Elemental composition of *Russula cyanoxantha* along an urbanization gradient in Cluj-Napoca (Romania)

Andreea R. Zsigmond, Izolda Kántor, Zoltán May, István Urák, Károly Héberger

PII: S0045-6535(19)31790-4

DOI: https://doi.org/10.1016/j.chemosphere.2019.124566

Reference: CHEM 124566

To appear in: *ECSN*

Received Date: 23 May 2019

Revised Date: 8 August 2019

Accepted Date: 9 August 2019

Please cite this article as: Zsigmond, A.R., Kántor, I., May, Zoltá., Urák, Istvá., Héberger, Ká., Elemental composition of *Russula cyanoxantha* along an urbanization gradient in Cluj-Napoca (Romania), *Chemosphere* (2019), doi: https://doi.org/10.1016/j.chemosphere.2019.124566.

Elemental composition of *Russula cyanoxantha* along an urbanization gradient in Cluj-Napoca (Romania)

Andreea R. Zsigmond[a], Izolda Kántor[a], Zoltán May[b], István Urák[a], Károly Héberger[b1]

[a] Department of Environmental Science, Sapientia Hungarian University of Transylvania, Calea Turzii 4, 400193 Cluj-Napoca, Romania, zsigmond.andrea@kv.sapientia.ro, kantorizolda@yahoo.com, urakistvan@gmail.com

[b] Plasma Chemistry Research Group, Institute of Materials and Environmental Sciences, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Magyar tudósok krt. 2, 1117 Budapest, Hungary, may.zoltan@ttk.mta.hu, heberger.karoly@ttk.mta.hu

[1]Corresponding author.
E-mail address: heberger.karoly@ttk.mta.hu (K. Héberger).

Elemental composition of *Russula cyanoxantha* along an urbanization gradient in Cluj-Napoca (Romania)

Andreea R. Zsigmond[a], Izolda Kántor[a], Zoltán May[b], István Urák[a], Károly Héberger[b1]

[a] Department of Environmental Science, Sapientia Hungarian University of Transylvania, Calea Turzii 4, 400193 Cluj-Napoca, Romania, zsigmond.andrea@kv.sapientia.ro, kantorizolda@yahoo.com, urakistvan@gmail.com

[b] Plasma Chemistry Research Group, Institute of Materials and Environmental Sciences, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Magyar tudósok krt. 2, 1117 Budapest, Hungary, may.zoltan@ttk.mta.hu, heberger.karoly@ttk.mta.hu

[1]Corresponding author.
E-mail address: heberger.karoly@ttk.mta.hu (K. Héberger).

Abstract

How far-reaching is the influence of the urban area over the mineral composition of the *Russula cyanoxantha* mushroom? We studied the metal uptake behavior of this fungus relying on the soil properties. We sampled mushroom and soil from six forests according to an urbanization gradient, and two city parks in Cluj-Napoca (Romania). The elements were quantified using inductively coupled plasma – optical emission spectroscopy (ICP-OES). The concentrations of some elements differed significantly ($p < 0.05$) in the samples from the city (0.39 ± 0.35 mg kg^{-1} for cadmium (Cd), 0.40 ± 0.19 mg kg^{-1} for chromium (Cr), 69.1 ± 29.9 mg kg^{-1} for iron (Fe), 10.9 ± 1.3 mg kg^{-1} for manganese (Mn), 0.76 ± 0.45 mg kg^{-1} for titanium (Ti) compared with the samples from the forests (3.15-14.1 mg kg^{-1} Cd, < 0.18 mg kg^{-1} for Cr, 22.6-34.5 mg kg^{-1} for Fe, 15.9-19.1 mg kg^{-1} for Mn, 0.19-0.36 mg kg^{-1} for Ti. We observed a definite negative trend in the mineral accumulation potential of this fungus along the urbanization gradient. The fungus turned from a cadmium-accumulator to a cadmium-excluder. This highlights a positive environmental influence of the urbanization over the toxic metal uptake of *R. cyanoxantha*. The hypothesis, that the urban soil pollution would increase the metal content of the mushroom was disproved. The possible explanation might be the elevated carbonate content of the urban soil, which is known to immobilize the metals in the soil.

Keywords: *Russula cyanoxantha*, elemental composition, urbanization gradient, urban areas, bioaccumulation factor

1. Introduction

The influence of the urban environment on the metal accumulation of macrofungi is mostly unknown. There is a scarcity of papers published on this subject. Schlecht and Säumel (2015), for example, quantified the concentration of Cd and lead (Pb) in several saprotrophic and mycorrhizal mushroom species found in Berlin. Mędyk *et al*. (2017) published the concentrations of some bio- and toxic elements in 10 edible mushrooms from unpolluted areas of a Swedish city. In a recent paper, we highlighted the differences in the elemental composition of the saprotrophic *Agaricus campestris* grown in urban and peri-urban regions. When compared with the peri-urban meadows, the urban environment had a univocal influence on this fungus (Zsigmond *et al*., 2018). In this paper, we focused on the influence of the urban environment and of the habitat proximity to a major city on the elemental composition of the edible mushroom *Russula cyanoxantha*. We also aimed to contribute to a substantial knowledge about the metal accumulation habit of this species in relation to the soil composition, pH, carbonate and organic matter content. We chose the *R. cyanoxantha* for many reasons: (i) this macrofungus is one of the most commonly spread edible mushroom in the European deciduous forests, (ii) we found it well represented in urban parks, (iii) it is known as sensitive taxa to anthropogenic factors like nitrogen input (Brandrud and Timmermann, 1998; Tarvainen *et al*., 2003), but less affected by the concentration changes of the heavy metals, base saturation, acidity and organic matter content in the soil (Hansen, 1988), and (iv) according to our knowledge, it is a fungus, which was less studied systematically.

The *R. cyanoxantha* is an ectomycorrhizal fungus dependent on the host plant, which in general is a deciduous tree (beech, birch, oak). It is a very tasty and delicious edible fungus, but it is not widely commercialized because of cultivating problems. This fungus is very similar in

appearance with other species from the *Russula* genus, like the *R. heterophylla*, *R. alutacea* or *R. virescens*, which grow in the same habitat. Nevertheless, the *R. cyanoxantha* has some specific characteristics, like flexible and soft gills, pure white stipes, without brownish or yellow spots and white spore prints (Kuo, 2009).

Due to the mycelium, mushrooms have peculiar capabilities of absorbing mineral components from the soil by the process of biomineralization (Gadd, 2013). It is well documented that in contrast with plant rhizomes, fungal hyphae are able to excrete numerous substances as leaching agents for metals and phosphorus from minerals (Rosling, 2009; McMaster, 2012; Smits and Wallander, 2017). That is why wild grown mushrooms contain mineral components in much higher concentrations, than plants. Generally, the mycelium of the *Russula* spp. is small-sized possessing few and short hyphae in contrast with *Suillus* spp. or *Cortinarius* spp. characterized by extensive mycelial systems (Taylor and Alexander, 2005). Probably this is the reason, why these species generally contain mineral components in lower concentrations, than other fungi (Kalač, 2016), and may persist in contaminated soils (Newbound *et al*., 2010). Since the 1980s, it was demonstrated that the occurrence of the *R. cyanoxantha* seemed not to be greatly affected by the soil and litter characteristics (Hansen 1988). Kutszegi *et al*. (2015) mentioned this fungus as one of the most frequent taxa in the deciduous forests. They also showed that the ectomycorrhizal fungi are the least influenced by the environmental factors, like substratum properties, tree species composition and microclimate. Nevertheless, the *R. cyanoxantha* was the most frequently distributed mushroom in Cluj-Napoca and the surrounding deciduous forest.

With respect to the elemental composition of macrofungi, the soil is the most influential driver. Although these organisms occasionally develop macroscopic fruiting bodies, they spend most of their lifetime in the soil in the form of the mycelium. The uptake of metals depends on several

factors related to the soil (bedrock geochemistry, organic matter content, pH, moisture availability, and porosity of the soil), as well as the species and lifestyle (saprotrophic or mycorrhizal) of the mushroom (Chatterjee *et al*., 2017).

The forest and urban soils present contrasting properties with regard to the acidity, carbonate and metal content. The particular characteristics of urban soils are the elevated pH, alkaline topsoil, less porosity, relatively high concentration of some toxic metals (Lal and Stewart, 2018). The wearing of the buildings and of the street pavements, the emissions from the industrial and construction activities contribute to an alkaline pollutant burden of the local atmosphere in the form of ash and dust (Newbound *et al*., 2010). Lovett *et al*. (2000) evidenced the deposition of the alkaline ions Ca and Mg to the urban soil surface, which gradually decreased with distance from the city.

In the light of these findings, we hypothesized a strong relationship between the pollution level and specific characteristics of the urban soil, and the elemental content of the fruiting body of the *R. cyanoxantha*, when compared with its natural habitat.

2. Materials and methods

2.1. Description of the sampling sites

We carried out our research in Cluj-Napoca (the second largest city in Romania) and its surroundings. It is a dynamically developing city with about 325 000 inhabitants. In order to exclude the varying influence of the air pollution, we chose forests, which lie to the north and to the south from the city center on a trajectory, which is perpendicular to the prevailing wind direction. The seven sampling sites (Fig. 1) were as follows: S1 (a forest near Feleacu, at 7.5 km to south from the city center), S2 (Făget, a forest close to the southern city border, at 5 km from

106 the city center), S3 (a forest near the Mănăștur district, which lies in the southern part of the city,
107 at 2.5 km from the city center), S4 (Iuliu Hațieganu Park and Botanical Garden in the center of
108 the city), S5 (Hoia, a forest in the north part of the city, at 2 km from the city center), S6 (a forest
109 near Popești, close to the northern border of the city, at 6 km from the city center) and S7 (a
110 forest near Deușu at 18 km to north from the city center).

111 Fig. 1

112

113 *2.2. Sampling and sample preparation*

114 We sampled a total number of 95 mushrooms and 95 soil samples in June-August, 2017. All the
115 samples were kept in plastic bags. Each mushroom sample consisted of 7-10 individuals, both
116 small-sized and well developed. The soil samples were taken from the topsoil (0-10 cm) exactly
117 where the mushrooms grew. Before washing the mushrooms, we separated the caps from the
118 stipes using a ceramic knife, and we removed the debris, so that the mass of the anatomic parts
119 could be determined separately. We used these results to determine the mean mass ratio between
120 the cap and the stipe. Next, the mushrooms were washed with tap water, and rinsed with distilled
121 water; they were cut into thin slices and dried at 60 °C, then at 105 °C until constant weight. The
122 samples were grinded and sieved through a stainless steel sieve with pore-size of 315 µm. A
123 mass of about 0.4 g was digested in glass beakers with 5 mL 65% HNO_3 (Merck, Suprapure) and
124 2 mL 30% H_2O_2 (Chempur, pure *p.a.*) at atmospheric pressure. The leaves, stones and living
125 organisms were removed from the soil samples, which were then dried at 20 °C, then at 105 °C
126 until constant weight (Malinowska *et al.*, 2004). About 0.2 g of grinded and sieved (1 mm pore-
127 size) soil samples were digested with 3 mL 65% HNO_3 (Merck, Suprapure) and 9 mL 30% HCl
128 (Merck, Suprapure) in glass beakers. All solutes were diluted to 50 mL with deionized water

(Merck, Millipore). The digests were stored in sealed plastic containers. All the glassware was washed after use with tap water, rinsed with distilled water and soaked in 0.1 M HNO_3 for 24 hours, then in deionized water for another 24 hours.

2.3. Instrumental analysis

We carried out the elemental composition of the mushroom and soil samples with an ICP-OES (Spectro Genesis, SPECTRO Analytical Instruments GmbH, Germany). The instrument conditions and measurement parameters used throughout this work was described recently (Zsigmond *et al*., 2018). The method detection limits (MDLs) for each element were calculated using the formula: (blank + 3×*sd*)×dilution factor, where the *blank* is the mean concentration of a certain element quantified in seven blank samples, and the *sd* is the standard deviation of this mean. We used two certified reference materials (CRM): NCS DC 73026 for soil (NACIS, China), SRM 1515 for apple leaves (NIST, USA) for the quality assurance of the instrumental method. For these materials, we followed the same sample pretreatment methods as described earlier. We prepared three samples of each CRM. The MDLs and the recoveries for the studied elements are reported in Table 1. All results were given for the dry weights of the samples.

Table 1.

2.4. The determination of soil properties

The pH of the soil samples was determined in two ways: using (1) deionized water and (2) 0.01 M $CaCl_2$ solution as extracting liquids, according to Carter and Gregorich (2008). We added 20 mL liquid to a mass of 10 g air-dried soil. We stirred the solution intermittently for 30 minutes,

151 and then we let it stay for one hour. We measured the pH in the supernatant with a combined
152 glass electrode (WTW, Weilheim, Germany).
153 In order to determine the organic matter and the carbonate content of the soil samples, we
154 performed the loss-on-ignition method, according to Heiri *et al*. (2001). Quantities of about 2 g
155 soil samples were placed in ceramic crucibles and dried at 105 °C to a constant weight. We
156 placed the crucibles in an oven and incinerated the samples for 4 hours, followed by a second
157 step at 950 °C for 2 hours. The differences in the weight gave the organic matter content (related
158 to the lost CO_2 and water vapor at 550 °C) and the carbonate content (calculated from the lost
159 CO_2 content at 950 °C).
160
161 *2.5. The bioaccumulation factor*
162 The bioaccumulation factor (BAF) is a dimensionless indicator of the accumulation rate of an
163 element in a living organism (plant, fungus), related to the soil. The BAF for a certain element
164 was calculated by dividing the concentration of the element in the mushroom with the
165 concentration of this element in the soil.
166
167 *2.6. Statistical analyses*
168 The statistical analyses were carried out on a data table of 95 rows and 52 columns (containing
169 all the data about the mushroom and soil). We tested the normality of the distributions with
170 Shapiro-Wilk-test. For the homogeneity of the variances, we used the *F*-test for two groups, and
171 the Levene-test for multiple groups. We used the two-sample *t*-test for independent groups
172 (sometimes the Welch-test or the nonparametric Mann-Whitney-Wilcoxon-test) in order to
173 compare the elemental composition of the caps and the stipes. We used the one-way ANOVA

(sometimes the Welch-ANOVA or the nonparametric Kruskal-Wallis-test) to compare the mean concentrations of the elements in the seven sampling sites. When the test showed significant differences in the means, we used the proper *post-hoc* test (Tukey-HSD or Games-Howell-test or Dunn's test) to identify the actual differences between pairs. The correlation between the variables was tested with calculation of the Spearman rank-correlation coefficients. These statistical tools are regularly used in the chemometric evaluation of the mineral composition of mushrooms (Malinowska *et al*., 2004; Brzezicha-Cirocka *et al*., 2019).

In order to test the existence of an urbanization gradient with regard to the elemental composition of the *R. cyanoxantha*, we used simple linear regression and factorial ANOVA. The bioaccumulation factor was taken as response variable, and the habitat distance from the city center, was used as explanatory variable. The normal distribution of the residuals was tested with Shapiro-Wilk test. All the statistics were carried out by R software, version 3.4.4.

3. Results and discussion

The mean mass ratio of the fresh anatomic parts (the caps and the stipes) of 228 individuals was of 3.0 g, with a standard deviation of 1.3 g. From about 850 specimen only 228 were measured because we counted for only the healthy, impeccable specimen. The minimum value was of 0.9 g, and the maximum value was of 7.2 g. The heaviest cap and stipe weighted 64.2 g and 31.3 g, the lightest ones 2.2 g and 0.6 g, respectively. The average water content of the mushrooms was of 88.5% (sd = 4.5%, n = 158). The data table, which contains all results, is provided in the supplementary material as AllData.xlsx (the *m* signifies the mushroom, the *s* signifies the soil).

3.1. The elemental composition of soils

According to the decree for soil contaminants released by the Ministry of Environment of Romania (Government Decree No 756/1997), the forest soils presented concentrations lower than the background levels for Cr, Cu and nickel (Ni). In many forest soils the concentrations of silver (Ag), barium (Ba) and Zn were much lower, than the given limits; on the other hand, Cd, Mn, and Pb had concentrations higher than the normal levels (Table 2). The soils from the city park contrasted the forest soils in much higher concentrations of Ag, and considerably lower concentrations of Cd, Mn, and Pb. The Ag exceeded the background level. The Na was detected only in Cluj-Napoca (S4) and in the forest to the north from the city (S5-S7).

Table 2.

Among the studied sites, the concentration of Cd in the soils exhibited the most heterogeneous distribution. The one-way ANOVA test revealed significantly different concentrations of aluminium (Al), Ba, calcium (Ca), Cu, Cr, Fe, K, magnesium (Mg), Ni, strontium (Sr), Zn in the samples from the sites S1-S4, and the concentrations increased from the southern periphery to the city center (Table S1, Fig. 5-8. in the supplementary material). Meanwhile, to the north from the city, the soils proved to be roughly homogenous in the mineral composition; for example, the S5 and S6 sites resembled the most. In addition, the soils from the city parks were not significantly different in the content of Al, Ca, Cu, Fe, K, Mg, Ni, Sr and Zn from the soils of sites S5 and S6, but significantly richer in these metals, than the soils from site S7. Among the studied sites, the soils of the city parks had significantly the highest concentration of Ag, P and Ti, and the lowest concentration of Mn and Pb.

3.2. The elemental composition of mushrooms

We compared the elemental composition of the *R. cyanoxantha* with the literature data for mushrooms (Kalač, 2016). Many of the elements (Ag, Al, Cu, Mn, Na, Ni, S, Ti, Zn) showed concentrations mainly in the lower part of the usual range (Table 2). All the samples had concentrations of Ca, Cr, K, and Mg below the usual range. Furthermore, some studies on the heavy metal content of the *R. cyanoxantha* from the forests of the southern part of Romania showed considerably higher concentrations of Cr, Mn, Fe and Pb; lower concentrations of Cu, Ni, and similar concentrations of Zn (Busuioc *et al*., 2011; Elekes and Busuioc, 2013). When we compared the results with the data published for *Agaricus campestris* growing in the same urban area, we found lower concentrations in the *R. cyanoxantha*, excepting for Ni and Zn (Zsigmond *et al*., 2018). It was recently demonstrated, that among the *Russula* spp., the *R. cyanoxantha* could be classified as an average Zn accumulator with concentrations between 50-150 mg kg^{-1} for dry matter, when coming from pristine areas (Leonhardt *et al*., 2019). We found that this species was less affected by the Zn contamination level of its habitat, since it exhibited very low variations in the Zn content (74.5-108 mg kg^{-1} average concentrations for dry matter) along the urbanization gradient.

A comparison between the samples from the forests with the samples from the city highlighted the ability of the *R. cyanoxantha* to accumulate more Fe and P but less Cd when grown in the city. These low levels of Cd coupled with the undetected Pb levels were somehow unexpected. However, two *Russula* spp. had median concentrations of 2.3-2.5 mg kg^{-1} for Cd and of 4.8 mg kg^{-1} for Pb in a recent study from Berlin (Schlecht and Säumel, 2015). Nevertheless, with the exception of S1 and S4, the average Cd concentration of the mushrooms exceeded the usual concentration range.

We compared the seven sites using one-way ANOVA test (Fig. 9-11. in the supplementary material). Along the urbanization gradient the alkaline-earth elements (Ba, Ca and Sr) as well as Cu, Na and Zn were evenly distributed in the samples. When compared with the samples from the forests, the influence of the urban environment manifested in significantly higher concentrations of Cr, Fe and Ti, and significantly lower concentrations of Cd and Mn in the samples from the urban parks. Although the highest Ag concentrations were measured in the samples from the city parks, the mean value did not differ significantly from the neighboring forests (S3 and S5). In general, the mushrooms from the S1 site exhibited the lowest mineral concentrations, with the exception of Al, Ba and Ca.

The elemental composition for the caps and the stipes are also given in the supplementary material (Table S1 in the supplementary material). Regardless the habitat, several elements (Cd, Cu, Mg, P, S, Zn) had significantly higher concentrations in the caps, than in the stipes, other elements (Al, Ba, Fe, K, Ni, Sr, Ti) were evenly distributed in the fungi (Tables S2 and S3 in the supplementary material). The Na was the only element, which was present in smaller concentrations in the caps, than in the stipes. This distribution pattern was in accordance with that of the *A. campestris* coming from the same urban and peri-urban area (Zsigmond *et al.*, 2018). We identified a habitat-dependent behavior of the *R. cyanoxantha* related to the accumulation of two metals (Ag and Ca). While in the forests the mushroom had significantly higher concentrations of these elements in the caps than in the stipes, there was a considerable shift in the quantity of these elements in the stipes in the urban area (the *t*-statistics have not revealed significant differences of these metals in the caps and the stipes of the mushrooms growing in the city).

3.3. Soil factors influencing the mineral uptake of the mushroom

The *R. cyanoxantha* has manifested a weak accumulating potential for minerals. We found BAF values greater than unity only in the case of the major elements K, P, S and a few minor elements like Cd, Cu and Zn (Table S4 in the supplementary material). The BAF values indicated a strong K, P and S uptake capability of the *R. cyanoxantha* with the highest median BAF values found in the samples from S1 (BAF_K = 33, BAF_P = 21, BAF_S = 12). The BAF values were considerably lower for Cd, Cu and Zn. The highest median values for Cu and Zn (BAF_{Cu} = 8.7, BAF_{Zn} = 3.2) were also found in the samples from S1; and for Cd (BAF_{Cd} = 6.2) in the samples from S7. These results are in agreement with literature data, which revealed that the *Russula* spp. could accumulate cadmium more efficiently than other ectomycorrhizal species (Demirbaş, 2001b; Cejpková *et al*., 2016; Melgar *et al*., 2016). For example, both *R. cyanoxantha* and *R. ochroleuca* grown in unpolluted and polluted forests were characterized with bioaccumulation factors of about 10 for Cd. Many studies also revealed the Zn and Cu accumulation property of the *Russula* spp., reporting BAF values of 5.9-7.9 for Cu and 3.4-5.2 for Zn (Demirbaş, 2001a; Alonso *et al*., 2003; Podlasińska *et al*., 2015; Cejpková *et al*., 2016).

On the other hand, this fungus species proved to be excluder of Pb. Although in some soils the Pb contents were higher than the normal background levels, we couldn't detect this metal in the mushroom. Proskura *et al*. (2017) found similar behavior of the ectomycorrhizal fungus *Boletus badius* against Pb. The essential elements like Ca and Mg had maximum median BAF values of 0.6 and 0.8 in the samples from site S1, and minimum median values of 0.04 and 0.2 for the samples from both S4 and S5 sites. The other elements had BAF values lower than 0.1; whereas the Fe had the lowest values (< 0.01).

The accumulation rates disagreed between the sampling sites suggesting a definite influence of the soil characteristics over the mineral uptake of this fungus (Fig. 2). The city parks proved to be a distinct habitat for this mushroom. Almost in all the cases, we found the weakest accumulation power of the *R. cyanoxantha* coming from the parks. The median BAF values were much lower than in the forests: 0.2 (Cd), 2.1 (Cu), 5.4 (K), 7.8 (P), 10 (S) and 1.3 (Zn). Site S1 was also unique from many points of view: it had the lowest concentration of the studied elements in the soil, it had low or average mineral content in the mushrooms with the exception of Al, Ba and Ca, and it exhibited unexpectedly high BAF values for Ca, K, Mg, P and Zn.

Fig. 2

The one-way ANOVA test revealed a clear trend in the elemental uptake potential of the *R. cyanoxantha*. The BAF values significantly decreased toward the city from the southern part in the case of Cu, Mg, P and Zn. On the northern part of the city, the furthermost forest (S7) exhibited significantly higher BAF values than the S3-S5 sites for Ca, Cu, Mg, K, Zn. It resembled the most with S1 site. We tested the existence of a BAF gradient statistically along the natural-outskirts-city trajectory using two-way factorial ANOVA. The first factor was the habitat and had three levels: the natural habitat (S1 and S7 sites), the outskirts (S2, S3, S5, S6 sites), and the city (S4 site). The second factor was the element, having five levels (Cu, K, Mg, P, Zn). The Fig. 3a. shows the means of the BAFs of each element according to the sampling sites. For each element, the mean concentration decreased from the natural habitat toward the urban area. The Fig. 3b. represents the weighted means of the BAFs of all the tested elements according to the habitat. The differences between the means were significant by ANOVA. This result proves the presence of a negative cumulated BAF gradient from the natural habitat of the mushroom to the

city. The urban environment seems to have an inhibitory effect over the mineral accumulation potential of the *R. cyanoxantha*.

Fig. 3

These results suggested the existence of a tight relationship between the soil properties and the elemental uptake capability of the mushroom. In order to elucidate this, we tested the correlation between the elemental composition of the mushroom and its bioaccumulation properties with the soil properties (Fig. 4). We found few significant correlations between the mineral content of the mushroom and the soil properties. The Spearman rank correlation coefficient values were low (< 0.45). Other studies also suggested the independence of metal accumulation from the soil properties (Brzostowski *et al*., 2011; Kojta and Falandysz, 2016; Ivanić *et al*. 2019). However, we found strong correlations between the bioaccumulation factors and the carbonate content of the soil ($r < -0.60$), for almost all the elements with high BAF values, and generally weaker correlation with the organic matter content and the pH of the soil. This pattern shows that the uptake of the elements by the mushrooms from the soil is a complex process. Some factors, as the organic matter (like chelating agents and siderophores) and the acids (like organic acids), originate from at least two sources: both from the mushrooms and the soil. Thus, the mobilization of metals from the soil might be controlled mainly by the fungi and not by the soil properties. However, it seems, that the carbonate content of the soil could hinder the chemical processes initiated by the mushroom in order to solubilize the metals. In the light of these findings, the several extreme BAF values for S1 and S7 in contrast with S4 could be explained by the contrast in the carbonate content and the pH values of the soils (Fig. 5). The rise of the soil pH coupled with higher carbonate content was expected, as the calcium-carbonate (the major carbonate type in the soil) raises the pH of the soil (Essington, 2016). We found Spearman rank

331 correlation coefficients of 0.38 and 0.51 for the carbonate content and the pH of the soil samples
332 (the former value refers to the pH measured when distilled water was added to the soil samples,
333 the last value when $CaCl_2$ solution was added to the soil samples). In a neutral or slightly
334 alkaline soil, most of the metals are insoluble (Meuser, 2010).

335 Fig. 4., Fig 5.

336

337

4. Conclusions

This research supported the previous findings related to the *Russula* spp. about the weak mineral accumulation potential of the genus, characterized with lower than the usual levels of all the elements, except for the Zn (generally), and the Cd (sporadically). We did not identify any trend in the mineral content of the *R. cyanoxantha* along the chosen urbanization gradient, but we disclosed a definite fingerprint of the urban environment on the elemental composition of this mushroom. We have also revealed a negative trend in the bioaccumulation potential of the mushroom along the urbanization gradient: the most notable behavior of the fungus was its turn from a cadmium-accumulator to a cadmium-excluder. This is an important finding, which highlights a positive environmental influence of the urbanization over the toxic metal uptake of edible mushrooms growing in Cluj-Napoca. The strongest inhibitory influence over the mineral uptake of the *R. cyanoxantha* turned to be the carbonate content of the soil. We found positive correlations between the carbonate content and the pH of the soil. The weaker correlation between the bioaccumulation potential of the mushroom with the organic matter content and the pH of the soil could show the importance of the peculiar mechanisms exerted by the mycelium for the solubilization of these elements resulting in considerably better uptakes. The hypothesis that the urban soil polluted with heavy metals would increase the content of these elements in the mushroom was thus disproved. The possible explanation might be the elevated carbonate content of the urban soil, which immobilized these metals in the soil.

Acknowledgements

The authors thank the financial support given by the Domus Hungarica Scientiarum et Artium research programme (5242/29/2017/HTMT, 5634/40/2016/HTMT) of the Hungarian Academy

of Sciences. KH thanks the financial support of the National Research, Development and Innovation Office of Hungary, under grant numbers OTKA K 119269.

References

Alonso, J., García, M.A., Pérez-López, M., Melgar, M.J., 2003. The concentrations and bioconcentration factors of copper and zinc in edible mushrooms. Arch. Environ. Con. Tox. 44, 180–188. https://doi.org/10.1007/s00244-002-2051-0

Brandrud, T.E., Timmermann, V., 1998. Ectomycorrhizal fungi in the NITREX site at Gårdsjön, Sweden; below and above-ground responses to experimentally-changed nitrogen inputs 1990–1995. Forest Ecol. Manag. 101, 207–214. https://doi.org/10.1016/S0378-1127(97)00138-2

Brzezicha-Cirocka, J. Grembecka, M., Grochowska, I., Falandysz, J., Szefer, P., 2019. Elemental composition of selected species of mushrooms based on a chemometric evaluation. Ecotox. Environ. Safe 173, 353–365. https:// doi.org/10.1016/j.ecoenv.2019.02.036

Brzostowski, A., Falandysz, J., Jarzyńska, G., Zhang, D., 2011. Bioconcentration potential of metallic elements by poison pax (*Paxillus involutus*) mushroom. J. Environ. Sci. Heal. A 46, 378–393. https://doi.org/10.1080/10934529.2011.542387

Busuioc, G., Elekes, C.C., Stihi, C., Iordache, S., Ciulei, S.C., 2011. The bioaccumulation and translocation of Fe, Zn, and Cu in species of mushrooms from *Russula* genus. Environ. Sci. Pollut. R. 18, 890–896. https://doi.org/10.1007/s11356-011-0446-z

Carter, M.R., Gregorich, E.G. (Eds.). 2008. Soil Sampling and Methods of Analysis, 2nd edition. CRC Press, Boca Raton, Florida.

Cejpková, J., Gryndler, M., Hršelová, H., Kotrba, P., Řanda, Z., Synková, I., Borovička, J., 2016. Bioaccumulation of heavy metals, metalloids, and chlorine in ectomycorrhizae from smelter-

polluted area. Environ. Pollut. 218, 176–185. https://doi.org/10.1016/j.envpol.2016.08.009

Chatterjee, S., Sarma, M.K., Deb, U., Steinhauser, G., Walther, C., Gupta, D.K., 2017. Mushrooms: from nutrition to mycoremediation. Environ. Sci. Pollut. R. 24, 19480–19493. https://doi.org/10.1007/s11356-017-9826-3

Demirbaş, A., 2001a. Heavy metal bioaccumulation by mushrooms from artificially fortified soils. Food Chem. 74, 293–301. https://doi.org/10.1016/S0308-8146(01)00155-8

Demirbaş, A., 2001b. Concentrations of 21 metals in 18 species of mushrooms growing in the East Black Sea region. Food Chem. 75, 453–457. https://doi.org/10.1016/S0308-8146(01)00236-9

Elekes, C.C., Busuioc, G., 2013. Influence of chemical composition of soil on metal accumulation in edible mushroom species of *Russula* genus. Rev. Roum. Chim. 58, 629–637.

Essington, M.E. 2016. Soil and Water Chemistry: An Integrative Approach. CRC Press, Boca Raton, Florida.

Gadd, G.M., 2013. Geomycology: fungi as agents of biogeochemical change. Biol. Environ. 113, 1–15. https://doi.org/10.3318/BIOE.2013.16

Government Decree No 756/1997. Ordinul Guvernamental Nr. 756/1997 pentru aprobarea Reglementării privind evaluarea poluării mediului [In Romanian].

Hansen, P.A., 1988. Prediction of macrofungal occurrence in Swedish beech forests from soil and litter variable models. Vegetatio 78, 31–44. https://doi.org/10.1007/BF00045637

Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. J. Paleolimnol. 25, 101–110. https://doi.org/10.1023/A:1008119611481

Ivanić, M., Fiket, Ž., Medunić, G., Furdek Turk, M., Marović, G., Senčar, J., Kniewald, G.,

2019. Multi-element composition of soil, mosses and mushrooms and assessment of natural and artificial radioactivity of a pristine temperate rainforest system (Slavonia, Croatia). Chemosphere 215, 668–677. https://doi.org/10.1016/j.chemosphere.2018.10.108

Kalač, P., 2016. Edible Mushrooms: Chemical Composition and Nutritional Value. Amsterdam; Boston: Elsevier/AP, Academic Press is an imprint of Elsevier.

Kojta, A.K., Falandysz, J., 2016. Metallic elements (Ca, Hg, Fe, K, Mg, Mn, Na, Zn) in the fruiting bodies of *Boletus badius*. Food Chem. 200, 206–214. https://doi.org/10.1016/j.foodchem.2016.01.006

Kuo, M., 2009. *Russula cyanoxantha*. Retrieved from the MushroomExpert.Com Web site: http://www.mushroomexpert.com/russula_cyanoxantha.html

Kutszegi, G., Siller, I., Dima, B., Takács, K., Merényi, Z., Varga, T., Ódor, P., 2015. Drivers of macrofungal species composition in temperate forests, West Hungary: functional groups compared. Fungal Ecol. 17, 69–83. https://doi.org/10.1016/j.funeco.2015.05.009

Lal, R., Stewart, B. A., 2018. Urban Soils. Taylor & Frances, Boca Raton, U.S.

Leonhardt, T., Borovička, J., Sácký, J., Šantruček, J., Kameník, J., Kotrba, P., 2019. Zn overaccumulating *Russula* species clade together and use the same mechanism for the detoxification of excess Zn. Chemosphere 225, 618–626. https://doi.org/10.1016/j.chemosphere.2019.03.062

Lovett, G.M., Traynor, M.M., Pouyat, R.V., Carreiro, M.M., Zhu, W.-X., Baxter, J.W., 2000. Atmospheric deposition to oak forests along an urban-rural gradient. Envir. Sci. Tech. 34, 4294–4300. https://doi.org/10.1021/es001077q

Malinowska, E, Szefer, P., Falandysz, J., 2004. Metals bioaccumulation by bay bolete, *Xerocomus badius*, from selected sites in Poland. Food Chem. 84, 405–416.

https:// doi.org/10.1016/S0308-8146(03)00250-4

McMaster, T.J., 2012. Atomic Force Microscopy of the fungi–mineral interface: applications in mineral dissolution, weathering and biogeochemistry. Curr. Opin. Biotech. 23, 562–569. https://doi.org/10.1016/j.copbio.2012.05.006

Mędyk, M., Grembecka, M., Brzezicha-Cirocka, J., Falandysz, J., 2017. Bio- and toxic elements in mushrooms from the city of Umeå and outskirts, Sweden. J. Environ. Sci. Heal. B 52, 577–583. https://doi.org/10.1080/03601234.2017.1318638

Melgar, M.J., Alonso, J., García, M.A., 2016. Cadmium in edible mushrooms from NW Spain: Bioconcentration factors and consumer health implications. Food Chem. Toxicol. 88, 13–20. https://doi.org/10.1016/j.fct.2015.12.002

Meuser, H., 2010. Contaminated Urban Soils. Springer, Dordrecht, New York.

Newbound, M., Mccarthy, M.A., Lebel, T., 2010. Fungi and the urban environment: A review. Landscape Urban Plan. 96, 138–145. https://doi.org/10.1016/j.landurbplan.2010.04.005

Podlasińska, J., Mazurkiewicz, N., Szymańska, A., 2015. Content of Pb, Hg, Zn, Mn, Cu, and Fe in macrofungi collected from Wkrzanska forest in Northwestern Poland. Pol. J. Environ. Stud. 24. https://doi.org/10.15244/pjoes/26959

Proskura, N., Podlasińska, J., Skopicz-Radkiewicz, L., 2017. Chemical composition and bioaccumulation ability of *Boletus badius* (Fr.) collected in western Poland. Chemosphere 168, 106–111. https://doi.org/10.1016/j.chemosphere.2016.10.003

Rosling, A., 2009. Trees, mycorrhiza and minerals – Field relevance of *in vitro* experiments. Geomicrobiol. J. 26, 389–401. https://doi.org/10.1080/01490450902929324

Schlecht, M.T., Säumel, I., 2015. Wild growing mushrooms for the Edible City? Cadmium and lead content in edible mushrooms harvested within the urban agglomeration of Berlin,

453 Germany. Environ. Pol. 204, 298–305. https://doi.org/10.1016/j.envpol.2015.05.018
454 Smits, M.M., Wallander, H., 2017. Role of Mycorrhizal Symbiosis in Mineral Weathering and
455 Nutrient Mining from Soil Parent Material. In *Mycorrhizal Mediation of Soil* (pp. 35–46).
456 Elsevier. https://doi.org/10.1016/B978-0-12-804312-7.00003-6
457 Tarvainen, O., Markkola, A.M., Strömmer, R., 2003. Diversity of macrofungi and plants in Scots
458 pine forests along an urban pollution gradient. Basic Appl. Ecol. 4, 547–556.
459 https://doi.org/10.1078/1439-1791-00156
460 Taylor, A.F.S., Alexander, I., 2005. The ectomycorrhizal symbiosis: life in the real world.
461 Mycologist 19, 102–112. https://doi.org/10.1017/S0269-915X(05)00303-4
462 Zsigmond, A.R., Varga, K., Kántor, I., Urák, I., May, Z., Héberger, K., 2018. Elemental
463 composition of wild growing *Agaricus campestris* mushroom in urban and peri-urban regions
464 of Transylvania (Romania). J. Food Compos. Anal. 72, 15–21.
465 https://doi.org/10.1016/j.jfca.2018.05.006
466

467 **Captions to Figures**

468

469 **Fig. 1.** The sampling sites distributed along an urbanisation gradient: S1 – forest (near Feleacu),
470 S2 – Făget forest, S3 –forest (Mănăştur), S4 – the Iuliu Haţieaganu Park and the
471 Botanical Garden inside the city, S5 – Hoia forest, S6 –forest (near Popeşti), S7 – forest
472 (near Deuşu).

473 **Fig. 2.** The variation of the normalized bioaccumulation factors along the sampling sites: S4-S1,
474 growing distance from the city center (S4) to the south; S4-S7, growing distance from the
475 city center to the north. Elements were chosen with BAF values slightly below unity (Ca,
476 Mg) and values above unity (Cd, Cu, K, P, S, Zn).

477 **Fig. 3.** The two-way factorial ANOVA test for the BAFs according to the habitat types and the
478 elements: a) the mean BAFs of some elements according to the habitat type; b) the
479 weighted means for cumulated BAFs according to the habitat types.

480 **Fig. 4.** Spearman rank-correlation coefficient values obtained for the elemental concentrations
481 for the mushroom fruiting body (mg kg^{-1} dry matter) and the soil properties, as well as
482 for the BAF values and the soil properties.

483 **Fig. 5.** Box and whiskers plots for the soil properties (median, IQR, outliers falling below Q1 –
484 1,5IQR or beyond Q3 + 1,5IQR).

485

Captions to Figures

Fig. 1. The sampling sites distributed along an urbanisation gradient: S1 – forest (near Feleacu), S2 – Făget forest, S3 –forest (Mănăştur), S4 – the Iuliu Haţieaganu Park and the Botanical Garden inside the city, S5 – Hoia forest, S6 –forest (near Popeşti), S7 – forest (near Deuşu).

Fig. 2. The variation of the normalized bioaccumulation factors along the sampling sites: S4-S1, growing distance from the city center (S4) to the south; S4-S7, growing distance from the city center to the north. Elements were chosen with BAF values slightly below unity (Ca, Mg) and values above unity (Cd, Cu, K, P, S, Zn).

Fig. 3. The two-way factorial ANOVA test for the BAFs according to the habitat types and the elements: a) the mean BAFs of some elements according to the habitat type; b) the weighted means for cumulated BAFs according to the habitat types.

Fig. 4. Spearman rank-correlation coefficient values obtained for the elemental concentrations for the mushroom fruiting body (mg kg^{-1} dry matter) and the soil properties, as well as for the BAF values and the soil properties.

Fig. 5. Box and whiskers of some physical characteristics of the soil as a function of the sampling sites. (median – solid bold line, 50% – green area, minimum and maximum – whiskers with dotted lines.).

Table 1

The method detection limits (MDL) of the elements quantified in dry soil and mushroom samples by ICP-OES, and the concentrations and the recoveries found for the reference certified materials (mean ± sd, n = 3).

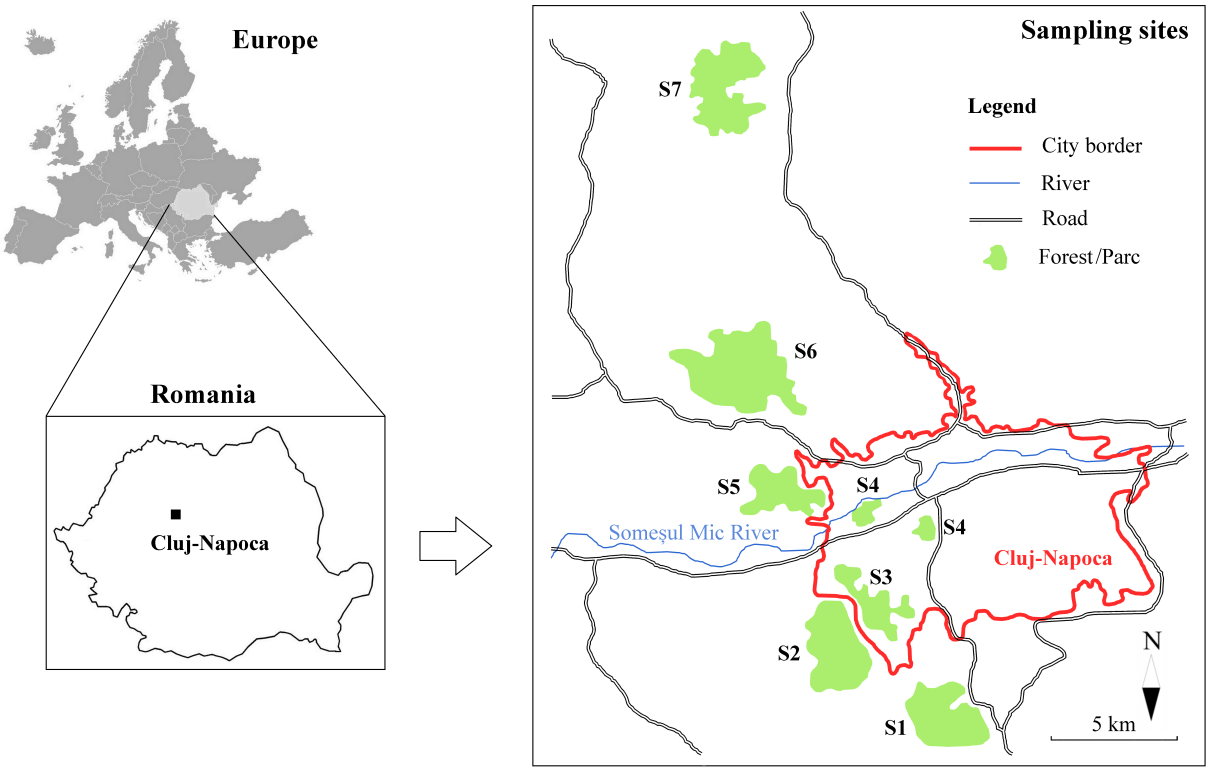
Element	MDL (mg kg^{-1})		Certified value	Measured value	Recovery (%)	Certified value	Measured value	Recovery (%)
	Soil	Mushroom	Soil (NCS DC73026)			Apple leaves (SRM 1515)		
Ag	0.73	0.13	0.068	< MDL		no data	< MDL	
Al	5.4	6.0	54990	41500 ± 325	75	284	230 ± 19	81
Ba	0.58	0.51	356	280 ± 2	79	48.8	48.2 ± 1.4	99
Ca	37	67	46312	45600 ± 455	98	15250	1560 0 ± 410	102
Cd	1.2	0.30	0.108	< MDL		0.013	< MDL	
Cr	0.66	0.18	43	37 ± 0.4	86	0.3[1]	0.2 ± 0.1	67
Cu	2.4	6.9	28	24 ± 1	86	5.69	5.2 ± 0.4	91
Fe	28	4.0	28816	26600 ± 185	92	82.7	72 ± 3	87
K	32	4.7	16519	14700 ± 263	89	16080	14900 ± 224	93
Mg	4.5	26	17970	19100 ± 101	106	2710	2830 ± 62	104
Mn	0.20	0.15	667	637 ± 5	96	54.1	52.1 ± 1.1	96
Na	117	23	66693	68600 ± 722	103	24.4	26.2 ± 5.8	107
Ni	1.0	0.66	20	20 ± 1	100	0.94	0.76 ± 0.11	81
P	297	304	706	810 ± 11	115	1593	1690 ± 15	106
Pb	4.0	0.85	3.4	< MDL		0.470	< MDL	
S	87	34	2.70	3.2 ± 0.3	119	1800[1]	1870 ± 32	104
Sr	0.27	0.12	435	520 ± 16	120	25.1	26.3 ± 0.7	105
Ti	0.28	0.01	3300	2600 ± 26	79	no data		
Zn	2.1	1.2	61	58 ± 2	95	12.45	12.7 ± 0.4	102

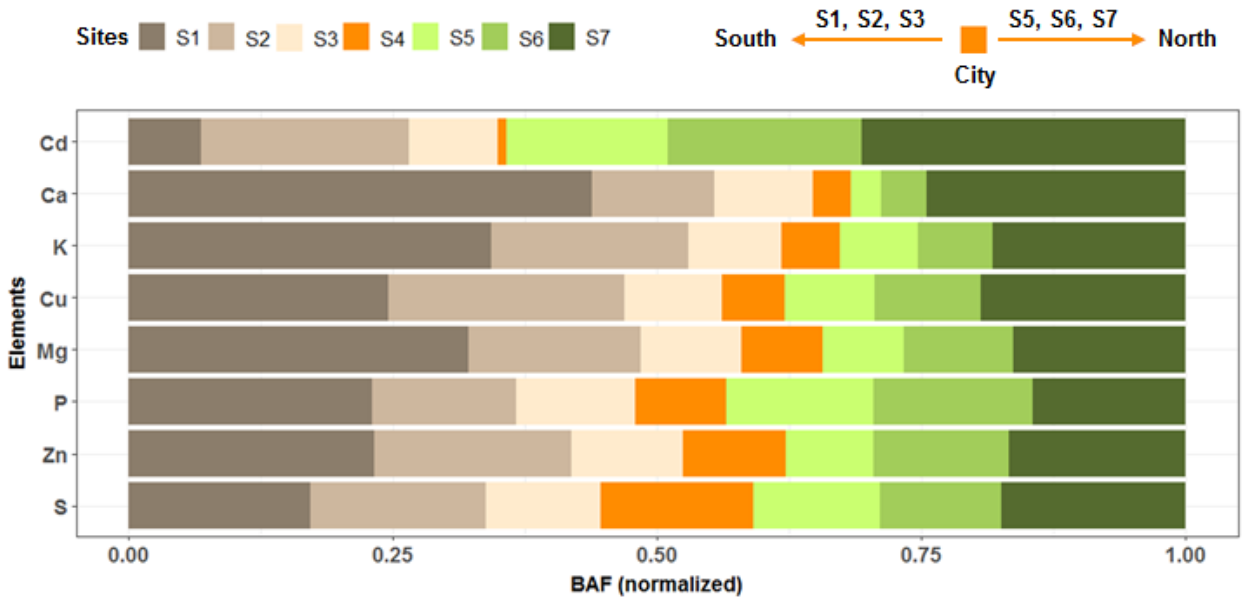
[1]Information mass fraction values.

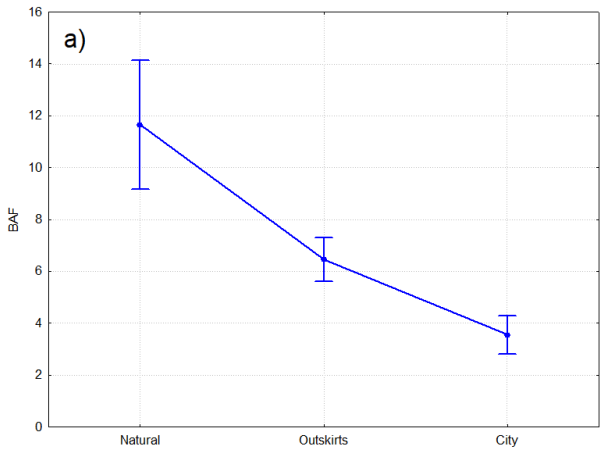
Table 2
The elemental composition (mean ± sd) of the *R. cyanoxantha* fruiting body (FB) and of the soil in the six forests and in the city parks given in mg kg^{-1} (dry matter). The statistics were calculated after removing the outliers.

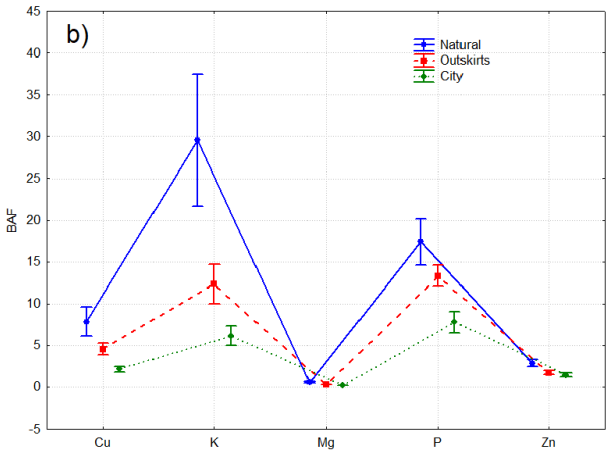
Element	Samples	Feleacu (S1) n = 13	Făget (S2) n = 15	Mănăștur (S3) n = 13	City (S4) n = 16	Hoia (S5) n = 14	Popești (S6) n = 12	Deușu (S7) n = 12	Usual content[a] Background level[b]
Ag	FB	0.29 ± 0.28	< MDL	0.28 ± 0.19	0.76 ± 0.50	0.48 ± 0.47	0.18 ± 0.14	0.21 ± 0.20	0.2–3
	soil	< MDL	< MDL	< MDL	4.57 ± 4.00	< MDL	< MDL	< MDL	< 2
Al	FB	170 ± 8.5	51.2 ± 10.4	153 ± 7.1	49.7 ± 26.2	68.6 ± 14.4	40.4 ± 14.1	25.4 ± 8.7	50–200
	soil	5460 ± 1130	12000 ± 3790	14500 ± 4700	18700 ± 3650	16600 ± 5600	18000 ± 6360	13000 ± 1710	–
Ba	FB	1.39 ± 0.66	< MDL	0.67 ± 0.28	0.65 ± 0.32	0.63 ± 0.47	1.27 ± 0.79	< MDL	1–5
	soil	45.9 ± 23.7	72.2 ± 24.6	88.5 ± 19.2	104 ± 28	120 ± 33	171 ± 69.4	59.9 ± 8.24	< 200
Ca	FB	236 ± 90	107 ± 17	167 ± 32	167 ± 98	218 ± 141	221 ± 102	173 ± 67	200–1000
	soil	415 ± 192	875 ± 377	1220 ± 628	3490 ± 805	4270 ± 2050	3920 ± 2290	480 ± 108	–
Cd	FB	3.15 ± 3.70	8.22 ± 4.90	6.13 ± 4.18	0.39 ± 0.35	9.54 ± 5.46	12.2 ± 8.8	14.1 ± 8.9	0.5–5
	soil	< MDL	2.08 ± 0.26	2.54 ± 0.74	1.23 ± 0.45	3.13 ± 0.40	3.39 ± 0.90	2.32 ± 0.37	< 1
Cr	FB	< MDL	< MDL	< MDL	0.40 ± 0.19	< MDL	< MDL	0.25 ± 0.14	0.5–5
	soil	5.44 ± 1.66	16.4 ± 5.89	18.9 ± 6.13	27.2 ± 6.25	27.1 ± 9.77	25.9 ± 7.31	22.7 ± 3.30	< 30
Cu	FB	37.1 ± 35.5	48.4 ± 45.5	37.6 ± 38.7	37.6 ± 33.8	47.1 ± 48.4	55.0 ± 48.4	47.8 ± 46.8	20–70
	soil	5.99 ± 3.67	7.84 ± 3.28	11.6 ± 4.05	18.6 ± 2.76	14.3 ± 4.25	21.6 ± 9.19	7.08 ± 1.43	< 20
Fe	FB	23.7 ± 8.54	23.4 ± 10.4	22.6 ± 6.76	69.1 ± 29.9	23.9 ± 5.29	34.5 ± 14.1	27.4 ± 4.28	30–150
	soil	5040 ± 600	12000 ± 3090	14500 ± 3720	18900 ± 4140	17400 ± 2660	18000 ± 5000	13000 ± 1420	–
K	FB	16400 ± 3580	16300 ± 2540	15800 ± 2770	20000 ± 1780	18800 ± 3020	19700 ± 3510	21400 ± 2350	20000–40000
	soil	479 ± 149	1090 ± 505	1740 ± 858	3540 ± 938	2660 ± 979	2610 ± 770	1230 ± 337	–
Mg	FB	564 ± 79	602 ± 53	543 ± 76	723 ± 87	634 ± 99	672 ± 112	787 ± 137	800–1800
	soil	800 ± 218	1900 ± 730	2450 ± 770	4370 ± 1630	3500 ± 495	3440 ± 1020	2270 ± 430	–
Mn	FB	17.2 ± 3.5	15.9 ± 3.2	18.3 ± 3.4	10.9 ± 1.3	17.7 ± 3.6	18.8 ± 5.1	19.1 ± 3.0	10–60
	soil	514 ± 229	1140 ± 447	1380 ± 540	478 ± 49.9	1030 ± 303	1320 ± 662	960 ± 187	< 900
Na	FB	150 ± 90	116 ± 78	258 ± 149	252 ± 112	136 ± 110	115 ± 78	337 ± 222	100–400
	soil	< MDL	< MDL	< MDL	145 ± 78	< MDL	< MDL	< MDL	–
Ni	FB	1.22 ± 0.52	1.50 ± 0.49	1.35 ± 0.44	2.49 ± 1.52	1.07 ± 0.57	1.42 ± 0.55	1.74 ± 0.76	0.5–5
	soil	5.13 ± 1.49	14.6 ± 6.88	18.0 ± 7.10	23.9 ± 4.38	29.1 ± 6.57	29.9 ± 11.3	14.9 ± 3.58	< 20
P	FB	3610 ± 480	4420 ± 310	3580 ± 290	5190 ± 400	4020 ± 680	4500 ± 740	5480 ± 610	5000–10000
	soil	188 ± 64.7	367 ± 39.7	327 ± 64.2	707 ± 197	338 ± 110	322 ± 109	428 ± 32.2	–
Pb	soil	16.2 ± 2.68	22.5 ± 3.22	22.4 ± 4.07	14.7 ± 1.97	31.1 ± 2.93	28.4 ± 9.39	23.6 ± 2.00	< 20
S	FB	1730 ± 150	2020 ± 150	1850 ± 140	2550 ± 330	2170 ± 400	2200 ± 330	2220 ± 400	1000–3000
	soil	136 ± 30.4	178 ± 26.5	244 ± 72.9	224 ± 73.5	315 ± 151	317 ± 118	189 ± 55.8	–
Sr	FB	0.59 ± 0.18	< MDL	0.52 ± 0.08	0.82 ± 0.45	0.74 ± 0.60	0.81 ± 0.34	0.43 ± 0.10	< 2
	soil	3.61 ± 1.27	8.91 ± 3.13	12.8 ± 5.37	24.2 ± 3.95	27.4 ± 9.55	24.9 ± 13.0	6.58 ± 0.90	–
Ti	FB	0.19 ± 0.12	0.20 ± 0.12	0.22 ± 0.09	0.76 ± 0.45	0.21 ± 0.15	0.28 ± 0.14	0.36 ± 0.14	< 10
	soil	110 ± 13.6	210 ± 80.3	202 ± 79.0	429 ± 123	225 ± 94.5	282 ± 96.7	364 ± 95.5	–
Zn	FB	85.5 ± 19.1	102 ± 26	74.5 ± 15.8	104 ± 29	86.3 ± 18.8	108 ± 35	101 ± 21	30–150
	soil	27.2 ± 5.49	43.7 ± 12.6	51.7 ± 13.5	72.8 ± 16.5	84.6 ± 10.2	81.4 ± 31.4	44.5 ± 6.41	< 100

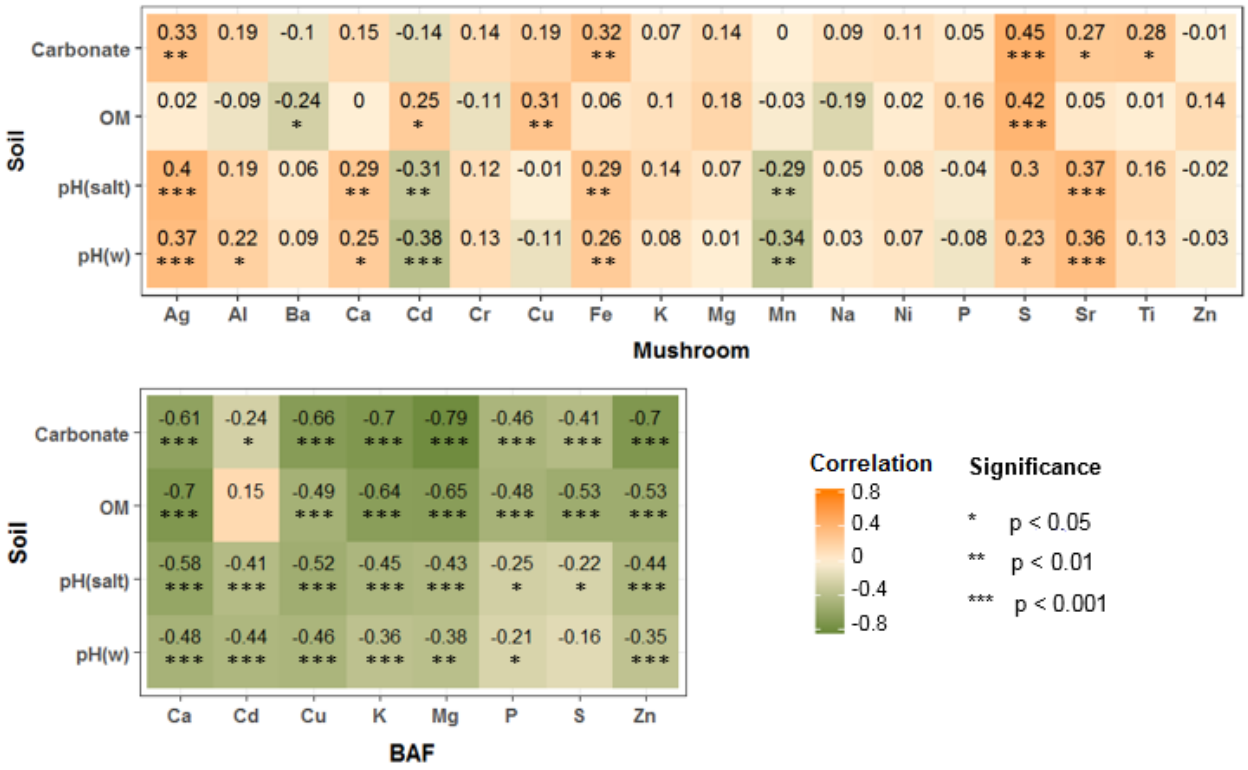
[a]Usual content of elements in mushrooms from unpolluted areas according to Kalač (2016).
[b]Background levels for soils given by the Ministry of Environment of Romania (Government Decree 756/1997, November 3, 1997).

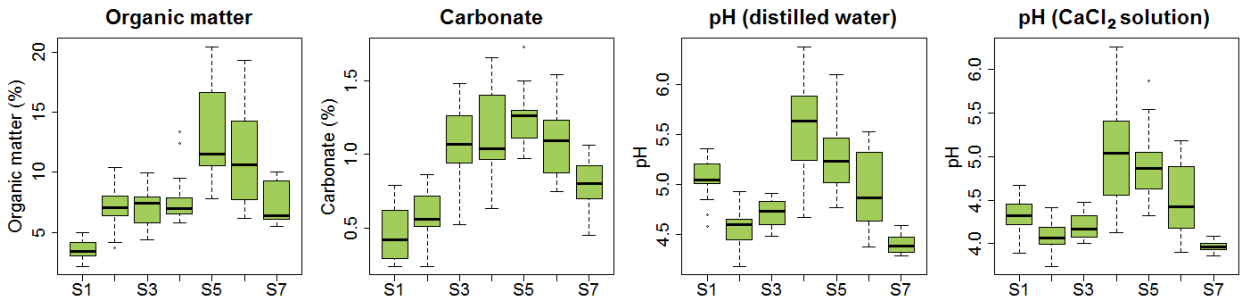












The city had local influence over the mineral composition of this mushroom.

The soil properties strongly affected the elemental uptake capability of the fungus.

The mineral accumulation potential of the fungus gradually decreased toward the city.

The carbonate content of the soil impeded the uptake of many metals by the mushrooms.