Scientific Bulletin. Series F. Biotechnologies, Vol. XXVIII, No. 2, 2024
ISSN 2285-1364, CD-ROM ISSN 2285-5521, ISSN Online 2285-1372, ISSN-L 2285-1364

HEAVY METAL CONTAMINATION IN SOIL AND ITS ACCUMULATION IN HOME GROWN TOMATO (*Solanum lycopersicum* L.) FRUITS

Natália ČERYOVÁ, Judita LIDIKOVÁ, Monika ŇORBOVÁ, Silvia FEDORKOVÁ, Alena VOLLMANNOVÁ, Janette MUSILOVÁ, Ľuboš HARANGOZO

Slovak University of Agriculture in Nitra, 2 Trieda Andreja Hlinku, Nitra, Slovakia

Corresponding author email: xceryova@uniag.sk

Abstract

The paper aimed to assess the hygienic quality of soils in home gardens and the safety of consumption of tomatoes grown in these soils. Fruits of three tomato cultivars, namely Radana, Tornado F1, and Cherolla F1 from four localities of Slovakia (Sabinov, Žilina, Oravská Lesná, Hliník nad Hronom) along with soil samples were analysed using Varian AA 240FS/240Z atomic absorption spectrometer. Based on the results, all soils can be classified as highly contaminated, extremely polluted, and of high to very high risk. Results showed that monitored cultivars are not bioaccumulators of analysed risk elements, however, the content of Pb and Cd exceeded the limits set by Commission Regulation (EU) 2023/915 in some of the samples. While the results of the health risk assessment showed that consumption of monitored cultivars does not pose a risk to the consumers, it is important to take other dietary sources of risk elements into account, since monitored tomatoes alone could contribute up to 5.7% of the provisional monthly intake of Cd.

Key words*: cadmium, lead, risk elements, Solanum lycopersicum L., tomato*

INTRODUCTION

Tomatoes, fruits of *Solanum lycopersicum* L., are one of the most widely grown and commonly consumed vegetables, utilized in a variety of processed food products, including sauces, ketchup, purees, pastes, soups, juices, and juice blends, as well as whole or diced, sliced, quartered, or stewed canned tomatoes. They are popular due to their taste, availability, affordability, and recognized health benefits (Salehi et al., 2019; Ali et al., 2020). According to FAO/WHO, tomatoes were the most-produced vegetable, with more than 186 million tons produced in 2022, and also the most-consumed vegetable with 22.66 kg consumed per capita in 2021.

Tomatoes are important not only because of the quantity consumed but also because of their high nutritional value and positive effects on human health (Ilić et al., 2014). They are a valuable source of essential nutrients and bioactive compounds, such as carotenoids, phenolics, and glycoalkaloids (Rao et al., 2018; Wang et al., 2022). A negative correlation was found between tomato consumption and the mortality rates from all causes, and the mortality rates from coronary heart disease, cerebrovascular illness, gastric cancer, and prostate cancer (Li et al., 2021).

Because of the abovementioned benefits, and low maintenance cultivation requirements, home growing of tomatoes is fairly popular. However, there is currently a major global issue regarding the contamination of soil and crops with heavy metals. Vegetable contamination is gaining a lot of attention as awareness of the potential health risks grows (Gupta et al., 2021). In addition to a health risk, the presence of heavy metals can also negatively impact the amount of nutrients, such as lycopene and ascorbic acid, in tomatoes (Collins et al., 2022).

Due to the popularity of tomatoes, and the pressing issue of heavy metal contamination, this manuscript addresses the content of heavy metals in the soils and its subsequent accumulation in homegrown tomato fruits.

MATERIALS AND METHODS

Localities

Samples were grown in home gardens in 4 localities in Slovak Republic: Sabinov (1), Žilina (2), Oravská Lesná (3), and Hliník nad Hronom (4)

Sampling

Three tomato cultivars, namely Radana (R), Tornádo F1 (T), and Cherolla F1 (Ch) were conventionally cultivated. Samples were collected by hand, in a state of full ripeness.

Soil samples were taken at 10 cm into the GeoSampler paedological probe (Thermo Fisher Scientific, Hampton, NH, USA). Air dryed samples were ground with a VEB Thurm ZG 1 grinding machine (Stahlbau Magdeburg GmbH, Magdeburg, Germany) to fine earth (0.125 mm average particle size).

Soil sample preparation

Total heavy metals in soil were extracted in the *aqua regia* (2.5 mL 65% HNO_3 Suprapur® (Merck, Darmstadt, Germany) and 7.5 mL 37% HCl Suprapur® (Merck, Darmstadt, Germany) at 160°C for 15 minutes using MarsX-press5 microwave digestion apparatus (CEM Corp., Matthews, NC, USA). After mineralization, samples were filtered through Filtrak 390 quantitative filter paper (Munktell, GmbH, Bärenstein, Germany) and diluted with deionized water (0.054 $\mu S.cm^{-1}$) to a volume of 100 mL.

The bioavailable forms of heavy metals were extracted by 20 g of dried soil sample in 50 mL of NH_4NO_3 (c = 1 $mol.L^{-1}$, Merck, Darmstadt, Germany) for 2 h using a Unimax 2010 horizontal shaker (Heidolph Instrument, GmbH, Schwabach, Germany).

After extraction, the samples were filtered through Filtrak 390 quantitative filter paper (Munktell, GmbH, Bärenstein, Germany), and 0.5 mL of HNO_3 was added.

Plant sample preparation

Homogenized dried samples were mineralized in a mixture of 5 mL of HNO_3 Suprapur® (Merck, Darmstadt, Germany) and 5 mL of deionized water (0.054 $\mu S.cm^{-1}$) using a Mars Xpress 5 closed microwave digestion system (CEM Corp., Matthews, NC, USA), at 160 °C for 15 min. and maintaining it at constant temperature for 10 min.

After digestion, samples were filtered through Filtrak 390 quantitative filter paper (Munktell, GmbH, Bärenstein, Germany) and filled to a volume of 50 mL with deionized water.

Determination of heavy metals in samples

Heavy metals in soil and plant samples were determined according to Vollmanova et al. (2014) by Flame AAS method (Fe, Mn, Zn, Cu, Co, Ni, Cr) using VARIAN AASpectra DUO 240FS atomic absorption spectrophotometer, and Graphite Furnace AAS method (Cd, Pb) using VARIAN AASpectra DUO 240Z atomic absorption spectrophotometer (Varian, Ltd., Mulgrave, VIC, AUS).

Bioaccumulation factor

To determine the ability of the plant to uptake heavy metal from the substrate to their fruits, the bioaccumulation factor was calculated as the ratio of the heavy metal content in the plant and the heavy metal content in the soil.

Environmental risk assessment

To evaluate the contamination of monitored soils, the Degree of contamination (Cdeg), pollution load index (PLI), and potential ecological risk factor (PERF) were calculated according to Čeryová et al., (2023)

Health risk assessment

To evaluate the risks arising from the consumption of monitored tomatoes, % of intake was calculated for adult humans weighting 70 kg using the average consumption of tomatoes (22.66 kg per capita in the year 2021), and tolerable intakes set by WHO and EFSA: 56 mg of Fe, 8 mg of Mn, 0.3-1 mg of Zn, 35 mg of Cu, 0.6 mg of Co, 0.91 mg of Ni, 56 mg of Cr per day, and 1.75 mg of Cd per month.

Statistical analysis

Statistical analyses were performed using XLSTAT (Lumivero, 2024).

RESULTS AND DISCUSSIONS

Heavy metal content in soil samples

Total heavy metal content and content of bioavailable forms of heavy metals in monitored soils are expressed in Table 1 and Table 2. The limit value of total Cd content was exceeded in all soil samples. The limit value of total Zn content was exceeded in soil samples from Sabinov, Oravská Lesná, and Hliník nad Hronom. The critical value of mobile forms of Cd and Pb was exceeded in all soil samples.

Table 1. Total heavy metal content in monitored soils (mg/kg)

Locality	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
1	21307±2214	967±112	345±51.5	28.1±3.33	9.73±1.12	38.2±0.42	32.5±0.33	35.7±0.28	2.42±0.02
2	25779±23547	1153±125	74.0±11.3	26.5±2.81	12.7±1.30	46.9±0.55	30.5±0.33	37.3±0.41	3.39±0.04
3	17978±1528	1468±158	890±99.9	36.9±4.69	8.60±0.95	32.7±0.28	35.5±0.32	46.4±0.44	4.42±0.04
4	17427±1855	616±79	162±18.1	57.7±7.53	7.60±0.71	19.9±0.18	21.8±0.28	47.2±0.40	2.84±0.03
Limit value*			150	60		50		70	0.7

*According to Act No 220/2004, valid in Slovak Republic

Table 2. Bioavailable heavy metal content in monitored soils (mg/kg)

Locality	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
1	0.39±0.03	0.26±0.02	0.23±0.03	0.15±0.01	0.16±0.02	0.30±0.04	0.06±0.007	0.53±0.06	0.18±0.02
2	0.22±0.02	0.15±0.01	0.15±0.02	0.06±0.01	0.17±0.02	0.29±0.03	0.04±0.005	0.52±0.04	0.20±0.02
3	0.69±0.08	2.04±0.02	0.40±0.03	0.40±0.05	0.22±0.02	0.42±0.04	0.05±0.005	0.68±0.06	0.24±0.03
4	0.17±0.02	0.24±0.02	0.20±0.02	0.11±0.13	0.11±0.01	0.22±0.02	0.01±0.001	0.31±0.04	0.13±0.01
Critical value*			2	1		1.5		0.1	0.1

*According to Act No 220/2004. valid in Slovak Republic.

Exceeded levels of total and mobile forms of Cd were also reported in other localities of Slovakia (Fazekašová et al., 2021; Lidiková et al., 2021a; Lidiková et al., 2021b; Musilová et al., 2021; Musilová et al., 2022). According to Fazekašová et al. (2021), Slovakia has many so-called geochemical anomalies, which are notably high in Cd.

Table 3. Environmental risk assessment of monitored soils

Locality	Cdeg	PLI	PERI
1	109.7	3.7	276.0
2	126.8	3.6	370.0
3	144.5	4.7	488.3
4	83.6	3.1	319.5

Based on the environmental risk assessment (Table 3), monitored soils can be defined as highly contaminated, extremely polluted, and of moderate to considerable risk.

Heavy metal content in plant samples

The contents of determined heavy metals in monitored samples are shown in Table 4. The content of Fe ranged from 2.47 to 5.57 mg.kg^{-1}. The content of Mn ranged from 0.72 to 1.55 mg.kg^{-1}. The content of Zn ranged from 0.09 to 0.32. The content of Cu ranged from 0.28 to 0.91. The content of Co ranged from 0.01 to 0.05. The content of Ni ranged from 0.02 to 0.17. The content of Cr ranged from 0.01 to 0.05. The content of Pb ranged from 0.02 to 0.17. The content of Cd ranged from 0.01 to 0.08. Maximum levels of Pb were exceeded in all cultivars from Žilina, in cultivars Radana and Cherolla F1 from Sabinov, and in cultivars Tornado F1 and Cherolla F1 from Hliník and Hronom. Maximum levels of Cd were exceeded in all cultivars from Sabinov and Žilina, in cultivar Radana from Oravská Lesná, and in cultivar Cherolla F1 from Hliník nad Hronom.

Musilová et al. (2022) determined heavy metals in tomatoes grown in the Spiš region of Slovakia and reported similar levels of Mn, Ni, and Pb (0.91-1.32, 0.03-0.15, 0.02-0.16 mg. kg^{-1}), higher levels of Fe, Zn, and Cu (5.41-14.7, 1.23-1.41, 1.10-1.81 mg.kg^{-1}) but lower levels of Cd (BDL). Suárez et al. (2007) reported that the content of Fe, Cu, Zn, and Mn in tomatoes is affected by the cultivar, cultivation method, period of sampling, and region of production. They reported 1.67-2.62 mg Fe.kg^{-1}, 0.18-0.34 mg Cu.kg^{-1}, 0.60- 1.06 mg Zn.kg^{-1}, and 0.55-1.53 mg Mn.kg^{-1} in different tomato cultivars. According to Vélez-Terreros et al. (2021) Cd, Cr, Ni, and Pb concentrations were higher in conventional tomatoes. On the other hand, Rossi et al. (2008) reported, that organic tomatoes had higher Cd and Pb levels but a lower Cu content.

Table 4. Content of heavy metals in monitored samples (mg/kg fresh weight)

Locality	Cultivar	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
1	R	2.47±0.31^{a}	0.83±0.12^{ab}	0.09±0.002^{a}	0.28±0.03^{a}	0.04±0.006^{fg}	0.05±0.008^{abc}	0.03±0.004^{bc}	0.09±0.01^{abc}	0.08±0.01^{b}
	T	3.19±0.41^{abc}	0.89±0.08^{b}	0.13±0.02^{abc}	0.45±0.04^{b}	0.01±0.001^{a}	0.02±0.002^{a}	0.03±0.003^{b}	0.03±0.003^{abc}	0.08±0.01^{b}
	Ch	4.07±0.37^{cde}	1.19±0.13^{b}	0.14±0.01^{abc}	0.47±0.05^{b}	0.02±0.003^{bc}	0.05±0.006^{abc}	0.03±0.004^{bc}	0.12±0.02^{abc}	0.06±0.01^{ab}
2	R	4.68±0.51^{def}	1±0.12^{ab}	0.19±0.01^{abc}	0.68±0.07^{bc}	0.02±0.002^{sb}	0.05±0.005^{abc}	0.03±0.004^{b}	0.14±0.02^{bc}	0.07±0.01^{ab}
	T	5.57±0.67^{f}	1.54±0.17^{ab}	0.32±0.05^{c}	0.91±0.11^{e}	0.03±0.002^{bcd}	0.07±0.007^{abc}	0.03±0.003^{b}	0.17±0.02^{c}	0.08±0.01^{b}
	Ch	4.14±0.46^{cde}	1.55±0.22^{ab}	0.28±0.07^{c}	0.59±0.06^{bcd}	0.03±0.003^{cde}	0.03±0.004^{ab}	0.03±0.004^{bc}	0.17±0.02^{c}	0.06±0.01^{ab}
3	R	4.97±0.6^{ef}	1.16±0.13^{ab}	0.23±0.04^{bc}	0.7±0.08^{cd}	0.04±0.004^{fg}	0.04±0.004^{abc}	0.01±0.001^{a}	0.03±0.004^{abc}	0.05±0.01^{ab}
	T	3.61±0.33^{bcd}	0.90±0.09^{ab}	0.17±0.03^{abc}	0.65±0.08^{cd}	0.04±0.004^{ef}	0.03±0.003^{abc}	0.01±0.002^{a}	0.02±0.003^{a}	0.02±0.002^{ab}
	Ch	3.81±0.46^{cd}	1.05±0.14^{ab}	0.15±0.02^{abc}	0.46±0.05^{b}	0.03±0.004^{de}	0.17±0.019^{c}	0.02±0.002^{a}	0.02±0.003^{ab}	0.02±0.001^{a}
4	R	2.67±0.29^{ab}	0.78±0.09^{a}	0.13±0.01^{abc}	0.54±0.06^{bc}	0.03±0.003^{de}	0.03±0.003^{ab}	0.03±0.003^{b}	0.04±0.005^{abc}	0.01±0.001^{a}
	T	4.01±0.36^{cde}	0.82±0.07^{ab}	0.15±0.02^{abc}	0.72±0.08^{d}	0.04±0.004^{ef}	0.07±0.008^{bc}	0.04±0.005^{cd}	0.13±0.02^{abc}	0.02±0.002^{ab}
	Ch	3.29±0.36^{abc}	0.72±0.08^{a}	0.11±0.02^{ab}	0.62±0.07^{bcd}	0.05±0.006^{g}	0.08±0.008^{bc}	0.05±0.005^{d}	0.11±0.01^{abc}	0.03±0.002^{ab}
ML*									0.05	0.02

*According to Commission Regulation (EU) 2023/915

Table 5. BAF of heavy metals in monitored samples

Locality	Cultivar	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
1	R	0.001^{a}	0.008^{abcd}	0.03^{abc}	0.09^{a}	0.04^{abc}	0.013^{ab}	0.009^{abcd}	0.024^{abcd}	0.29^{b}
	T	0.001^{ab}	0.008^{bcd}	0.04^{abc}	0.15^{abc}	0.01^{a}	0.005^{a}	0.008^{abcd}	0.007^{abcd}	0.29^{b}
	Ch	0.002^{abcd}	0.010^{cde}	0.04^{abc}	0.14^{abc}	0.02^{abc}	0.010^{ab}	0.009^{abcd}	0.028^{abcd}	0.21^{ab}
2	R	0.002^{cd}	0.009^{bcd}	0.26^{bc}	0.26^{bc}	0.01^{ab}	0.011^{ab}	0.010^{abcd}	0.040^{bcd}	0.20^{ab}
	T	0.002^{d}	0.013^{ef}	0.28^{bc}	0.32^{c}	0.02^{abc}	0.013^{ab}	0.009^{abcd}	0.043^{d}	0.21^{ab}
	Ch	0.001^{abc}	0.012^{ef}	0.25^{bc}	0.20^{abc}	0.02^{abc}	0.006^{a}	0.010^{abcd}	0.041^{cd}	0.16^{ab}
3	R	0.003^{d}	0.007^{abc}	0.02^{ab}	0.18^{abc}	0.05^{bc}	0.011^{ab}	0.004^{ab}	0.006^{abc}	0.10^{ab}
	T	0.002^{bcd}	0.006^{a}	0.02^{a}	0.16^{abc}	0.04^{abc}	0.009^{ab}	0.004^{a}	0.004^{a}	0.04^{a}
	Ch	0.002^{bcd}	0.006^{ab}	0.02^{a}	0.11^{abc}	0.03^{abc}	0.047^{b}	0.004^{abc}	0.004^{ab}	0.02^{a}
4	R	0.002^{bcd}	0.014^{f}	0.10^{abc}	0.10^{ab}	0.05^{bc}	0.017^{ab}	0.013^{bcd}	0.010^{abcd}	0.04^{a}
	T	0.002^{d}	0.012^{ef}	0.11^{abc}	0.11^{abc}	0.04^{abc}	0.033^{b}	0.017^{cd}	0.024^{abcd}	0.05^{ab}
	Ch	0.002^{bcd}	0.010^{de}	0.09^{abc}	0.10^{a}	0.06^{c}	0.034^{b}	0.020^{d}	0.021^{abcd}	0.08^{ab}

The factors of accumulation of the determined heavy metals (BAF) are shown in Table 5. Based on the BAF, we can state that monitored cultivars show none to low accumulation of Fe (0.001-0.003), Mn (0.006-0.014), Co (0.01-0.05), Ni (0.005-0.047), Cr (0.004-0.02), and Pb (0.004-0.043) and low to medium accumulation of Zn (0.02-0.28), Cu (0.09-0.32), and Cd (0.02-0.29). No differences were observed in the accumulation of heavy metals by individual cultivars, but differences were observed between localities, which suggests that different agro-environmental factors influence the rate of accumulation. The low accumulation of heavy metals in tomato fruits was also reported by other authors (Arslan Topal et al., 2022; Musilová et al., 2022; Bounar et al., 2020). According to Murtić et al. (2018), the accumulation of heavy metals in tomato fruits is low because of the combined effects of several plant defense mechanisms. According to Taghipour and Jalali (2020), the accumulation of heavy metals in tomatoes is lower when organic wastes, especially plant wastes such as rice husk, are applied to the soil.

Table 6. Relationships between contents of monitored heavy metals

Variables	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
Fe	**1**	**0.726**	**0.789**	**0.788**	-0.227	0.070	-0.201	0.430	0.282
Mn	**0.726**	**1**	0.539	0.410	-0.287	-0.052	-0.209	0.511	0.477
Zn	**0.789**	0.539	**1**	**0.880**	0.002	-0.094	-0.202	0.272	-0.024
Cu	**0.788**	0.410	**0.880**	**1**	0.008	-0.072	-0.003	0.389	-0.069
Co	-0.227	-0.287	0.002	0.008	**1**	0.173	0.083	-0.145	-0.492
Ni	0.070	-0.052	-0.094	-0.072	0.173	**1**	-0.065	-0.115	-0.400
Cr	-0.201	-0.209	-0.202	-0.003	0.083	-0.065	**1**	**0.624**	0.082
Pb	0.430	0.511	0.272	0.389	-0.145	-0.115	**0.624**	**1**	0.440
Cd	0.282	0.477	-0.024	-0.069	-0.492	-0.400	0.082	0.440	**1**

Values in bold are significant ($p<0.05$)

The relationships between the contents of determine heavy metals in monitored samples are shown in Table 6. The content of Fe positively correlated with the content of Mn, Zn, and Cu, and the content of Zn positively correlated with the content of Cu. Also, a positive correlation was observed between the content of Cr and Pb. Suárez et al. (2007) also observed positive correlations between Fe and Zn, and Fe and Mn, between Cu and Zn, and Cu and Mn, and between Mn and Zn.

The content of individual elements varied depending on both cultivar and locality. While we could not characterize individual cultivars by the content of heavy metals, samples from Žilina could be characterized by their Fe, Mn, and Zn content, and by accumulation of Co and Pb. Samples from Hliník nad Hronom could be characterized by the accumulation of Mn. These results suggest that locality could have a greater impact on the accumulation and content of elements than cultivars.

Health risk assessment

The percentages of tolerable intake of the determined heavy metals by consumption of monitored tomatoes are shown in Table 7. While the Fe, Mn, Zn, Cu, Co Ni, and Cr are essential elements, and their content in tomatoes does not pose a threat to human health, Pb and Cd are highly toxic (Musilová et al., 2022). According to EFSA (2012a; 2012b), food is the major source of human exposure to Pb and Cd. Based on the daily intake of tomatoes, we can state that tolerable intakes of heavy metals would not be exceeded, however, it is important to take other dietary sources of risk elements into account since monitored tomatoes alone could contribute up to 5.7% of the provisional monthly intake of Cd.

Table 7. The percentages of tolerable intake of the elements by consumption of tomatoes (%)

Locality	**Cultivar**	**Fe**	**Mn**	**Zn**	**Cu**	**Co**	**Ni**	**Cr**	**Cd**
	R	0.19	0.44	0.07-0.25	0.03	0.30	0.25	0.002	5.6
1	T	0.24	0.48	0.10-0.33	0.06	0.08	0.10	0.002	5.6
	Ch	0.31	0.64	0.09-0.30	0.06	0.16	0.22	0.003	4.5
	R	0.36	0.54	0.11-0.38	0.08	0.12	0.24	0.002	4.9
2	T	0.43	0.83	0.13-0.45	0.11	0.18	0.30	0.002	5.7
	Ch	0.32	0.83	0.12-0.41	0.07	0.22	0.14	0.003	4.5
	R	0.38	0.62	0.13-0.42	0.09	0.31	0.18	0.001	3.5
3	T	0.28	0.48	0.12-0.41	0.08	0.28	0.16	0.001	1.4
	Ch	0.29	0.56	0.10-0.33	0.06	0.23	0.82	0.001	0.9
	R	0.20	0.42	0.09-0.30	0.07	0.23	0.15	0.002	0.7
4	T	0.31	0.44	0.12-0.41	0.09	0.26	0.35	0.003	1.3
	Ch	0.25	0.39	0.10-0.34	0.08	0.36	0.36	0.004	1.9

CONCLUSIONS

Monitoring of heavy metals in soil, and their accumulation in tomato fruits is important to assess the contamination, and the associated health risks. While monitored cultivars are not accumulators of heavy metals, the content of Pb and Cd exceeded the maximum levels. The results of this study suggest that the accumulation and content of heavy metals in tomatoes depend mainly on agro-environmental factors. However, it is necessary to conduct further studies dealing with the heavy metal contamination of tomatoes.

ACKNOWLEDGEMENTS

This research was supported by a scientific grant VEGA 1/0113/21

REFERENCES

Ali, M.Y., Sina, A.A.I., Khandker, S.S., Neesa, L., Tanvir, E.M., Kabir, A., ... & Gan, S.H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, 10(1), 45.

Arslan Topal, E. I., Topal, M., & Öbek, E. (2022). Assessment of heavy metal accumulations and health risk potentials in tomatoes grown in the discharge area of a municipal wastewater treatment plant. *International Journal of Environmental Health Research, 32*(2), 393-405.

Bounar, A., Boukaka, K., & Leghouchi, E. (2020). Determination of heavy metals in tomatoes cultivated under green houses and human health risk assessment. *Quality Assurance and Safety of Crops & Foods, 12*(1), 76-86.

Collins, E. J., Bowyer, C., Tsouza, A., & Chopra, M. (2022). Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology, 11*(2), 239.

Čeryová, N., Lidiková, J., Šnirc, M., Harangozo, Ľ., Pintér, E., Bobko, M., ... & Vollmannová, A. (2023). Heavy metals in onion (*Allium cepa* L.) and environmental and health risks. *Food Additives & Contaminants: Part B*, 1-11.

European Food Safety Authority. (2012a). Cadmium dietary exposure in the European population. EFSA Journal, 10(1), 2551.

European Food Safety Authority. (2012b). Lead dietary exposure in the European population. EFSA Journal, 10(7), 2831.

Fazekašová, D., Petrovič, F., Fazekaš, J., Štofejová, L., Baláž, I., Tulis, F., & Tóth, T. (2021). Soil contamination in the problem areas of agrarian Slovakia. *Land*, 10(11), 1248.

Gupta, N., Yadav, K. K., Kumar, V., Krishnan, S., Kumar, S., Nejad, Z. D., ... & Alam, J. (2021). Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis. *Environmental toxicology and pharmacology, 82*, 103563.

Ilić, S. Z., Mirecki, N., Trajković, R., Kapoulas, N., Milenković, L., & Šunić, L. (2015). Effect of Pb on germination of different seed and his translocation in bean seed tissues during sprouting. *Fresenius Environmental Bulletin*, 24(2A), 670-675.

Li, N., Wu, X., Zhuang, W., Xia, L., Chen, Y., Wu, C., ... & Zhou, Y. (2021). Tomato and lycopene and multiple health outcomes: Umbrella review. Food Chemistry, 343, 128396.

Lidiková, J., Čeryová, N., Šnirc, M., Vollmannová, A., Musilová, J., Brindza, J., ... & Fehér, A. (2021). Comparison of Heavy Metal Intake by Different Species of the Genus Allium L. *Biological Trace Element Research, 199*, 4360-4369.

Lidiková, J., Čeryová, N., Šnirc, M., Musilová, J., Harangozo, Ľ., Vollmannová, A., ... & Grygorieva, O. (2021). Heavy metals presence in the soil and their content in selected varieties of chili peppers in Slovakia. *Foods, 10*(8), 1738.

Lumivero (2024). XLSTAT statistical and data analysis solution. https://www.xlstat.com/en.

Musilová, J., Franková, H., Lidiková, J., Chlpík, J., Vollmannová, A., Árvay, J., ... & Tóth, T. (2022). Impact of old environmental burden in the Spiš region (Slovakia) on soil and home-grown vegetable contamination, and health effects of heavy metals. *Scientific Reports*, 12(1), 16371.

Musilová, J., Harangozo, Ľ., Franková, H., Lidiková, J., Vollmannová, A., & Tóth, T. (2021). Hygienic quality of soil in the Gemer region (Slovakia) and the impact of risk elements contamination on cultivated agricultural products. *Scientific Reports*, 11(1), 14089.

Rao, A.V., Young, G.L., & Rao, L.G. (Eds.). (2018). *Lycopene and tomatoes in human nutrition and health*. Boca Raton, FL USA: CRC Press.

Salehi, B., Sharifi-Rad, R., Sharopov, F., Namiesnik, J., Roointan, A., Kamle, M., ... & Sharifi-Rad, J. (2019). Beneficial effects and potential risks of tomato consumption for human health: An overview. *Nutrition*, 62, 201-208.

Suárez, M. H., Rodríguez, E. R., & Romero, C. D. (2007). Mineral and trace element concentrations in cultivars of tomatoes. *Food Chemistry*, 104(2), 489-499.

Taghipour, M., & Jalali, M. (2020). Effects of some industrial and organic wastes application on growth and heavy metal uptake by tomato (*Lycopersicum esculentum*) grown in a greenhouse condition. *Environmental Science and Pollution Research,* 27, 5353-5366.

Vélez-Terreros, P. Y., Romero-Estevez, D., Yanez-Jacome, G. S., Simbaña-Farinango, K., & Navarrete, H. (2021). Comparison of major nutrients and minerals between organic and conventional tomatoes. A review. *Journal of Food Composition and Analysis,* 100, 103922.

Vollmannova, A., Musilova, J., Toth, T., Arvay, J., Bystricka, J., Medvecky, M., & Daniel, J. (2014). Phenolic compounds, antioxidant activity and Cu, Zn, Cd and Pb content in wild and cultivated cranberries and blueberries. *International journal of environmental analytical chemistry*, 94(14-15), 1445-1451.

Wang, C., Li, M., Duan, X., Abu-Izneid, T., Rauf, A., Khan, Z., ... & Suleria, H. A. (2023). Phytochemical and nutritional profiling of tomatoes; impact of processing on bioavailability-a comprehensive review. *Food Reviews International, 39*(8), 5986-6010.