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Heavy Metal Uptake and Bioaccumulation in Chives (*Allium schoenoprasum* L.)

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This study aimed to evaluate the uptake and accumulation of trace elements in three cultivars of chives (*Allium schoenoprasum* L.; Bohemia, Pobrežná, and Pražská) grown under identical field conditions in Veľká Mača (Slovak Republic), in order to determine their food safety and suitability for cultivation in moderately contaminated soils. Pseudo-total and mobile forms of heavy metals in soil were determined, along with metal concentrations in plant leaves, using microwave-assisted digestion followed by flame and graphite furnace atomic absorption spectrometry. The soil exhibited elevated pseudo-total concentrations of Zn, Ni, and Cd, with Cd and Pb mobile fractions exceeding regulatory critical values, indicating potential soil–plant transfer risk. Despite these conditions, all chive cultivars accumulated essential micronutrients (Fe, Mn, Zn, Cu) within nutritionally relevant ranges, while concentrations of Pb and Cd in fresh biomass remained below European food safety limits (Commission Regulation (EU) 2023/915). Significant inter-cultivar differences ($p < 0.05$) were observed, particularly for Fe, Zn, Pb, and Cd. Principal component analysis revealed clear cultivar clustering driven by micronutrient content and Pb accumulation. Bioaccumulation factors were <1 for all elements except Cd (0.43–0.65), confirming low overall metal transfer from soil to plants, with moderate Cd uptake typical for *Allium* species. The results demonstrate that *A. schoenoprasum* cultivars differ in trace element uptake capacity and can be safely cultivated even under moderately contaminated soil conditions. These findings support the importance of cultivar selection and soil monitoring to ensure both nutritional value and food safety in *Allium* crops.

Keywords: *Allium schoenoprasum*, cadmium, lead

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Introduction

Chives (*Allium schoenoprasum* L.) is a perennial plant belonging to the family Alliaceae Herb. and the genus *Allium* L. (Yoldas et al., 2019). This taxonomic group includes more than 500 species, such as *A. cepa* L. (onion), *A. sativum* L. (garlic), *A. chinense* G. Don (Chinese onion), *A. ascalonicum* (= *A. cepa*) (shallot), *A. hookeri* Thwaites (Hooker's chives), and others (Parvu et al., 2014; Kim et al., 2016). *A. schoenoprasum*, known as chives, is the smallest edible species within this genus (Štajner et al., 2011).

The name "*schoenoprasum*" is derived from the Greek words skhoínos (grass) and prason (leek). The plant is believed to have originated in Siberia, from where it spread to Asia, Europe, and North America. The English word "chive" comes from the French term cive (Charles, 2013). Today, chives are commonly used in households, with fresh or dried leaves employed for culinary purposes. Chives are cultivated as a garden crop and are available in many grocery stores (Charles, 2013; Krishnan and Nair, 2016; Singh et al., 2016).

Chives are known for their content of essential oils rich in sulphur compounds (Baranazi et al., 2004; Kim et al., 2016; Krishnan and Nair, 2016), which give them their characteristic flavour (Mnayer et al., 2014). They are low in calories (30 kcal·100 g^{-1}) and are a rich source of minerals (calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, manganese, selenium), vitamins (vitamin C, thiamine, riboflavin, niacin, pantothenic acid, vitamins B6, A, E, K), lipids, and amino acids (United States Department of Agriculture, 2017; Singh et al., 2018). Nutritionally, chives are particularly notable for their high content of vitamin A (4,353 IU·100 g^{-1}) and vitamin K (212.7 µg·100 g^{-1}) (Singh et al., 2018).

Various studies highlight the presence of phenolic compounds (Zheng and Wang, 2001; Štajner et al., 2011; Mnayer et al., 2014), flavonoids such as kaempferol, quercetin, quercetol, isorhamnetin, and rutin (Carotenuto et al., 1996; Lachman et al., 2003; Kuceková et al., 2011), as well as anthocyanins (Fossen et al., 2000). *A. schoenoprasum* exhibits various biological activities, including antifungal, anthelmintic, anti-inflammatory, antihypertensive, and anticancer effects (Singh et al., 2018).

Our study aims to analyse the pseudototal and bioavailable fractions of selected heavy metals in agricultural soil and their subsequent accumulation in the leaves of three *A. schoenoprasum* cultivars, with emphasis on inter-cultivar variability, bioaccumulation potential, and compliance with international food safety limits.

Material and Methodology

Plant Material

Three cultivars of *A. schoenoprasum* – Bohemia, Pobrežná, and Pražská – were cultivated conventionally under identical agronomic and environmental conditions at the same locality (Veľká Mača, Slovak Republic). Fully mature plants were harvested manually and mechanically cleaned of organic and inorganic debris immediately after collection.

Sample Preparation

Leaves were washed with distilled water, cut into small pieces, and dried to constant weight at 45 °C. The dried material was homogenized for 30 s at 25,000 rpm using an IKA A10 basic grinder (IKA-Werke GmbH & Co. KG, Staufen, Germany) and stored in polyethylene bags until analysis.

Determination of Dry Matter Content

Dry matter content was determined gravimetrically by drying samples at 105 °C to constant weight using a Kern DLB 160-3A moisture analyzer (Kern & Sohn GmbH, Frommern, Germany).

Soil samples were collected from a depth of 0–0.1 m using a GeoSampler pedological probe (Thermo Fisher Scientific, Hampton, NH, USA). Organic residues were removed, and the soil was air-dried at room temperature. Dried samples were ground in a VEB Thurm ZG 1 mill (Stahlbau Magdeburg GmbH, Magdeburg, Germany) to a particle size of approximately 0.125 mm, homogenized, and stored in polyethylene bags until analysis.

Determination of Pseudo-total Heavy Metal Content in Soil

Pseudo-total metal contents (excluding metals bound in silicate lattices) were determined following aqua regia digestion. Soil samples were digested in a MarsX-press 5 microwave digestion system (CEM Corp., Matthews, NC, USA) using 2.5 mL of 65% HNO_3 Suprapur® and 7.5 mL of 37% HCl Suprapur® (Merck, Darmstadt, Germany). Digests were filtered through Filtrak 390 quantitative filter paper (Munktell GmbH, Bärenstein, Germany) and diluted with deionized water (0.054 µS·cm^{-1}). Concentrations of Fe, Mn, Zn, Cu, Co, Ni, and Cr were determined by FAAS using a VARIAN AASpectra DUO 240FS spectrophotometer, while Cd and Pb were quantified by GFAAS using a VARIAN AASpectra DUO 240Z (Varian Ltd., Mulgrave, VIC, Australia). Calibration was conducted using CertiPUR® multi-element standards (Merck, Darmstadt, Germany).

Determination of Bioavailable Forms of Heavy Metals in Soil

Bioavailable (mobile) metal forms were assessed by extraction with 1 mol·L^{-1} NH_4NO_3 solution. Dried soil (20 g) was shaken with 50 mL NH_4NO_3 (Merck, Germany) for 2 h using a Unimax 2010 horizontal shaker (Heidolph Instrument GmbH, Schwabach, Germany). Extracts were filtered through Filtrak 390 filter paper. Element concentrations were determined using the same FAAS/GFAAS instrumentation and calibration procedure described above. Results were evaluated against maximum permissible and critical values defined by Act No. 220/2004 Coll. (Slovak Republic).

Determination of Heavy Metal Content in Plant Material

Approximately 0.5 g of homogenized dried plant material was digested in a Mars Xpress 5 microwave system (CEM Corp.) using 5 mL HNO_3 Suprapur® and 5 mL deionized water at 160 °C for 15 min, followed by a 10 min hold. Digests were filtered and diluted to 50 mL with deionized water. Fe, Mn, Zn, Cu, Co, Ni, and Cr were determined by FAAS, while Cd and Pb were analyzed by GFAAS as described above. The obtained concentrations were compared with the maximum permissible levels for vegetables set by Commission Regulation (EU) 2023/915.

Statistical analysis

Statistical analyses were performed using XLSTAT (Lumivero, 2025). Data are presented as mean ±SD of four independent replicates. Normality and homogeneity of variance were assessed using the Shapiro-Wilk and Levene's tests, respectively. Differences among cultivars were evaluated using one-way ANOVA followed by Tukey's post hoc test ($p < 0.05$). Where assumptions of normality or homogeneity were violated, the Kruskal-Wallis test and Dunn's multiple comparisons test ($p < 0.05$) were applied. Multivariate relationships among elements and cultivar similarities based on elemental composition were examined using Principal Component Analysis (PCA).

Results and Discussion

The soil sample showed a relatively high pseudototal content of several metals, particularly Fe (31,836 mg·kg^{-1}) and Mn (852 mg·kg^{-1}), reflecting the natural geochemical background of many agricultural soils. When compared to regulatory limit values, Zn and Ni exceeded the respective thresholds (Zn: >60 mg·kg^{-1}; Ni >50 mg·kg^{-1}), suggesting possible anthropogenic influence or naturally enriched parent material. Cadmium also surpassed the permissible level (0.7 mg·kg^{-1}), which raises environmental and food-safety concerns due to its high mobility and toxicity. Conversely, Cu, Co, Cr, and Pb remained below the critical regulatory levels.

Plant uptake of heavy metals is strongly influenced by their bioavailable fraction in the soil, rather than by total metal content (Gao et al., 2018; Sihlahla et al., 2019). The proportion of mobile (bioavailable) forms of metals was relatively low, suggesting limited immediate mobility and plant uptake potential. However, Pb and Cr exhibited slightly higher mobility fractions (1.47 and 15.7%, respectively), which could become environmentally significant under changing soil pH or redox conditions. When compared to the critical values for mobile fractions, Pb (0.48 mg·kg^{-1}) and Cd (0.34 mg·kg^{-1}) exceeded their respective critical values (0.10 mg·kg^{-1}), implying enhanced environmental availability and potential uptake by plants. This finding suggests that, despite relatively moderate total concentrations, Pb and Cd are present in forms that may pose a risk to soil-plant transfer and consequently to the food chain. Overall, the soil can be characterized as moderately contaminated, with cadmium and lead representing the primary ecological and toxicological concerns due to their elevated

Table 1 Content of heavy metals in the soil sample (mg·kg^{-1})

Heavy metal content	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
Pseudototal content	31836	852	87.4	29.3	12.5	61.7	43.3	32.6	2.18
Limit value	NE	150	60	NE	50	NE	NE	70	0.7
Mobile forms	0.34	0.34	0.33	0.34	0.38	0.40	0.41	0.48	0.34
Critical value	NE	NE	2.00	1.00	NE	1.50	NE	0.10	0.10

Notes: NE – not established

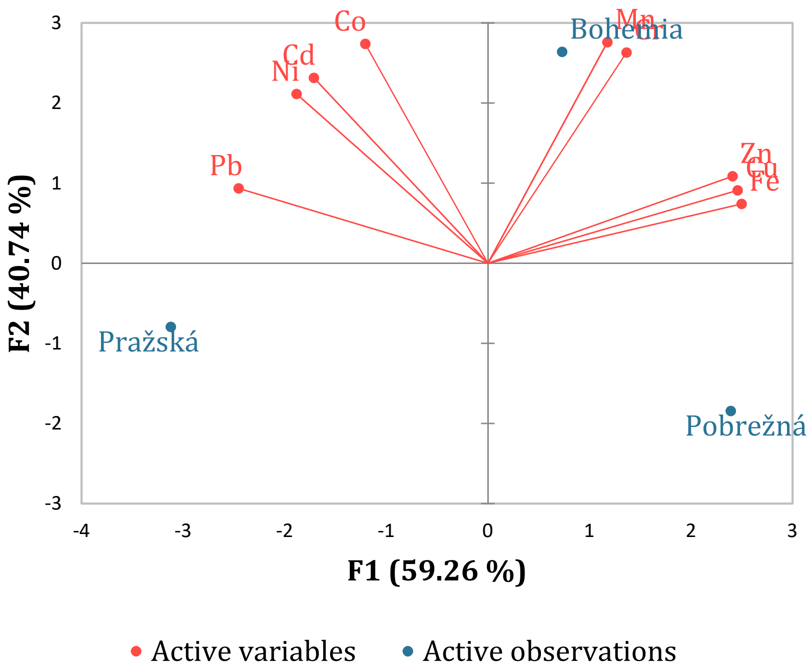

Figure 1 Principal component analysis (PCA) biplot showing the relationships among heavy metals and the distribution of chives cultivars

mobile fractions. Continuous monitoring, control of anthropogenic inputs, and remediation measures such as increasing soil organic matter content or applying immobilizing amendments (e.g., biochar, phosphates) are recommended to reduce metal mobility and bioavailability.

Significant differences ($p < 0.05$) were observed among chives cultivars in their elemental composition (Table 2). Iron content varied widely, ranging from 76 ±5 mg·kg^{-1} DW in cv. Pražská to 161 ±9 mg·kg^{-1} DW in cv. Pobrežná. The highest Fe level in cv. Pobrežná was significantly different from cv. Pražská ($p < 0.05$), whereas cv. Bohemia showed an intermediate value. Manganese content (30.3–34.2 mg·kg^{-1} DW) did not differ significantly among cultivars, while zinc levels were markedly higher in 'Bohemia' (21.8 ±1.1 mg·kg^{-1} DW) compared with cv. Pražská (12.8 ±0.9 mg·kg^{-1} DW). Copper concentrations ranged from 4.20 ±0.22 to 6.20 ±0.33 mg·kg^{-1} DW, showing no significant cultivar differences. According to Singh et al. (2018), chives contain higher content of microelements: 1,600 mg of Fe, 373 mg of Mn, 560 mg of Zn, and 157 mg of Cu per kilogram. Cobalt and nickel exhibited low levels (0.10–0.40 mg·kg^{-1} DW and 1.60–2.40 mg·kg^{-1} DW, respectively), with statistically significant variation in Co content, highest in cv. Bohemia (0.40 ±0.02 mg·kg^{-1} DW) and lowest in cv. Pobrežná (0.10 ±0.01 mg·kg^{-1} DW). Chromium levels were lowest in cv. Pražská (0.20 ±0.01 mg·kg^{-1} DW) and highest in cv.Bohemia (0.50 ±0.02 mg·kg^{-1} DW), showing clear inter-cultivar variation ($p < 0.05$). Lead (Pb) and cadmium (Cd) exhibited the greatest variability among potentially toxic elements. Pb content ranged from 1.09 ±0.07 mg·kg^{-1} DW in cv. Pobrežná to 2.95 ±0.16 mg·kg^{-1} DW in cv. Pražská, while Cd varied from 0.93 ±0.05 to 1.42 ±0.10 mg·kg^{-1} DW, both showing significant differences among cultivars. Despite this variability, when recalculated to a fresh weight basis, none of the samples exceeded the maximum allowable limits (Pb ≤0.3 mg·kg^{-1} FW; Cd 0.2 mg·kg^{-1} FW, Commission Regulation (EU) 2023/915).

Table 2 Content of heavy metals in the plant samples (mg·kg^{-1} DM)

Cultivar	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
Bohemia	156 ±8ab	34.2 ±1.7a	21.8 ±1.1b	6.20 ±0.33a	0.40 ±0.02b	2.40 ±0.02a	0.50 ±0.02c	2.15 ±0.11b	1.42 ±0.10b
Pobrežná	161 ±9b	31.3 ±1.5a	21.2 ±1.1ab	6.20 ±0.25a	0.10 ±0.01a	1.60 ±0.01a	0.30 ±0.01b	1.09 ±0.07a	0.93 ±0.05a
Pražská	76 ±5a	30.3 ±1.5a	12.8 ±0.9a	4.20 ±0.22a	0.30 ±0.03ab	2.40 ±0.02a	0.20 ±0.01a	2.95 ±0.16c	1.37 ±0.08b

Notes: different letters mean statistically significant ($p < 0.05$) differences between cultivars

Soil contamination by heavy metals in agricultural contexts has been assessed, with some studies finding low ecological risk and human health risk for certain areas growing hotbed chives. However, heavy metals from various sources, including traffic, industrial activities, and agricultural activities, may still present contamination concerns (Gong et al., 2022). Some agronomic practices have been found effective in mitigating metal uptake by chives and related crops. For instance, intercropping with sunflower or garlic can reduce the bioavailability and root uptake of Cd and Pb by modifying rhizosphere pH and altering metal chelation and competition processes (Thang et al., 2019).

To better understand the interrelationships among elements and the differentiation of *A. schoenoprasum* cultivars based on their elemental composition, a principal component analysis (PCA) was performed using standardized values. The first two principal components (PC1 and PC2) together accounted for approximately 90–95% of the total variance, allowing a clear visualization of cultivar grouping and metal associations (Figure 1).

PC1, which explained around 70% of the total variance, was strongly and positively correlated with the essential micronutrients Fe, Mn, Zn, Cu, and Cd, representing a general nutrient accumulation axis. PC2 (explaining approximately 20–25% of the variance) was mainly associated with Pb, Cr, and Ni, reflecting the variability linked to potentially toxic elements and soil-derived inputs.

The PCA biplot revealed two distinct patterns. Cultivars Bohemia and Pobrežná were closely clustered in the positive region of PC1, characterized by relatively high levels of Fe, Mn, Zn, and Cu, indicating a balanced and nutritionally favorable elemental composition. In contrast, cv. Pražská was clearly separated along PC2 due to its higher Pb content and lower concentrations of essential micronutrients. This separation highlights cultivar-specific differences in metal uptake and translocation efficiency, which may be related to genetic variability and soil-root interactions.

Overall, the PCA results confirmed that the elemental composition of chives is cultivar-dependent, with the main variation driven by Fe, Zn, and Cd on one axis, and Pb and Cr on the other. These findings are consistent with previous studies reporting genotype-dependent metal accumulation patterns in *Allium* species (Soudek et al., 2009; Cavanagh et al., 2019; Lidiková et al., 2021; Čeryová et al., 2023; Czarnek et al., 2023). The combined interpretation of the univariate and multivariate analyses demonstrates that all examined chives cultivars accumulated essential elements within nutritionally relevant ranges, while maintaining low levels of toxic metals. The calculated bioaccumulation factors (BAFs) for chives cultivars revealed generally low metal transfer efficiency from soil to plant tissue, with values well below 1 for all elements except cadmium (Table 3). These results are consistent with previous findings for related taxa (Sipter et al., 2009; Gordanić et al., 2023; Vuković et al., 2023; Din et al., 2024).

The highest BAFs were observed for Cd (0.43–0.65) and Zn (0.15–0.25), indicating a moderate ability of chives to accumulate these elements. In contrast, Fe, Mn, Co, Ni, and Cr exhibited very low BAFs (<0.05), suggesting limited root uptake and translocation to aboveground tissues. Among cultivars, Bohemia and Pražská showed slightly higher Cd bioaccumulation (0.65 and 0.63, respectively) compared with Pobrežná (0.43), while Pb accumulation remained low in all cultivars (0.03–0.09). Zinc and copper, both essential micronutrients, also showed moderate accumulation efficiency, reflecting their physiological importance in enzymatic and redox processes. Overall, the results indicate that chives act as moderate accumulators of Cd and Zn, but exhibit strong exclusion capacity for Pb, Cr, and Fe. The low BAF values (<1) confirm that the studied cultivars were grown under safe soil conditions and do not pose a toxicological risk to consumers. However, cultivar-specific differences suggest potential genotypic variation in metal uptake and translocation efficiency that may influence the nutritional and safety profile of the final product.

The limited lead accumulation observed in the present study is consistent with previous findings on the restricted Pb uptake ability of *Allium schoenoprasum*. Alikasturi et al. (2020) reported that *A. schoenoprasum* failed to absorb Pb when grown

Table 3 Bioaccumulation factor of monitored cultivars

Cultivar	Fe	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd
Bohemia	0.005	0.04	0.25	0.21	0.03	0.04	0.01	0.07	0.65
Pobrežná	0.005	0.04	0.24	0.21	0.01	0.03	0.01	0.03	0.43
Pražská	0.002	0.04	0.15	0.14	0.02	0.04	0.00	0.09	0.63

in distilled water, mineral water, and surface water media, indicating a very low affinity for lead uptake from aqueous environments. In contrast, *Allium fistulosum* demonstrated a significant capacity to absorb Pb under similar conditions, suggesting species-specific physiological differences in Pb transport and accumulation. Sapčanin et al. (2019), reported low concentrations of lead and cadmium in chives, which they attributed to the generally good soil quality, minimal industrial impact, and effective agricultural practices in the region. Barazani et al. (2004) reported that chives cultivated in Hoagland medium with 50 and 250 µM Cd accumulated up to 0.2 and 0.5% Cd in dry weight after 28 days, respectively, without visible toxicity at moderate exposure levels. Moreover, repeated shoot harvesting for 96 days under 50 µM Cd conditions did not induce stress symptoms, indicating strong physiological tolerance. The authors suggested that sulfur-containing compounds, rather than glutathione, play a key role in Cd detoxification mechanisms. Eisazadeh et al. (2018) investigated the phytoextraction potential of chives grown in Cd-contaminated soils and found that cadmium accumulated predominantly in the roots, with limited translocation to aerial parts. The ratio of Cd concentration in shoots to that in roots remained below 1 at all tested contamination levels and decreased further with increasing soil Cd concentrations, confirming restricted Cd mobility and strong root retention capacity. The authors reported the maximum Cd absorption and uptake rate, as well as the shortest clean-up time, at a soil Cd concentration of 60 $mg \cdot kg^{-1}$, suggesting that *A. schoenoprasum* can tolerate moderate contamination while contributing to soil remediation through root accumulation.

Similarly, studies on other *Allium* species confirm that metal accumulation patterns and tolerance levels are metal- and species-dependent. Soudek et al. (2009) reported that plant species belonging to the genus *Allium* are capable of accumulating relatively high concentrations of heavy metals; however, they also noted that the translocation of metals from the root system to above-ground tissues (bulbs and leaves) was very limited. In contrast, our findings do not fully support this observation, as we recorded comparatively high concentrations of several metals in chive leaves. This discrepancy may be attributed to differences in cultivar characteristics, soil properties, and environmental conditions, which can substantially influence metal mobility and distribution within plant tissues. Gharehbaghli and Sepehri (2022) reported that garlic (*Allium sativum* L.) cultivated hydroponically with cadmium chloride and sodium hydrosulfide exhibited significant growth inhibition and reduced biomass, accompanied by high Cd accumulation in both roots and shoots. Liu et al. (2009) and Carabulea et al. (2022) demonstrated that Pb exposure negatively affected the growth and development of *A. sativum* plants, with the highest accumulation occurring in roots and substantially lower concentrations detected in bulbs and leaves. Aljuhaimi et al. (2025) reported that among various metals analyzed in different anatomical parts of the leek, heavy metals, such as Cd, Pb, Cr, Ni, and Cu, were found only in trace amounts across the roots, leaves, and bulbous layers.

Conclusions

The study revealed that the analyzed soil contained moderate levels of heavy metals, with slightly mobile forms of Cd and Pb exceeding critical values, suggesting potential plant uptake. Nevertheless, all examined *A. schoenoprasum* cultivars remained within EU safety limits, both on a dry and fresh weight basis. PCA differentiated the cultivars by their metal profiles, grouping Bohemia and Pobrežná together due to higher Fe, Zn, and Cu contents, while Pražská was separated by elevated Pb. Bioaccumulation factors (BAF <1) indicated limited metal transfer from soil to plants, except for moderate Cd and Zn accumulation. Overall, the cultivars showed good nutritional quality and low contamination risk, suggesting that chives can be safely grown in similar soils, provided that Cd and Pb mobility is regularly monitored.

Conflicts of Interest

The authors declare no conflict of interest.

Ethical Statement

This article doesn't contain any studies that would require an ethical statement.

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References

Alikasturi, A. S., Mokhtar, M. I., Zainuddin, M. A., Serit, M. E., & Rahim, N. S. A. (2020). Phytoremediation of lead in mineral, distilled and surface water using Pennisetum purpureum and *Allium fistulosum*. *Materials Today: Proceedings*, 31, A175-A179. https://doi.org/10.1016/j.matpr.2021.02.434

Barazani, O., Dudai, N., Khadka, U. R., & Golan-Goldhirsh, A. (2004). Cadmium accumulation in *Allium schoenoprasum* L. grown in an aqueous medium. *Chemosphere*, 57(9), 1213–1218. https://doi.org/10.1016/j.chemosphere.2004.08.037

Carotenuto, A., De Feo, V., Fattorusso, E., Lanzotti, V., Magno, S., & Cicala, C. (1996). The flavonoids of *Allium ursinum*. *Phytochemistry*, 41(2), 531–536. https://doi.org/10.1016/0031-9422(95)00574-9

Cavanagh, J. A. E., Yi, Z., Gray, C. W., Munir, K., Lehto, N., & Robinson, B. H. (2019). Cadmium uptake by onions, lettuce and spinach in New Zealand: Implications for management to meet regulatory limits. *Science of the total Environment*, 668, 780–789. https://doi.org/10.1016/j.scitotenv.2019.03.010

Čeryová, N., Lidikova, J., Šnirc, M., Harangozo, Ľ., Pinter, E., Bobko, M., & Vollmannová, A. (2024). Heavy metals in onion (*Allium cepa* L.) and environmental and health risks. *Food Additives & Contaminants: Part B*, 17(1), 66–76. https://doi.org/10.1080/19393210.2023.2291369

Charles, D. J. (2013). *Antioxidant properties of spices, herbs and other sources* (pp. 225–230). Springer. https://doi.org/10.1007/978-1-4614-4310-0_1

Czarnek, K., Tatarczak-Michalewska, M., Szopa, A., Klimek-Szczykutowicz, M., Jafernik, K., Majerek, D., & Blicharska, E. (2023). Bioaccumulation capacity of onion (*Allium cepa* L.) tested with heavy metals in biofortification. *Molecules*, 29(1), 101. https://doi.org/10.3390/molecules29010101

Din, I. U., Muhammad, S., Tokatli, C., ur Rehman, I., Ali, W., Shaik, M. R., & Hussain, S. A. (2024). Potentially harmful elements contamination, risk assessment, and their bioaccumulation in food crops. *Physics and Chemistry of the Earth, Parts A/B/C*, 136, 103747. https://doi.org/10.1016/j.pce.2024.103747

Eisazadeh, S., Asadi Kapourchal, S., Homaee, M., Noorhosseini, S. A., & Damalas, C. A. (2019). Chive (*Allium schoenoprasum* L.) response as a phytoextraction plant in cadmium-contaminated soils. *Environmental Science and Pollution Research*, 26(1), 152–160. https://doi.org/10.1007/s11356-018-3545-2

Fossen, T., Slimestad, R., Ovstedal, D. O., & Andersen, Ø. M. (2000). Covalent anthocyanin-flavonol complexes from flowers of chive, *Allium schoenoprasum*. *Phytochemistry*, 54(3), 317–323. https://doi.org/10.1016/S0031-9422(00)00102-3

Gao, L., Gao, B., Yin, S., Xu, D., & Gao, J. (2018). Predicting Ni dynamic mobilization in reservoir riparian soils prior to water submergence using DGT and DIFS. *Chemosphere*, 195, 390–397. https://doi.org/10.1016/j.chemosphere.2017.12.090

Gharehbaghli, N., & Sepehri, A. (2022). The ameliorative effect of hydrogen sulfide on cadmium toxicity and oxidative stress damage in garlic (*Allium sativum*) seedlings. *South African Journal of Botany*, 150, 161170. https://doi.org/10.1016/j.sajb.2022.07.014

Gong, C., Wang, S., Wang, D., Lu, H., Dong, H., Liu, J., & Wang, L. (2022). Ecological and human health risk assessment of heavy metal (loid) s in agricultural soil in hotbed chives hometown of Tangchang, Southwest China. *Scientific Reports*, 12(1), 8563. https://doi.org/10.1038/s41598-022-11397-0

Gordanić, S. V., Kostić, A. Ž., Krstić, Đ., Vuković, S., Kilibarda, S., Marković, T., & Moravčević, Đ. (2023). A detailed survey of agroecological status of *Allium ursinum* across the republic of Serbia: Mineral composition and bioaccumulation potential. *Heliyon*, 9(11). https://doi.org/10.1016/j.heliyon.2023.e22134

Kim, S., Kim, D. B., Lee, S., Park, J., Shin, D., & Yoo, M. (2016). Profiling of organosulphur compounds using HPLC–PDA and GC–MS system and antioxidant activities in hooker chive (*Allium* hookeri). *Natural Product Research*, 30(24), 2798–2804. https://doi.org/10.1080/14786419.2016.1164700

Krishnan, R. J., & Nair, S. R. (2016). Preliminary study on the antibacterial activity of six medicinal plants against two naso-pharyngeal pathogens – *Streptococcus pyogenes* and *Pseudomonas aeruginosa*. *American Journal of Plant Sciences*, 7(6), 907–915. https://doi.org/10.4236/ajps.2016.76086

Kucekova, Z., Mlcek, J., Humpolicek, P., Rop, O., Valasek, P., & Saha, P. (2011). Phenolic compounds from *Allium schoenoprasum*, *Tragopogon pratensis* and *Rumex acetosa* and their antiproliferative effects. *Molecules*, 16(11), 9207–9217. https://doi.org/10.3390/molecules16119207

Lachman, J., Pronek, D., Hejtmánková, A., Dudjak, J., Pivec, V., & Faitová, K. (2003). Total polyphenol and main flavonoid antioxidants in different onion (*Allium cepa* L.) varieties. *Horticultural Science*, 30(4), 142–147. https://doi.org/10.17221/3876-HORTSCI

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(11), 4360–4369. https://doi.org/10.1007/s12011-020-02536-7

Liu, D., Zou, J., Meng, Q., Zou, J., & Jiang, W. (2009). Uptake and accumulation and oxidative stress in garlic (*Allium sativum* L.) under lead phytotoxicity. *Ecotoxicology*, 18(1), 134–143. https://doi.org/10.1007/s10646-008-0266-1

Lumivero (2025). XLSTAT statistical and data analysis solution. https://www.xlstat.com/en

Mnayer, D., Fabiano-Tixier, A. S., Petitcolas, E., Hamieh, T., Nehme, N., Ferrant, C., Fernandez, X., & Chemat, F. (2014). Chemical composition, antibacterial and antioxidant activities of six essential oils from the Alliaceae family. *Molecules*, 19(12), 20034–20053. https://doi.org/10.3390/molecules191220034

Parvu, A. E., Parvu, M., Vlase, L., Miclea, P., Mot, A. C., & Silaghi-Dumitrescu, R. (2014). Anti-inflammatory effects of *Allium schoenoprasum* L. leaves. *Journal of Physiology and Pharmacology,* 65(2), 309–315.

Sapcanin, A., Hasanovic, A., Salihovic, M., Pehlic, E., & Špirtović-Halilović, S. (2019, May). Screening of heavy metal occurence in edible plants from bosnian market. In *International Conference on Medical and Biological Engineering* (pp. 635–639). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-17971-7_96

Sihlahla, M., Odiyo, J. O., & Edokpayi, J. N. (2019). Assessment of heavy metal bioavailability and accumulation in vegetables irrigated with wastewater. *Environmental Monitoring and Assessment*, 191(8), 510. https://doi.org/10.1007/s10661-019-7645-3

Singh, V., Chauhan, G., Krishan, P., & Shri, R. (2018). *Allium schoenoprasum* L.: A review of phytochemistry, pharmacology and future directions. *Natural Product Research*, 32(18), 2202–2216. https://doi.org/10.1080/14786419.2017.1367783

Sipter, E., Auerbach, R., Gruiz, K., & Mathe-Gaspar, G. (2009). Change of bioaccumulation of toxic metals in vegetables. *Communications in Soil Science and Plant Analysis*, 40(1–6), 285–293. https://doi.org/10.1080/00103620802647165

Soudek, P., Kotyza, J., Lenikusová, I., Petrová, Š., Benešová, D., & Vaněk, T. (2009). Accumulation of heavy metals in hydroponically cultivated garlic (*Allium sativum* L.), onion (*Allium cepa* L.), leek (*Allium porrum* L.) and chive (*Allium schoenoprasum* L.). *Journal of Food, Agriculture and Environment*, 7(3), 761–769.

Štajner, D., Popović, B. M., Ćalić-Dragosavac, D., Malenčić, D., & Zdravković-Korać, S. (2011). Comparative study on *Allium schoenoprasum* cultivated plant and *Allium schoenoprasum* tissue culture organs antioxidant status. *Phytotherapy Research*, 25(11), 1618–1622. https://doi.org/10.1002/ptr.3394

United States Department of Agriculture. (2025). *FoodData Central*. https://fdc.nal.usda.gov/

Vuković, S., Moravčević, D., Gvozdanović-Varga, J., Dojčinović, B., Vujošević, A., Pećinar, I., & Kostić, A. Ž. (2023). Elemental profile, general phytochemical composition and bioaccumulation abilities of selected *Allium* species biofortified with selenium under open field conditions. *Plants*, 12(2), 349. https://doi.org/10.3390/plants12020349

Yoldas, F., Ceylan, S., & Mordogan, N. (2019). Residual effect of organic manure and recommended NPK fertilizer on yield and bulb performance of onion (*Allium cepa* L.) as second crop under greenhouse conditions. *Applied Ecology and Environmental Research*, 18(1), 303–314. https://doi.org/10.15666/aeer/1801_303314

Zhang, Y., Hu, J., Bai, J., Qin, H., Wang, J., Wang, J., & Lin, X. (2019). Intercropping with sunflower and inoculation with arbuscular mycorrhizal fungi promotes growth of garlic chive in metal-contaminated soil at a WEEE-recycling site. *Ecotoxicology and Environmental Safety*, 167, 376–384. https://doi.org/10.1016/j.ecoenv.2018.10.046

Zheng, W., & Wang, S. Y. (2001). Antioxidant activity and phenolic compounds in selected herbs. *Journal of Agricultural and Food Chemistry*, 49(1), 5165–5170. https://doi.org/10.1021/jf010697n