Root vegetables			0.023 mg kg^{-1} ww (n = 2913)	0.068 mg kg^{-1} ww (n = 2756)	0.004 mg kg^{-1} ww (n = 2043)		
Leaf vegetables			0.061 mg kg^{-1} ww (n = 9729)	0.154 mg kg^{-1} ww (n = 9580)	0.014 mg kg^{-1} ww (n = 672)		

[1]10 m from the street; [2]60 m from the street; [3]Short-term harmless; [4]Middle-term harmless; [5]Long-term harmless; [6]Organic.

as production sites is essential to control levels of toxic metals in food in order to protect human health.

Regulations set specific maximum levels (MLs) for certain chemical contaminants in food. These are established in an effort to reduce exposure to a particular contaminant. The European Union has set new MLs (Table 2), based on wet weight, for the toxic metals Cd and Pb in vegetables by product class (Commission Regulations (EC) No 1881/2006, (EC) No 629/2008, (EU) No 2021/1317 and (EU) No 2021/1323). The new Serbian Regulation on "maximum levels of certain contaminants in food" (Official Gazette RS No 81/2019, 126/2020, 90/2021 and 118/2021) is fully harmonised with the European Union Regulations. The new Regulations have significantly reduced the MLs for Cd and Pb in certain types of vegetables, when compared to European Union and Serbian Regulations before their revision [Commission Regulations (EC) No 1881/2006 and (EC) No 629/2008 and Serbian Regulations 2014 (amended in 2015, 2016 and 2017) and 2018 (amended in 2019)], as shown in Table 3.

Like fruits, described in a former paper (Lazović et al. 2022), vegetables are important components of a healthy diet. Reduced vegetable and fruit consumption is linked to poor health and increased risk of noncommunicable diseases (NCDs). Moreover, vegetables and fruits are rich sources of vitamins and minerals, dietary fibre and of beneficial non-nutrient substances, including plant sterols, flavonoids and other antioxidants, so consuming a variety of vegetables helps to ensure an adequate intake of many of these essential nutrients. World Health Organization (2003) suggests consuming more than 400 grams of vegetables and fruits per day to improve overall health and reduce the risk of certain NCDs. According to the Food and Agricultural Organization (FAO), average vegetable consumption per capita, measured in kilograms per year, in 2017 in Serbia reached 110.2 kg (302 grams per day). In 2017, the world production of vegetables and fruits reached 390 g per person per day, but this includes non-edible portions, loss and waste, which can be as high as 50%, during storage and on farms in some regions. In the same year, world consumption of vegetables and fruits reached 267 g per person per day (Our World in Data, source: United Nations Food and Agricultural Organization).

Vegetables are defined as the fresh parts of plants which, either raw, cooked, canned or processed in some other way, provide suitable human nutrition. From a botanical point of view, vegetables can be divided into algae, mushrooms, root vegetables, tubers, bulbs and stem or stalk, leafy, inflorescence, seed and fruit vegetables (Belitz and Grosch 1999). The most important Serbian Regulation (1979, amended in 1987, 2003 and 2004) relevant to fresh vegetables is rulebook on the quality of fruits, vegetables and mushrooms. This Rulebook prescribes the minimal conditions which have to be fulfilled with respect to the quality of vegetables (tomato, aubergine, pepper, watermelon, melon, cucumber, zucchini, pumpkins and cucurbits, young potato, potato, cabbage, cauliflower, kail, kail umbilicus, kohlrabi, Chinese cabbage, carrot, beetroot, radish, little radish, rutabaga, chard, spinach, lettuce, endive, radicchio, young onion, onion, garlic, leek, celeriac, parsley, parsnip, horseradish, white asparagus, green bean, young peas, peas in kernel, lens, bean in kernel), which are intended for consumption in fresh condition, as well as packaging conditions, with the purpose of ensuring the maintenance of the quality and hygiene safety of products. In terms of this Rulebook, vegetables means harvested fruits and other edible parts of vegetable plants

Table 2. Cadmium and lead maximum levels (mg kg $^{-1}$ wet weight) in vegetables (Commission Regulation (EC) No 1881/2006; Commission Regulation (EC) No 629/2008; Commission Regulation (EU) No 2021/1317; Commission Regulation (EU) 2021/1323; Serbian Regulation 2019, amended 2020 and 2021).

Metals	Vegetables[1]	ML (mg kg^{-1} ww)
Cadmium	Root and tuber vegetables, except radishes, tropical roots and tubers, parsley roots and turnips, beetroots, celeriac and horseradish, parsnips and salsify (For potatoes, the maximum level applies to peeled potatoes); Leafy brassica; Leaf vegetables, except spinaches and similar leaves, mustard seedlings and fresh herbs; Celeries	0.10
	Radishes; Fruiting vegetables, except aubergines; Legume vegetables	0.020
	Tropical roots and tubers, parsley roots, turnips; Garlic	0.050
	Beetroots	0.060
	Celeriac	0.15
	Horseradish, parsnips, salsify; Spinaches and similar leaves, mustard seedlings and fresh herbs	0.20
	Bulb vegetables, except garlic; Aubergines; Stem vegetables, except leeks and celeries	0.030
	Brassica, other than leafy brassica; Leeks	0.040
Lead	Cereals and pulses	0.20
	Root and tuber vegetables (excluding salsifies, fresh ginger and fresh turmeric), bulb vegetables, flowering brassica, head brassica, kohlrabies, legume vegetables and stem vegetables; Sweetcorn	0.10
	Leafy brassica, salsify, the following fungi *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom) and leafy vegetables (excluding fresh herbs)	0.30
	Wild fungi, fresh turmeric and fresh ginger	0.80
	Other than sweetcorn	0.050

[1]The maximum level applies after washing of the vegetables and separating the edible part.

Table 3. Regulations of Cd, Pb, Hg and as MLs (mg kg $^{-1}$ wet weight) in vegetables before 2021 [Commission Regulation (EC) No 1881/2006; Commission Regulation (EC) No 629/2008; Serbian Regulation 2014 (amended 2015, 2016 and 2017); Serbian Regulation 2018 (amended 2019)].

Metals	Vegetables	ML (mg kg^{-1} ww)
EU Regulation [Commission Regulation (EC) No 1881/2006; Commission Regulation (EC) No 629/2008]		
Cadmium	Vegetables, excluding leaf vegetables, fresh herbs, fungi, stem vegetables, root vegetables and potatoes[1]	0.050
	Stem vegetables, root vegetables and potatoes, excluding celeriac[1]. For potatoes the maximum level applies to peeled potatoes	0.10
	Leaf vegetables, fresh herbs, celeriac and the following fungi[1]: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)	0.20
Lead	Cereals, legumes and pulses	0.20
	Vegetables, excluding brassica vegetables, leaf vegetables, fresh herbs and fungi[1]. For potatoes the maximum level applies to peeled potatoes	0.10
	Brassica vegetables, leaf vegetables and the following fungi[1]: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)	0.30
Serbian Regulation (2014 (amended 2015, 2016 and 2017))		
Cadmium	Vegetables, excluding leaf vegetables, fresh herbs, fungi, stem vegetables, root and tuber vegetables and seaweed[1]	0.050
	Stem vegetables, root and tuber vegetables, including potato, excluding celeriac[1]. For potatoes the maximum level applies to peeled potatoes	0.10
	Leaf vegetables, fresh herbs, celeriac and the following fungi[1]: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)	0.20
Lead	Pulses[1], cereals and legumes	0.20
	Vegetables, excluding brassica vegetables, leaf vegetables, fresh herbs, fungi and seawees[1]. For potatoes the maximum level applies to peeled potatoes	0.10
	Brassica vegetables, leaf vegetables and the following fungi[1]: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)	0.30
Mercury	Vegetables (fresh)	0.02
Arsenic[2]	Vegetables	0.3
Serbian Regulation [2018 (amended 2019)]		
Cadmium	Vegetables, excluding root and tuber vegetables, leaf vegetables, fresh herbs, leafy brassica, stem vegetables, fungi and seaweed[2]	0.050
	Root and tuber vegetables (except celeriac, parsnips, salsify and horseradish) and stem vegetables (except celeries)[1]. For potatoes the ML applies to peeled potatoes	0.10
	Leaf vegetables, fresh herbs, leafy brassica, celeriac, parsnips, salsify and the following fungi[1]: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)	0.20
Lead	Cereals and pulses	0.20
	Vegetables, excluding leafy brassica, salsify, leaf vegetables, fresh herbs, fungi, seaweed and fruiting vegetables[1]	0.10
	Leafy brassica, salsify, leaf vegetables, fresh herbs and the following fungi: *Agaricus bisporus* (common mushroom), *Pleurotus ostreatus* (Oyster mushroom), *Lentinula edodes* (Shiitake mushroom)[1]	0.30
	Fruiting vegetables	
	Sweetcorn	0.10
	Other than sweetcorn	0.05

[1]The maximum level applies after washing of the vegetables and separating the edible part.
[2]Total arsenic.

such as leaves, bulbs, tuberose, roots, legumes and trees, which are intended for human consumption in fresh condition or after culinary preparation, cultivated in open air (in gardens or growing areas) or in greenhouses and orangeries.

The relevant European Union (EU) Regulations on fresh and processed vegetables quality standards are (EU) No 1308/2013 and (EU) No 543/2011. According to Serbian Regulation (2020, amended in 2021) vegetable products included frozen vegetables, sterilised vegetables, pasteurised vegetables, marinated vegetables, fermented vegetables, vegetable juice, tomato puree and pasta, dried vegetable, vegetable sauce and tomato ketchup.

Agriculture and food production in Serbia have an extensive tradition. The ideal climate for vegetable production makes Serbia the main vegetable exporter and supplier of South-Eastern Europe. The most popular vegetables produced in Serbia are paprika (pepper), cabbage, tomato and potato. In the last few years, the production of peas and sweetcorn is rising due to the increased consumption of frozen, ready-to-eat meals worldwide (RAS, Development Agency of Serbia 2020). Also, Serbian vegetable processing industry is well developed. On the other hand, vegetables and fruits have the largest share in the structure of Serbia agri-food import, with a share of 23.7% of total imports (Chamber of Commerce and Industry of Serbia 2020).

Therefore, the aim of this study was to evaluate the concentrations of cadmium, lead, mercury and arsenic in fruits and fruit products intended for human consumption in the Republic of Serbia and to compare these levels with both old and new maximum levels.

Materials and methods

From January 2015 to December 2017 concentrations of Cd, Pb, Hg and As were determined in 455 samples of fresh vegetables (n = 387) and vegetable products (n =

Table 4. Characteristics of the analysed vegetables and vegetable product samples and the concentration range (mg kg^{-1} ww) for Cd and Pb.

Vegetables (common name)	N	> new ML for Cd	> new ML for Pb	Country of origin	Range of Cd concentration	Range of Pb concentration
Arugula	6			Italy	<lod-0.0380	<lod-0.0913
Aubergine	15	4	7	Greece, Italy, North Macedonia, Spain, the Netherlands, Turkey	<lod-0.0474	<lod-0.0981
Bean	16	3		Argentina, Egypt, Kyrgyzstan, Poland, Ukraine	<lod-0.0413	<lod-0.0619
Beetroot	1			The Netherlands	0.0270	0.0489
Broccoli	8			Italy, Poland, Spain	<lod-0.0341	<lod-0.0365
Cabbage	19	3		Albania, Croatia, North Macedonia, Poland, Serbia, the Netherlands	<lod-0.0480	<lod-0.0851
Carrot	3			Austria, the Netherlands	<lod-0.0944	<lod-0.0513
Cauliflower	13	1		Croatia, Greece, France, Italy, Poland, the Netherlands	<lod-0.0413	<lod-0.0628
Celeriac	4			Poland, Spain, The Netherlands	<lod-0.0994	<lod
Chickpea	1	1		Russia	0.0453	0.1234
Chinese cabbage	3			Hungary, Poland	<lod-0.0960	<lod-0.0662
Cucumber	35	13	6	Albania, Bosnia and Herzegovina, Croatia, Greece, North Macedonia, Serbia, Spain	<lod-0.0770	<lod-0.2184
Garlic	7	1		China, Spain, the Netherlands	<lod-0.0602	<lod-0.0510
Ginger	7	1	1	China, Thailand	<lod-0.2515	<lod-0.1299
Horseradish	2			Hungary	0.0444–0.0523	<lod-0.0452
Kail	3			Belgium, Italy, Poland	<lod-0.0217	<lod
Leek	1			Albania	0.0361	<lod
Lettuce	12			Germany, Great Britain, Italy, Poland, Spain, the Netherlands, Tunis	<lod-0.0428	<lod-0.0529
Onion	22	4		Croatia, France, Germany, North Macedonia, Poland, Serbia, Spain, the Netherlands	<lod-0.0409	<lod-0.0799
Pepper	43	15	3	Albania, Bosnia and Herzegovina, China, Greece, Italy, North Macedonia, Serbia, Spain, Turkey	<lod-0.0490	<lod-0.0973
Potato	60		5	Austria, Belarus, Belgium, Bosnia and Herzegovina, China, France, Germany, Greece, Slovenia, the Netherlands	<lod-0.0859	<lod-0.1602
Radicchio	2			Italy, Poland	<lod-0.0286	<lod
Radish	5			Italy	<lod-0.0137	<lod-0.0900
Spinach	3			Italy	<lod-0.0535	<lod-0.1255
Tomato	72	20	5	Albania, Croatia, Belgium, Greece, Italy, Morocco, North Macedonia, Slovenia, Spain, The Netherlands, Turkey	<lod-0.0515	<lod-0.0960
Watermelon	17	1	1	Albania, Brazil, Greece, Italy, Nicaragua, North Macedonia, Serbia	<lod-0.0347	<lod-0.0624
Zucchini	7			Albania, Italy, Spain, Turkey	<lod	<lod
Pasteurised ajvar*	5	4	2	Croatia, North Macedonia	<lod-0.0450	<lod-0.0540
Pasteurised artichokes	1			Italy	<lod	<lod
Beetroot powder	1	1	1	Poland	0.1876	1.2300
Beetroot juice	1			Slovenia	0.0196	0.0170
Frozen broccoli	3	1		Serbia	<lod-0.0409	<lod-0.0650
Broccoli powder	1			China	0.0336	<lod
Frozen butternut puree	1			Serbia	0.0152	<lod
Dried carrot	1	1		Poland	0.2012	<lod
Frozen carrot	2			Serbia	<lod-0.0120	<lod
Frozen cauliflower	2			Poland, Serbia	<lod-0.0291	<lod-0.0160
Dried chickpea	1	1		Greece	0.0476	0.0353

(*Continued*)

Table 4. (Continued).

Vegetables (common name)	N	> new ML for Cd	> new ML for Pb	Country of origin	Range of Cd concentration	Range of Pb concentration
Dried green bean	6			Serbia	<lod	<lod
Dried onion	3	1		Germany, India	<lod-0.0445	<lod
Onion powder	1	1		France	0.0721	0.0783
Frozen peas	4	1		Serbia	<lod-0.0265	<lod
Frozen pepper	11	7		Serbia	<lod-0.0388	<lod-0.0384
Pickled pepperoni pepper	1			North Macedonia	<lod	<lod
Frozen pepper puree	1			Serbia	<lod	<lod
Potato gnocchi	1			Austria	0.0590	0.0658
Frozen pumpkin	1	1		Serbia	0.0291	0.0340
Pasteurised ratatouille**	1			North Macedonia	<lod	<lod
Sauerkraut	5			Serbia	<lod-0.0219	<lod
Frozen spinach	1			Serbia	0.0492	0.1063
Frozen sweetcorn	1			Serbia	<lod	<lod
Sterilised sweetcorn	1			Serbia	0.0187	<lod
Tomato paste (2× concentrated)	2	1		Italy, Spain	<lod-0.0445	<lod
Tomato powder	1			Italy	<lod	<lod
Frozen mixed vegetables	8			Serbia	<lod-0.0282	<lod

*Ajvar is a type of relish, made principally from roasted red bell peppers (with aubergine and garlic).
**Ratatouille is a type of soup (stew), made principally from tomato, pepper, aubergine and onion (with zucchini, carrot, parsley).

68). Analyses were mainly performed at the request of the Ministry of Agriculture, Forestry and Water Economy of the Republic of Serbia in an accredited laboratory before the products were put on the market. Detailed characteristics of the analysed samples are presented in Table 4.

The methods for sample preparation and analysis of the concentrations of Cd, Pb, Hg and As in the collected biological plant materials (vegetables and vegetable products) and quality control using standard reference material were conducted as described in detail in Lazović et al. (2022). In all analysed samples, Cd, Pb, Hg and As concentrations were reported as mg kg^{-1} wet weight. Primary samples of each vegetable and vegetable product were taken from eight different packages, where five vegetable and vegetable products were taken randomly from each package. Prior to homogenisation, each vegetable was washed separately under water (about 60–70°C) and dried with a paper towel to remove impurities that could affect the assay result. The following edible parts of the vegetables and vegetable products were used for homogenisation:

(i) clove (bulb) without tunica and root from garlic,
(ii) bulb without tunica, stem and root from onion,
(iii) florets and steams from broccoli and cauliflower,
(iv) fruit without pedicel and calyx and/or stem from aubergine, butternut, cucumber, pepper, pumpkin, tomato and zucchini,
(v) fruit without peel and rind from watermelon,
(vi) leaves from arugula, artichokes, cabbage, Chinese cabbage, kale, lettuce, radicchio and spinach,
(vii) pod without pedicel and calyx from green bean,
(viii) root without stem and leaf from celeriac, beetroot, carrot, ginger, horseradish and radish,
(ix) seeds (kernels) from bean, chickpea, peas and sweetcorn,
(x) steam and leaves without root from leek,
(xi) tuber without peel from potato.

The examined vegetable products did not contain inedible parts.

When levels of toxic metals in vegetable products were not set, values from the vegetables from which the products are made were taken as reference values for the maximum levels of metals in vegetable products. For example: values for fresh pepper were taken as appropriate values for frozen pepper; values for fruit vegetables were taken as appropriate values for pasteurised ajvar and ratatouille; values for carrot were taken as appropriate values for frozen mixed vegetables.

Results and discussion

The individual concentrations of the analysed toxic metals (Cd, Pb, Hg and As) in all sample of vegetables (n = 387) and vegetables products (n = 68) are shown in the Supplemental material (individual results). The highest contamination of cadmium in vegetables was found in ginger (0.252 mg kg^{-1}), while the highest contamination of cadmium in vegetable products was found in the dried carrot sample (0.201 mg kg^{-1}). The highest level of lead in vegetables was found in a cucumber sample (0.218 mg kg^{-1}), while the highest level of lead in vegetable products was found in a beetroot powder sample (1.230 mg kg^{-1}). The highest level of arsenic in vegetables was found in potato (0.467 mg kg^{-1}), while the highest level of arsenic in vegetables was also found in the dried carrot sample (0.938 mg kg^{-1}). The concentration of mercury was less than 0.011 mg kg^{-1} in each analysed sample of vegetables and vegetable products. The levels of cadmium, lead and arsenic were less than 0.008, 0.009 and 0.010 mg kg^{-1} in 209, 283 and 284 samples of vegetables (n = 387), respectively, and less than these LOD values in 31, 53 and 51 samples of vegetables products (n = 68) (Table 4).

Interpretation by legislation until September 2021

The evaluation of the obtained results of the official control of 455 different samples of vegetables and vegetable products for four different toxic metals (Cd, Pb, Hg and As) has shown that 4.2% of all samples numerically exceeded the maximum levels: 19 out of the 455 samples and 95.8% of the samples were below the MLs (436 out of the 455 samples). In addition, 3.4% of the vegetable samples numerically exceeded the MLs (13 out of the 387 samples) and 8.8% of the vegetable products numerically exceeded the MLs (6 out of the 68 samples). The ML for cadmium was exceeded in 3 (cucumber, garlic, ginger) out of the 387 vegetable samples (0.8%) and also in 3 (beetroot powder, dried carrot, onion powder) out of the 68 vegetable products samples (4.4%). The ML for lead was exceeded in 9 out of the 387 (2.3%) samples: cucumber (3), ginger (1) and potato (5) and also in 1 out of the 68 vegetable products samples (1.5%): beetroot powder. The ML for arsenic was exceeded in only 1 potato sample out of the 387 vegetable samples (0.3%) and also in 2 out of the 68 vegetable products samples (2.9%): beetroot powder and dried carrot. Only 1 vegetable (potato) sample had levels higher than the MLs for cadmium and arsenic and only 1 vegetable product (dried carrot) had levels higher than the MLs for lead and arsenic. A sample of beetroot powder exceeded the MLs for 3 metals: cadmium, lead and arsenic.

Interpretation by legislation since September 2021

According to the new MLs for cadmium and lead set by EU and Serbian legislation, 118 out of the 455 samples (25.9%) numerically exceeded these maximum levels and 337 out of the 455 samples (74.1%) were below these MLs. For cadmium 67 out of the 387 vegetable samples (17.3%) exceeded the ML: aubergine (4), bean (3), cabbage (3), cauliflower (1), chickpea (1), cucumber (13), garlic (1), ginger (1), onion (4), pepper (15), tomato (20) and watermelon (1), as well as 20 out of the 68 vegetable product samples (29.4%): pasteurised ajvar (4), beetroot powder (1), frozen broccoli (1), dried carrot (1), dried chickpea (1), dried onion (1), onion powder (1), frozen peas (1), frozen pepper (7), frozen pumpkin (1), double concentrated tomato paste (1). For lead 28 out of the 387 vegetable samples (7.2%) exceeded the ML: aubergine (7), cucumber (6), ginger (1), pepper (3), potato (5), tomato (5), watermelon (1), as well as 3 out of the 68 vegetable products samples (4.4%): pasteurised ajvar (2) and beetroot powder (1). From these data it is evident that the new MLs for cadmium and lead in certain foodstuffs significantly increase the number of exceedances of the MLs. Eighteen samples: aubergine (4), cucumber (6), pepper tomato (3), watermelon (1), pasteurised ajvar (2) and beetroot powder (2) exceeded the MLs for both cadmium and lead.

In total, 455 different samples of vegetables (n = 387) and vegetable products (n = 68) were analysed in the period between January 2015 and December 2017. From these 455 samples measurable Cd, Pb, Hg and As levels were found in 215 (47.3%), 118 (25.9%), 0 and 120 (26.4%), respectively. One or multiple metals (Cd, Pb and/or As) were found in 250 of these 455 samples (54.9%). Regarding EU and Serbian legislation which was enforced until September 2021, the MLs of Cd, Pb and As for vegetables and vegetable products were exceeded in 19 samples (4.2%): Cd in 3, Pb in 9 and As in 1 samples of vegetables and in 6 samples of vegetable products: Cd in 3, Pb in 1 and As in 2. When regarding the new EU and Serbian MLs of Cd and Pb for vegetables and vegetable products, these were exceeded in 118 samples (25.9%), i.e. in 95 samples of vegetables: Cd in 67 and Pb in 28 samples, and in 23 samples of vegetable products: Cd in 20 and Pb in 3 samples, which shows the new legislation might have rather an impact on food control.

Conclusions

The focus of this study was to evaluate concentrations of heavy metals in vegetables and vegetable products before placing them on the market. The obtained results showed that the levels of Cd, Pb and As in all types of analysed vegetables and vegetable product samples were very diverse. Individual concentrations of Cd and Pb in vegetables and vegetable products could exceed both old and new maximum levels set by European Union and Serbian legislation. Therefore, determination of heavy metals for the quality control of food is an important food safety item. The new regulation with reduced maximum levels, especially for cadmium, will further decrease the presence of heavy metals in vegetables in order to improve public health.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was funded by the Ministry of Education, Science and Technological Development, Republic of Serbia, under Grant 451-03-68/2022-14/200134. Also, this research has been done in liaison with the activities defined by the grant for the establishment and implementation of the research-innovation-scientific program "Centre of Excellence (CoE) for digitalization of microbial food safety risk assessment and quality parameters for accurate food authenticity certification (FoodHub)", financed by the Ministry of Education, Science, Culture and Sports of Montenegro, under the Grant No 01-3660/2.

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