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ORIGINAL PAPER

CONCENTRATION OF HEAVY METALS IN URBAN ALLOTMENT SOILS AND THEIR UPTAKE BY SELECTED VEGETABLE CROP SPECIES – A CASE STUDY FROM GORZÓW WIELKOPOLSKI, POLAND*

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Abstract

Due to the growing popularity of urban agriculture, it is important to understand the influence of the quality of urban soils and crops cultivated on them. This study analyses the content of heavy metals – micronutrients (Cu, Fe, Mn, Ni, Zn) and toxic heavy metals (Cd, Cr, Pb), in samples of soils and three vegetable crops (carrot, lettuce, and tomato) grown in allotment gardens (AGs) in Gorzów Wielkopolski, a medium-sized Polish city with an average level of industrialisation. Emphasis was laid on the transfer of toxic heavy metals from soil to vegetables since they are the most exposed to environmental pollution while being an essential part of the human diet and. The content of heavy metals in the topsoil in the allotment gardens was diversified and was arranged in a descending order of Fe> Zn> Mn> Cu = Pb> Ni = Cr> Cd. The soil was not contaminated with heavy metals. The highest accumulation of micronutrients and toxic heavy metals was found in lettuce leaves, whereas the lowest was in tomato fruits. The lettuce leaves also had a particularly high Fe content. Hence, bearing in mind food safety, we can recommend to grow vegetables with fruits as edible parts in the allotment gardens located in Gorzów Wielkopolski. The values of the health risk quotient (HQ) for Cd and Pb in the carrots and lettuce grown in all the AGs were greater than 1 and posed a health risk for consumers. The HQ values for Cd, Pb, Ni, and Cr in the tomatoes grown in all the AGs were less than 1, which indicated no health hazard and safe consumption.

Keywords: urban gardening, carrot, lettuce, tomato, vegetables, food security.

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INTRODUCTION

Cities across the world are an important element in the food system in regard to both demand for food by urban residents and production of food in urban and peri-urban areas.

Urban agriculture contributes to the creation of an edible green infrastructure, the main purpose of which is to supply cities with food (Russo et al. 2017).

15-20% of the world's food is produced in cities. In 2010, around 14% of the global population was nourished by food produced in urban and peri-urban areas (Kriewald et al. 2019).

As participation in urban agriculture grows, understanding both the quality of urban soils and cultivated crops is of increasing importance. The cultivation of crops for consumption requires good quality soil. Meanwhile, urban soils are often strongly transformed and polluted.

Pollution of cities is mainly anthropogenic, emissions from road traffic, from industrial activities (Chen et al. 2005, Kabała et al. 2009, Säumel et al. 2012, Antisari et al. 2013, Antisari et al. 2015, Noli, Tsamos 2016). Urban soils are exposed to heavy metal contamination, which can be absorbed by plants in various amounts (Tei et al. 2010, Säumel et al. 2012, Jolly et al. 2013, Rutiglianoa et al. 2019).

Vegetables and fruits are often grown in Polish cities, in different types of urban agriculture, such as allotment gardens, community gardens, small traditional farms and home gardens. We focused on allotment gardens, which have been very popular in Poland since the mid-20th century. In Poland, there are currently about a million allotment plots used by approximately 10% of all Poles (Dymek et al. 2021). Allotment gardeners cultivate vegetables and fruits for private use, trusting that they are healthy. The problem of food security is therefore very important here. Very rarely, the soil of allotment gardens and cultivated vegetables are tested for the content of toxic heavy metals due to the small scale of production, but only these can answer the question – is the food actually produced there healthy?

The aim of the present work was to estimate the content of heavy metals – micronutrients (Cu, Fe, Mn, Ni, Zn) and toxic heavy metals (Cd, Cr, Pb), in samples of soils in the allotment gardens of Gorzów Wielkopolski. The same measurements were performed in three common garden crops with different edible parts – carrots, lettuce and tomatoes – because the consumption of vegetables grown in the city might pose a possible risk to human health due to elevated levels of these elements. Emphasis was laid on the transfer of toxic heavy metals from soil to vegetables since they are the most exposed to environmental pollution while being an essential part of the human diet and.

The research was the Polish part of the international project 'FEW--Meter – an Integrative Model to Measure and Improve Urban Agriculture towards Circular Urban Metabolism', implemented between 2018 and 2021.

MATERIALS AND METHODS

Study area and allotment site selection

The study carried out in the six allotment gardens (AGs) in Gorzów Wielkopolski (52°43′51″N 15°14′18″E) a medium-sized city (total area 8 572 ha, population 124 295 residents) in western Poland (Figure 1). A more detailed description of the city and AGs can be found in the paper of Bosiacki et al. (2021).

Fig. 1. The location of the allotment gardens in Gorzów Wielkopolski where the samples of soil and plant material were collected, after Bosiacki et al. (2021)

Soil and plant material sampling

Soil samples were collected on March 15, 2020. From each of the 19 plots, 10 individual soil samples were collected, making up two mixed samples. In places where vegetables were grown, these samples were taken from the depth of 20.0 cm. A total of 38 mixed samples (380 single samples) were taken.

Samples of plant material consisting of carrot roots, lettuce leaves and tomato fruit were collected from the same 19 plots, (Table 1). Two samples of each vegetable species were taken from each plot.

Soil and water analysis

Soil samples were cleaned of mechanical impurities and dried. At the volume ratio of 1:2 v/v in soils, the pH of H_2O and the EC were determined by potentiometry and conductometry, respectively (Golcz 2011).

Table 1

The number of allotment plots from which soil and vegetable samples were collected

AGs	Carrot	Lettuce	Tomato
Jedność	1	1	1
Malwa	2	2	2
Metalowiec	4	4	4
Nowalijka	5	5	5
Tulipan	6	6	6
Ustronie	1	1	1
Total	19	19	19

AGs – allotment gardens

A solution of 0.03 mol dm^{-1} CH_3COOH (Kozik, Golcz 2011) was used to determine the macronutrients and sodium in the soil.

Then, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ were measured by distillation, P and $S\text{-}SO_4$ colorimetrically, K, Ca, Na by flame photometry, and Mg by atomic spectrometry absorption.

The Tyurin method was used to determine the content of humus and C org in soils, while the Kjeldahl method was used to determine the content of total N (Golcz, Bosiacki 2011).

By directly heating the soil at high temp. (440°C), the content of organic matter was determined (Golcz, Bosiacki 2011).

With the Lindsay solution, Cu, Fe, Mn, Ni, Zn, Cd, Cr, Pb were extracted from the soil and then determined in the AAS 5 Zeiss apparatus by the FAAS method (Nowosielski 1988).

The content of Fe in water for irrigation was measured by FAAS with an AAS-5 spectrophotometer (Zeiss).

Chemical analysis of plant material

The carrot roots, lettuce leaves and tomato fruits were dried for 48 h at 105°C. Then the material was mineralized in HNO_3 and $HClO_4$ (Bosiacki, Roszyk 2010).

The content of Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn was determined in mineralized plant material using the FAAS method with the AAS-5.

Transfer factors and health hazard quotients

The transfer factor values (TF) from soil to plants for various vegetables were calculated using the following equation (Jolly et al. 2013, Xu et al. 2013):

$$TF = C_{plant} / C_{soil},$$

where C_{plant} and C_{soil} refer to the concentration of each element in a specific vegetable or soil respectively.

In order to assess the risk to human health by the intake of metal-contaminated vegetables, the hazard quotient (HQ) was determined as described by Guerra et al. (2012) following the US EPA (1989) protocol. The HQ is the ratio between the exposure and the reference oral dose (RfD). HQ was calculated based on the equation:

$$HQ = (D_{iv}) \times (C_{metal}) / RfD \times B_o,$$

where, (Div) refers to the daily intake of vegetables (kg per day), (Cmetal) indicates the concentration of metal in the vegetable (mg kg^{-1}), RfD is the oral reference dose for the metal (mg kg^{-1} of body weight per day), and Bo is the human body mass (kg). RfD is an estimate of a daily oral exposure for the human population which does not cause deleterious effects during a lifetime, generally used in EPA's noncancerous health assessments (Guerra et al. 2012).

For HQ calculations, (Div) – the considered daily intake value of each vegetables studied was 100 g (0.1 kg). The RfD values for Cd (0.001 mg kg^{-1} per day), Ni (0.02 mg kg^{-1} per day) and Cr (1.5 mg kg^{-1} per day) were derived from the Integrated Risk Information System (US Environmental Protection Agency – US EPA, 2010). The value of RfD for Pb (0.0035 mg kg^{-1} per day) was taken from WHO (1993). The average Bo considered for adults was 70 kg (WHO 1993).

If the calculated HQ value of a respective element is lower than 1, then there is no obvious risk or negative health concerns associated with consumption of vegetables.

Statistical analysis

The results were analysed statistically to determine minimum, maximum, average, standard deviation (SD), and coefficients of variation (CV) for heavy metals in the soil and vegetable samples. For chemical characteristics of soils from six AGs, only average and standard deviation (SD) were calculated.

One-way analysis of variance with significance α=0.05 was used to compare the content of microelements and toxic heavy metals in edible parts of the three tested vegetable species, using the Duncan's test.

The strength of the relationship between the iron content in soil and the iron content in lettuce was tested using the Pearson correlation coefficient.

RESULTS AND DISCUSSION

Soil properties

Table 2 shows general characteristics of the chemical composition of the soils in which the three species of vegetables tested in this study were grown.

Table 2

Characteristics of the soil of 6 allotment gardens in Gorzów Wielkopolski (±standard deviation)

Chemical composition		AGs					
		Jedność	Malwa	Metalowiec	Nowalijka	Tulipan	Ustronie
pH H_2O		7.51±0.04	7.24±0.19	7.01±0.32	7.59±0.20	7.14±0.33	7.50±0.04
EC (mS cm^{-1})		0.27±0.03	0.34±0.03	0.43±0.23	0.36±0.09	0.38±0.08	0.50±0.04
C org	(%)	1.00±0.16	0.99±0.09	1.76±1.41	0.90±0.21	0.99±0.17	0.93±0.06
N total		0.08±0.01	0.09±0.01	0.12±0.04	0.09±0.02	0.10±0.01	0.08±0.01
C\N	ratio	12.50	11.00	14.67	10.00	9.90	11.63
N-NH_{+4}	(mg kg^{-1})	trace	trace	28.00±28.00	9.72±5.26	trace	trace
N-NO_{-3}		15.00±1.41	56.50±29.59	82.44±78.91	27.71±39.06	36.91±35.48	157.00±4.24
P		80.05±10.47	309.66±100.68	94.34±69.75	127.03±49.34	132.49±40.34	217.95±11.53
K		171.52±5.21	130.10±36.09	110.43±60.44	152.76±23.53	72.85±25.98	40.12±3.13
Ca		3745.55±47.02	1849.18±765.27	1595.24±301.41	2417.85±692.43	1516.50±612.70	3591.60±24.27
Mg		317.95±7.85	222.83±107.16	225.03±71.71	168.61±76.84	162.47±84.83	420.94±15.93
S-SO_4		59.81±0.38	34.52±13.38	65.42±39.33	33.20±23.53	37.37±16.38	131.57±7.40
Na		27.80±0.57	29.13±3.82	29.40±1.30	32.40±7.22	42.91±28.74	77.05±0.92
Cl		9.10±0.02	12.09±2.41	13.27±3.05	12.86±4.11	14.07±3.77	23.45±0.47

The pH (H_2O) in the soils in the allotment gardens in Gorzów Wielkopolski ranged from 7.01 to 7.59. Thus, the soil was neutral or slightly alkaline. The pH of the soils in the allotment gardens in Gorzów Wielkopolski resulted from the annual, systematic liming of the soils. Soil acidity has significant influence on the growth and yield of vegetables (Komosa et al. 2009). The optimal pH (H_2O) for field cultivation of carrots, lettuce, and tomatoes is 6.0-6.5. Soil acidity also influences the uptake of toxic heavy metals by plants. An acidic soil pH increases the mobility of toxic heavy metals and their absorption by vegetables (Kabata-Pendias, Pendias 2001).

The organic carbon content (C%) ranged from 0.90% to 1.76%. The soils were not rich in organic carbon. The content of organic carbon has significant influence on the detoxification of heavy metals in soil (Tyksiński et al. 2002, Bosiacki, Tyksiński 2003). The enrichment of soil with organic substance, which forms humus in the humification process, reduces the forms of cadmium and lead available to plants (Bosiacki, Tyksiński 2004, Bosiacki, Tyksiński 2006). Therefore, it is recommended to apply organic fertilisers to soils in urban areas in order to reduce the uptake of toxic heavy metals by edible plants.

The recommended content of mineral nitrogen in cultivated soil should range from 50 to 130 mg dm^{-3} (Komosa et al. 2009). The highest content of mineral N was found in the Ustronie and Metalowiec AGs. Most of the soils in the allotment gardens in Gorzów Wielkopolski require nitrogen fertilisation.

The following content of macronutrients (mg dm^{-3} of soil) is optimal for growing field vegetables: phosphorus – carrot 40-80, lettuce 50-70, tomato 60-80; magnesium – carrot, lettuce, tomato 60-120; calcium – 1000-2000 (Komosa et al. 2009). Most of the soils in the allotment gardens in Gorzów Wielkopolski have a high content of phosphorus, magnesium, and calcium. The following content of potassium is recommended for the cultivation of field vegetables: carrot 125-250, lettuce 150-200, tomato 200-250 mg dm^{-3} of soil (Komosa et al. 2009). The Jedność, Malwa, and Nowalijka AGs had the right content of potassium to grow vegetables. The soils in the other allotment gardens were deficient in potassium and needed to be fertilised. The content of $S\text{-}SO_4$ in the Jedność, Metalowiec, and Ustronie AGs was higher than the recommended level of 20-40 mg dm^{-3} of soil. The mean sodium content in the soil in the Ustronie AG was higher than the recommended limit of 50 mg dm^{-3} of soil. The soil chloride content recommended for vegetable cultivation was not exceeded in any of the allotment gardens.

Metal concentrations in soils

Plants take up the greatest amount of nutrients for their growth and development from soil. However, they also take up pollutants, including toxic heavy metals, e.g. cadmium and lead. As the popularity of vegetable growing in urban gardens has increased recently, it is necessary to conduct research in these areas. Research on the sources and content of toxic heavy metals in horticultural crops grown in urban areas was carried out by Bretzel, Calderisi (2006), Kabała et al. (2009), Antisari et al. (2015) and Bosiacki et al. (2021).

The ranges and mean concentrations of micronutrients and toxic heavy metals in soils are shown in Table 3. The calculated values showed a decreasing order of Fe>Zn>Mn>Cu=Pb>Ni=Cr>Cd. The optimal iron content for growing field vegetables is 50-100 mg dm^{-3} of soil (Sady 2000). The iron content in the allotment gardens in Gorzów Wielkopolski ranged from 38.85 to 123.45 mg kg^{-1} of soil (Table 3). The content of copper, zinc and manganese in these gardens did not exceed the recommended levels for vegetable cultivation, i.e. Cu <10, Zn <50, Mn <70 mg dm^{-3} of soil. The content of nickel and chromium in these soils was natural (low).

Table 3

Metal concentrations in soils of 6 AGs in Gorzów Wielkopolski (mg kg^{-1} dm)

Elements	Range	Mean ± SD
Micronutrients		
Cu	0.36-4.53	2.01±1.14
Fe	38.85-123.45	97.34±24.90
Mn	3.81-53.65	20.13±12.88
Ni	0.12-0.76	0.50±0.16
Zn	9.20-37.11	20.52±7.75
Toxic heavy metals		
Cd	0.10-0.29	0.20±0.05
Cr	0.12-0.76	0.50±0.10
Pb	0.84-3.51	2.01±0.63

According to the Regulation of the Minister of the Environment of September 1, 2016, on the method of assessing soil and ground pollution (Journal of Laws 2016, No. 1395), the maximum permissible heavy metal content in a layer of 0-25 cm is: Cd – 3 mg kg^{-1} d.m., Cr – 300 mg kg^{-1} d.m., Cu – 150 mg kg^{-1} d.m., Ni – 150 mg kg^{-1} d.m., Pb – 250 mg kg^{-1} d.m., Zn – 500 mg kg^{-1} d.m. In this research, the content of available heavy metals in the topsoil of the allotment gardens in Gorzów Wielkopolski did not exceed these limits.

Metal concentrations in vegetables

The ranges of the content of individual micronutrients and toxic heavy metals in the edible parts of vegetables are shown in Tables 4 and 5. The content of micronutrients and toxic heavy metals in the edible parts of the examined vegetable species was diversified. The content of copper, nickel,

Table 4

Micronutrient content in vegetables grown in 6 AGs in Gorzów Wielkopolski (mg kg^{-1} dm)

Micronutrients	Statistics	Carrot	Lettuce	Tomato
Cu	range	2.86-5.11	4.23-13.45	1.89-7.68
	mean ± SD	3.93 ± 0.58	7.28±1.85	3.83±1.33
	CV (%)	14.84	25.42	34.72
Fe	range	56.85-267.43	485.77-745.54	55.33-165.60
	mean ± SD	144.08±53.81	615.90±77.50	91.45±22.55
	CV (%)	37.35	12.58	24.65
Mn	range	8.78-23.22	46.73-182.41	8.40-21.89
	mean ± SD	15.35±4.47	107.97±39.13	13.09±3.05
	CV (%)	29.12	36.24	23.32
Ni	range	1.04-2.13	1.76-3.96	0.66-1.11
	mean ± SD	1.64±0.26	2.62±0.56	0.84±0.10
	CV (%)	16.00	21.48	11.62
Zn	range	15.55-41.94	33.31-97.84	7.65-28.43
	mean ± SD	23.74±6.55	52.94±14.64	19.45±3.86
	CV (%)	27.59	27.66	19.83

Table 5

Toxic heavy metal content in vegetables grown in 6 AGs in Gorzów Wielkopolski (mg kg^{-1} dm)

Heavy metals	Statistics	Carrot	Lettuce	Tomato
Cd	range	0.69-1.19	0.89-1.55	0.18-0.54
	mean ± SD	0.91±0.11	1.09±0.13	0.39±0.11
	CV (%)	12.15	12.14	29.19
Cr	range	3.23-12.29	7.11-14.92	3.31-4.86
	mean ± SD	6.30±2.63	10.21±1.98	4.12±0.37
	CV (%)	41.74	19.38	8.87
Pb	range	1.67-3.26	4.32-10.76	0.62-1.90
	mean ± SD	2.70±0.37	7.26±1.63	1.32±0.32
	CV (%)	12.39	22.44	24.34

cadmium, and lead in the carrot roots was characterised by low variability (CV<25%). The content of iron, manganese, zinc, and chromium was characterised by average variability (CV25-45%). The mean values of metal content in carrot showed a decreasing order of Fe> Zn> Mn> Cr> Cu> Pb> Ni> Cd. The lettuce leaves were characterised by low variability (CV<25%) in the content of iron, nickel, cadmium, chromium, and lead, but average variability (CV25-45%) in the content of copper, manganese, and zinc. The mean values of the metal concentrations in lettuce in the descending order was as follows:

Fe> Mn> Zn> Cr> Cu> Pb> Ni>Cd. The tomato fruits were characterised by low variability (CV<25%) in the content of iron, manganese, zinc, nickel, lead, and chromium, but average variability (CV25-45%) in the content of copper and cadmium. The mean concentrations of metals in tomatoes in the descending order was as follows Fe> Zn> Mn> Cr> Cu> Pb> Ni> Cd.

An important objective of this research was to determine differences in the content of micronutrients and toxic heavy metals in the edible parts of vegetables. Among the vegetable species under study, the highest content of copper, iron, manganese, nickel, and zinc was found in the lettuce leaves, whereas the lowest content of these micronutrients was found in the tomato fruits (Figure 2). The content of copper, manganese, nickel, and zinc in the tomato fruits did not differ significantly from the content of these elements in the carrot roots. The lettuce leaves were the most abundant in iron, followed by manganese, zinc, copper, and nickel. The carrot roots and tomato fruits were the most abundant in iron, followed by zinc, manganese, copper, and nickel.

The lettuce grown in the allotment gardens of Gorzów Wielkopolski contained more cadmium, chromium, and lead than the carrots and tomatoes (Figure 3). The lowest content of these heavy metals was found in the tomato fruits.

As the consumption of vegetables might involve a health risk, the European Union defined the maximum permissible levels of lead and cadmium (Commission Regulation EU No 420/2011). The average dry matter content

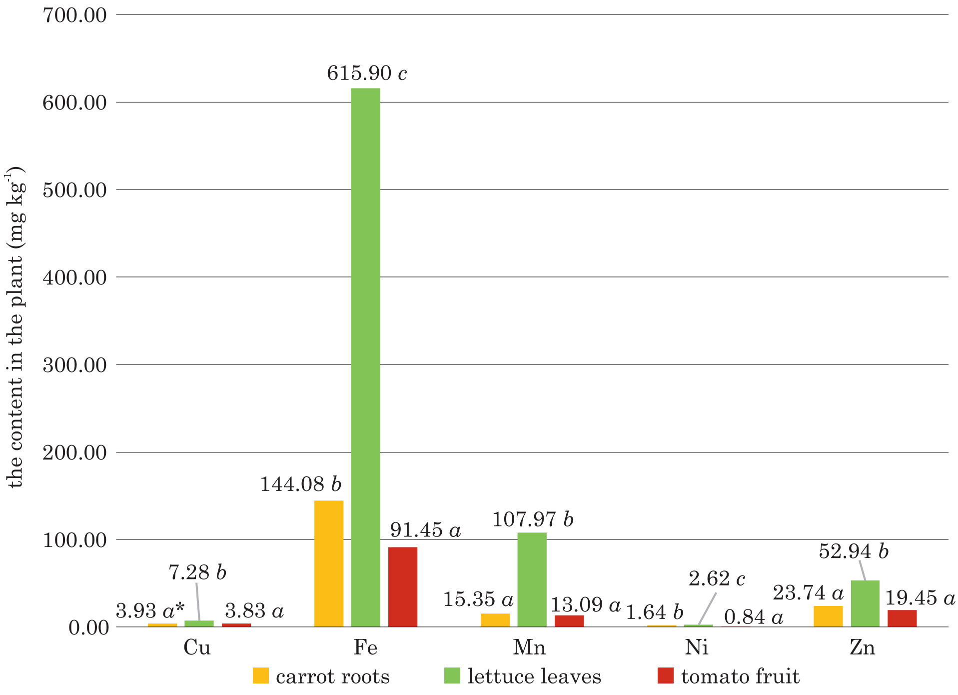

Fig. 2. The content of micronutrients in edible parts of the tested vegetables
* means followed by the same letters do not differ significantly at α=0.05 (Duncan's test)

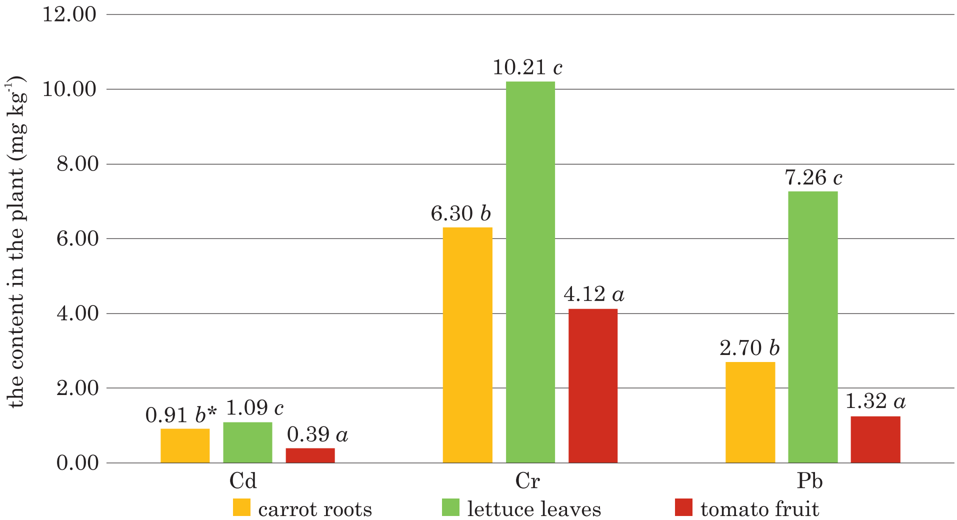

Fig. 3. Toxic heavy metals content in edible parts of the tested vegetables.
* means followed by the same letters do not differ significantly at α=0.05 (Duncan's test)

in the carrot roots was 8%, whereas in the lettuce leaves and tomato fruits it was 6%. Taking the average dry matter and water content in the edible parts of vegetables into account, the cadmium and lead content expressed as mg kg^{-1} of dry weight was converted into mg kg^{-1} of fresh weight for comparison with the applicable standards. The standard Cd and Pb content for carrots is 0.1 mg kg^{-1} fresh weight; for lettuce and tomatoes the standard Cd content is 0.2 mg kg^{-1}, whereas the standard Pb content is 0.3 mg kg^{-1} fresh weight (Commission Regulation EU No 420/2011). The permissible cadmium content in the carrot roots, lettuce leaves, and tomato fruits was not exceeded. The permissible lead content limit in the tomatoes was not exceeded, but it was exceeded in all carrot samples and 92% of the lettuce samples.

Bosiacki et al. (2021) did not observe cadmium, chromium or lead contamination in the topsoil (available forms) of the allotment gardens of Gorzów Wielkopolski in 2019. However, the permissible cadmium and lead content limits in the edible part of carrots were exceeded. In order to detoxify the heavy metals in these soils and reduce the uptake of cadmium, chromium, and lead by carrots, gardeners were recommended to use larger amounts of organic fertilizers to enrich the soil with organic carbon and make its pH neutral. In order to ensure the safety of consumers the chemical composition of the soil and the content of toxic heavy metals in the edible parts of the vegetables grown in these gardens were monitored.

The comparison of the three species of vegetables showed a particularly high iron content in the lettuce leaves, where it ranged from 485.77 to 745.54 mg kg^{-1} of dry weight (Table 4, Figure 2). Such high iron content proved the significant nutritional value of the lettuce for humans. The research showed that the high content of iron in the lettuce leaves was not correlated with the content of this micronutrient in the soil (Figure 4). In fact, the statistical analysis demonstrated that the correlation between the soil iron content and the lettuce iron content was not statistically significant (Pearson's r=-0.11; p=0.05). The high concentration of iron in the lettuce leaves may have been caused by the supply of this nutrient in the water

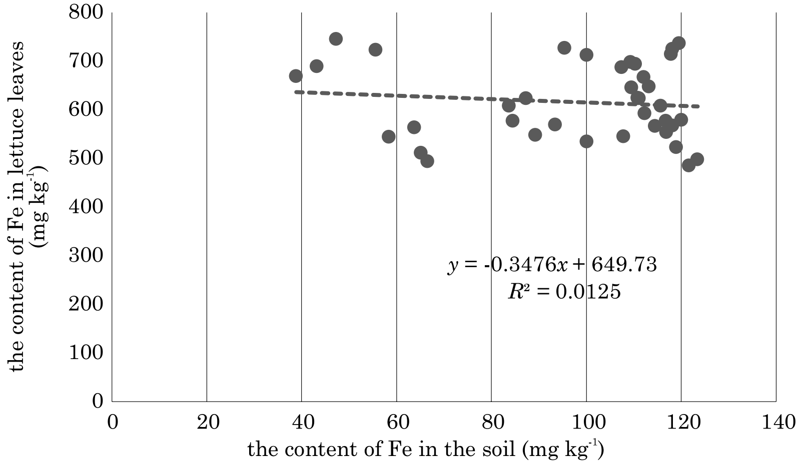

Fig. 4. Relationship between the iron content in edible parts of vegetables and the iron content in the soil of 6 AGs in Gorzów Wielkopolski

used for irrigation. Therefore, the content of soluble forms of iron in the water used for the irrigation of vegetables in the allotment gardens in Gorzów Wielkopolski was also measured. The content of soluble forms of iron ranged from 0.085-1.281 mg dm^{-3} (mean = 0.387, SD = 0.39). The iron content was highly variable (CV% = 101.90). Such high iron content in the water may have increased the iron content in the lettuce leaves. Lopez et al. (2019) conducted a study in Seville and also found an unusually high iron content in lettuce leaves, which was caused by falling dust from the Sahara Desert.

Transfer factors and health hazard quotients

The values of the transfer factor (TF) referring to the uptake of heavy metals from the soil to the vegetables grown in the allotment gardens are shown in Table 6. This study was conducted on carrot, lettuce and tomato as they seem to be the most common home-grown vegetables. The highest TF values were noted for lettuce. The highest TF for Cu (7.66), Mn (16.57), Fe (16.59), Ni (10.95), and Cr (44.05) was observed in the Jedność AG. The highest TF for Zn (3.12), Cd (8.20), and Pb (5.27) was observed in the Nowalijka, Metalowiec, and Tulipan AGs. There were lower TF values noted

Table 6

Transfer factors (TF) from respective AGs soil to carrot, lettuce and tomato

AGs	Cu	Mn	Zn	Fe	Cd	Pb	Ni	Cr
Carrot								
Jedność	3.35	2.00	0.76	3.63	4.00	0.90	5.46	20.77
Malwa	1.05	0.46	0.98	1.64	3.04	1.62	2.61	18.98
Metalowiec	4.63	2.08	1.64	1.18	7.57	1.48	7.11	26.37
Nowalijka	2.33	1.23	1.28	1.08	4.40	1.45	3.22	16.55
Tulipan	2.49	0.98	1.41	2.21	4.56	1.65	2.63	12.15
Ustronie	1.67	0.84	0.89	1.46	4.05	0.85	4.29	11.72
Lettuce								
Jedność	7.66	16.57	2.08	16.59	4.63	3.02	10.95	44.05
Malwa	3.03	3.66	2.37	6.35	3.57	3.96	3.65	22.07
Metalowiec	5.99	12.18	2.97	4.97	8.20	3.35	8.50	33.08
Nowalijka	4.13	6.69	3.12	6.39	5.38	3.71	5.23	29.89
Tulipan	4.36	8.10	2.90	7.49	5.64	5.27	5.08	23.47
Ustronie	3.91	4.33	2.36	7.64	5.08	2.05	5.41	23.88
Tomato								
Jedność	3.11	1.88	0.49	3.96	0.83	0.21	2.73	12.21
Malwa	0.76	0.57	0.85	0.89	0.93	0.47	1.19	8.30
Metalowiec	6.35	1.90	1.31	0.82	3.46	0.78	3.90	15.44
Nowalijka	2.38	0.94	1.04	0.86	2.16	0.76	1.78	11.87
Tulipan	1.98	0.70	1.37	0.96	1.80	0.86	1.31	8.72
Ustronie	2.74	1.11	0.83	1.74	1.87	0.46	1.80	12.73

for Cu (0.76), Mn (0.57), Ni (1.19), and Cr (8.30) in the tomatoes grown in the Malwa AG. Similarly, there were lower TF values noted for Zn (0.49), Cd (0.83), and Pb (0.21) in the Jedność AG. There was a lower TF noted for Fe (0.82) in the Metalowiec AG. Of the three vegetables (carrot, lettuce, and tomato) analysed in our study, there were higher TF values noted for Cu, Mn, Zn, Fe, Cd, Pb, Ni, and Cr in lettuce (Table 6), especially in the Jedność AG. This suggests that lettuce was capable of taking up more elements than the other vegetables. These results are in line with the findings of the study conducted by Murray et al. (2011), who also observed that lettuce contained more trace elements than other vegetables. Moreover, the higher TF values were associated with higher concentrations of elements in respective soils (Table 3) and the concentrations of Cu, Mn, Zn, Fe, Cd, Pb, Ni, and Cr in the vegetables (Tables 4 and 5). These results are in line with the findings of the study conducted by Ru et al. (2008), who observed that the absorption and accumulation of heavy metals (Cu, Zn, Pb, and Cd) in *Spinacia oleracea* increased significantly along with their higher content in the soil.

The HQ values for Cd, Pb, Ni, and Cr in the three vegetables sampled from respective AG plots are listed in Table 7. The HQ-Cd for the carrots and lettuce amounted to 1.14-1,46 and 1.35-1.61, respectively. The HQ-Pb for the carrots was 1.02-1.26, whereas the HQ-Pb for the lettuce ranged from

2.65 to 4.21. The AGs with the HQ values in the descending order were: Jedność > Tulipan > Malwa > Ustronie > Metalowiec > Nowalijka. The HQ values for both Cd and Pb in the carrots and lettuce were greater than 1, which indicates health hazards for consumers.

The HQ values for Cd (0.28-0.66), Pb (0.29-0.64), Ni (0.05-0.24), and Cr (0.004-0.013) in the tomatoes were less than 1 in all the AGs, which indicated no health hazard for consumers. The HQ-Cd and HQ-Pb values for the carrots and lettuce were greater than 1 in all the AGs, which indicated a health risk (Table 7). On the other hand, the HQ values for Cd, Pb, Ni, and Cr in the tomatoes were less than 1 in all the AGs, which indicated safe consumption without health hazard. Research results showed that the consumption of vegetables with higher concentrations of trace elements and toxic heavy metals may pose a health risk. Murray et al. (2011) also observed HQ values greater than 1 in lettuce, which indicated a health hazard for consumers. Säumel et al. (2012) conducted a study in Berlin and also suggested that the consumption of vegetables grown in urban areas posed a health risk. Xiang et al. (2021) also suggested that the heavy metal pollution of *S. oleracea* and its rhizosphere in lime soil in karst areas still posed a health hazard to humans. On the contrary, Warming et al. (2015) noted that the HQs for As, Cd, Cr, Cu, Ni, and Zn were within the permissible level and did not indicate a health risk for urban gardeners in Copenhagen. According to Noli and Tsamos (2016), the values of the transfer factor (TF)

Table 7

Hazard quotients (HQ) calculated values for carrot roots, lettuce leaves and tomato fruits among studies AGs

AGs	Species	Cd	Pb	Ni	Cr
Jedność	carrot	1.35	1.26	0.12	0.006
	lettuce	1.56	4.21	0.24	0.013
	tomato	0.28	0.29	0.06	0.004
Malwa	carrot	1.14	1.19	0.12	0.009
	lettuce	1.35	2.85	0.16	0.010
	tomato	0.35	0.34	0.05	0.004
Metalowiec	carrot	1.46	1.19	0.13	0.007
	lettuce	1.59	2.69	0.15	0.009
	tomato	0.66	0.62	0.06	0.004
Nowalijka	carrot	1.27	1.05	0.11	0.005
	lettuce	1.57	2.65	0.19	0.009
	tomato	0.62	0.54	0.07	0.004
Tulipan	carrot	1.27	1.02	0.11	0.005
	lettuce	1.59	3.26	0.21	0.010
	tomato	0.54	0.57	0.06	0.004
Ustronie	carrot	1.28	1.18	0.13	0.004
	lettuce	1.61	2.83	0.17	0.008
	tomato	0.59	0.64	0.06	0.004

referring to the uptake of elements from soil to vegetables (tomato, parsley, and cucumber) and the respective HQ values for Cr, Zn, and As did not indicate any health risk.

CONCLUSIONS

The soils of Gorzów Wielkopolski allotment gardens are not contaminated with toxic heavy metals. Nonetheless, it was revealed that the limit of lead was exceeded in carrot roots and in lettuce leaves but not in tomato fruits. Hence, bearing in mind food safety, we can recommend growing vegetables with fruits as edible parts in the allotment gardens located in Gorzów Wielkopolski.

With the obtained concentrations of the soluble forms of micronutrients in the examined soils, most of which were within the permissible limits for vegetable crops, significant amounts of these elements were found in edible parts of vegetables, and in particular in lettuce leaves. The leaves of lettuce grown in the allotment gardens of Gorzów Wielkopolski are characterized by a significant nutritive value in terms of the source of iron for humans.

Considering the revealed transfer factor (TF) and health hazard quotient (HQ) values, soil reclamation activities are necessary in all studied AGs, especially to decrease the Cd and Pb levels in all AGs soils. It is necessary to regulate the pH to the optimum soil reaction for growing vegetables, and to introduce more organic matter into the soil.

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