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Anthropogenic contamination leads to changes in mineral composition of soil- and tree-growing mushroom species: A case study of urban vs. rural environments and dietary implications

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HIGHLIGHTS

- Mineral composition of mushrooms and soils in urban and rural areas were studied.
- City soil/tree mushrooms have higher total element contents than rural mushrooms.
- Linkage between Hg and Sr content in mushrooms and soil was found in urban sites.
- Only Mo content exceeded recommended level in city mushrooms.
- Generally, low metal accumulation in mushrooms indicates no consumption risk.

GRAPHICAL ABSTRACT

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ABSTRACT

Because wild-growing edible mushroom species are frequently consumed, a knowledge of their mineral composition is essential. The content of elements in mushrooms and their possible beneficial or harmful effect may be influenced by the human-impacted environment. Thus, the aim of the study was to analyse the mineral composition of the soil, trees, and especially soil- and tree-growing mushroom species collected from within a city and from rural areas. Due to potentially higher pollution in urban areas, we assumed that mushrooms from a city environment will contain higher levels of mineral elements than those from rural areas and that the high content will be attributed to greater contamination of city soils. Significantly higher concentrations of several elements in soils (Ca, Ba, Bi, Hg, Pb, Sb, Sr, W and Zr) and trees (Ag, Bi, Ce, Co, Mn, Mo, Nd, Pr, Ta, Tm and W) were observed from the samples collected in the city. Additionally, significantly higher contents of Ag, Fe, Hg, Mn, Mo, Sr, Y and Zn in soil-growing, and Al, As, Ba, Cr, Fe, Hg, Ni, Pb, Sr, Ta and Zn in tree-growing mushroom species were recorded from the urban area. These differences formed the basis for the observation that the content of elements in urban mushrooms is generally higher than in those from rural areas. However, a higher content of several soil

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Traffic pollution
Tree species

elements does not necessarily mean that there will be a significantly higher content in fruit bodies. There was also no real risk of consuming soil-growing mushroom species collected in recent years from the city, suggesting that this practice may still be continued.

1. Introduction

There has been a growing interest in mushrooms during recent years (Rizzo et al., 2021). Wild-growing mushrooms constitute a considerable dietary component in selected regions of the world and a global trend, related to the consumption of cultivated mushrooms observed over the last 40 years, has indicated that their share in the human diet is generally increasing. The change in the approach to these organisms has resulted from the development of research describing the presence of active substances in mushrooms and the possibility of conducting effective fortification to obtain functional food (Gargano et al., 2017; Fijałkowska et al., 2020; Thakur, 2020). These activities have led to a significant increase in the world mushroom industry along with new possibilities of using mushrooms for various purposes (Chang, 2006; Royse et al., 2017). Unfortunately, there has also been an increase in environmental degradation, especially in the concentration of toxic trace elements in soils due to their non-biodegradable nature. This aspect has become the subject of ever-expanding research with respect to wild-growing mushrooms (Falandysz and Treu, 2017). So far, the assessment of the content of elements has covered both clean and heavily polluted areas, and authors' attention has focused on several elements or several dozens of them (Falandysz et al., 2017; Siwulski et al., 2020). Wild mushrooms can grow in extremely contaminated substrates (Mleczek et al., 2015) and because of their dynamic accumulation of elements the process of enrichment may have a significant impact on their usefulness. This has resulted in parallel research on their use as food or for mycoremediation purposes (Kulshreshtha et al., 2014; Rhodes, 2014).

The accumulation of elements by macrofungi depends on several factors, including the chemical characteristics of the underlying soil and the species of fungus (Kokkoris et al., 2019; Mleczek et al., 2021a). Therefore, although there may be a higher content of elements in the soil it does not necessarily result in a higher accumulation in fruit bodies, and vice versa. In the majority of available studies, a relationship between the concentration of bioavailable forms of elements and their content in mushrooms has been observed (Lalotra et al., 2016; Ndimele et al., 2017; Świsłowski and Rajfur, 2018). The outcome of mushroom growth on various substrates is a diversified mineral profile of elements, and in the case of their more significant accumulation, the need to monitor the content for health reasons. Thus forming a starting point for questions about the possibility of obtaining and ultimately eating fruit bodies from areas potentially exposed to the emission of detrimental elements into the environment (Chatterjee et al., 2017). As a consequence of dynamic economic development, the recipients of such a pollutant load are found not only in cities but also in areas outside them, especially forests constituting a reservoir for mushrooms (Davidson et al., 2020; Grodzińska et al., 2020). This phenomenon is particularly worrying from the point of view of mushroom chemical safety since mushrooms constitute a fundamental component of the daily diet in selected regions of the world (Mleczek et al., 2021b). Hence it would seem more reasonable to obtain fruit bodies from unpolluted areas that allow mushrooms to grow in conditions where concentrations of elements are lower than the permissible values (Sarikurkcu et al., 2020; Svoboda and Chrastný, 2008).

Roads play a unique role in transporting elements to the environment due to their abrasion, road transport, and the emission of pollutants as a result of the wear of car parts (Mleczek et al., 2021c). The differences in the content of elements in individual species of fungi growing alongside roads and beyond indicate the evident influence of anthropogenic activity (Işiloğlu et al., 2001; Mleczek et al., 2016). Due to the greater traffic volume on city roads, it seems justified to assume that the content of elements in fruit bodies collected in the city will be significantly higher than outside it, but is it really so? It seems justifiable to ask whether they should be collected in forests outside cities or whether cities can also be safe places for collecting this valuable food item. We also forget that many people avoid deep forests and collect mushrooms near road zones where there is often an intensive migration of elements. Many potential consumers of mushrooms collect them from parks, lawns or neighbourhood squares where collection of mushrooms is easy, which, growing among trees, seem to be no different from those collected in forests. Unfortunately, long term consumption of mushroom species can lead to an accumulation of toxic elements and may pose a health risk also in the case for mushrooms collected in rural areas (Zsigmond et al., 2015).

Since urban areas are likely to be more prone to anthropogenic pollution, we hypothesized that mushroom species from the city will have a higher content of mineral elements than those from rural areas. We have also assumed that an increase of mineral element levels in mushroom fruit-bodies will correspond to the higher contamination of city soils. Therefore, the aim of the study was to compare the mineral profile of underlying soils, trees and especially soil- and tree-growing mushroom species (edible and inedible) collected from two types of environments differing in the level of pollution – 1/from the urban area within the City of Poznań (Poland) and 2/beyond the urban area from locations in the rural landscape. In order to reduce the impact of habitat specificity on the mineral content in soils and mushroom fruit-bodies all research sites were placed near roads. The obtained data should elucidate the real influence of the city in terms of a more extensive production and finally higher concentration of major and trace elements in fruit bodies.

2. Materials and methods

2.1. Characteristics and collection of experimental materials

The research was concentrated on the fruit bodies of the most widespread species in sites within a city environment (urban area) and outside a city environment (rural area). The research points were chosen along transportation routes - up to 50 m from the edge of the road. All precise locations and the distance from the roads were determined using the Garmin Oregon 650 GPS system as presented in Fig. 1. Experimental materials were 10 tree-growing (TM) [*Auricularia auricula-judae* (Bull.) Quél., *Cerioporus squamosus* (Huds.) Quél., *Flammulina velutipes* (Curtis) Singer, *Ganoderma applanatum* (Pers.) Pat., *Ganoderma resinaceum* Boud, *Laetiporus sulphureus* (Bull.) Murrill and *Pholiota aurivella* (Batsch.) P. Kumm.] and 6 soil-growing (SM) [*Agaricus arvensis* Schaeff., *Calvatia gigantea* (Batsch) Lloyd, *Chlorophyllum rhacodes* (Vittad.) Vellinga, *Lyophyllum fumosum* (Pers.) P.D. Orton, *Poxillus involutus* (Batsch.) Fr. and *Tricholoma equestre* (L.) P. Kumm.] mushroom species collected in two following seasons: summer and autumn over three years: 2018, 2019 and 2020 from Poznań (C) and outside (OC) (Table 1).

From among the group of 10 tree-growing mushroom species, 6 were collected beyond the city, and 5 from selected districts of Poznań (Table 1). In the case of the group of 6 soil-growing mushroom species,

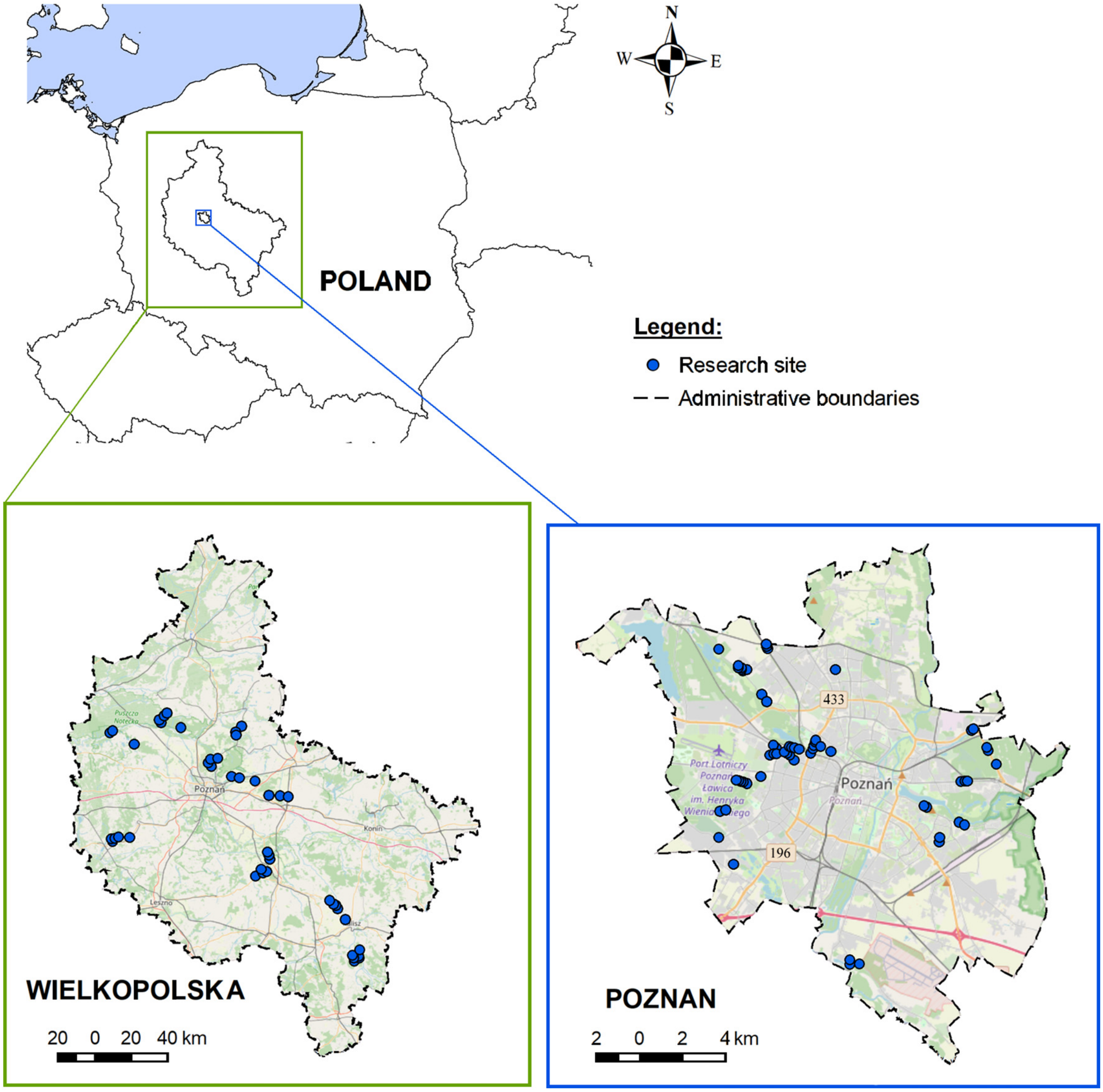

Fig. 1. Location of research sites of sample collection.
Source: own study based on data from National Geodetic and Cartographic Resource and © OpenStreetMap and contributors CC-BY-SA.

4 species were collected from both the city and rural areas. Collection of mushrooms from numerous locations (altogether 121 sites were considered) and distances from roads allowed a better averaging of the observations resulting from the study of different species of mushrooms. Because the research was conducted over 3 consecutive years and there was the possibility to collect fruit bodies of the same species from various locations within and outside the city, it was possible to compare the element contents in the two types of environments varying in the level of pollution. The collected fruit bodies of selected mushrooms contained elements in amounts depending on their place of growth. Moreover, the collected fruit bodies differed in respect to the tree species on which they grew. Nevertheless, they reflected the specific image of the relationships existing in the environment.

Additionally, 4 samples of each tree species hosting tree-mushrooms, were collected using a Pressler drill with an external diameter of 5.15 mm. The wood samples were taken from the point of complete removal of the fruit body towards the pith. Wood samples of various lengths, depending on the trunk and tree species' diameter, were collected in such a way as to consider all annual rings. Finally, underlying soil samples were collected from a 0–200 mm depth under the sampled soil-growing species and trees using a soil auger.

2.2. Sample preparation

Samples (soils, tree samples, mushrooms) were dried at 45 ± 5 °C in an electric oven (Thermocenter, Salvislab, Switzerland) until they reached a constant weight and were then powdered. Accurately weighed 0.200–0.500 ($\pm$ 0.001) g samples were digested in closed Teflon containers in the microwave digestion system Mars 6 Xpress (Mars 6 Xpress, CEM USA) with concentrated nitric acid (65%; Sigma-Aldrich, USA). The inductively coupled plasma mass spectrometry system PlasmaQuant MS Q (AnalytikJena, Germany) was used for element determination under the following conditions: plasma gas flow 9.0 L min^{-1}, nebuliser gas flow 1.05 L min^{-1}, auxiliary gas flow 1.5 L min^{-1}, Radio Frequency (RF) power 1.35 kW. The interferences were reduced using the integrated Collision Reaction Cell (iCRC) working sequentially in three modes: with helium as a collision gas, hydrogen as a reaction gas and without the addition of gases. The uncertainty of the analytical procedure, including sample preparation, was at the level of 20%. The detection limits were determined at the level of 0.001–0.010 mg kg^{-1} dry weight (DW) for all elements determined [3 times standard deviation of blank analysis ($n = 10$)]. Accuracy was checked by an analysis of the reference materials CRM 2709 – soil;

Table 1
Characteristics of tree-growing (TM) and soil-growing (SM) mushroom species collected in the city (C) and beyond (OC).

Mushroom group	Mark	Name of species	Family	Edibility	Nutritional strategy	Found on	Distances from the road	n
Soil-growing mushrooms	SM_1OC	*Agaricus arvensis* Schaeff.	Agaricaceae	Edible	Saprotrophic	Roadside deciduous forest	15–20 m	12
	SM_1C	*Agaricus arvensis* Schaeff.	Agaricaceae	Edible	Saprotrophic	Lawn	15–20 m	18
	SM_2OC	*Calvatia gigantea* (Batsch) Lloyd	Lycoperdaceae	Edible	Saprotrophic	Lawn with shrubs	25–45 m	3
	SM_3OC	*Chlorophyllum rhacodes* (Vittad.) Vellinga	Agaricaceae	Inedible	Saprotrophic	Roadside deciduous forest	30–35 m	7
	SM_4OC	*Lyophyllum fumosum* (Pers.) P.D. Orton	Lyophyllaceae	Edible	Saprotrophic	Roadside deciduous forest	20–40 m	21
	SM_4C	*Lyophyllum fumosum* (Pers.) P.D. Orton	Lyophyllaceae	Edible	Saprotrophic	City park	20–40 m	23
	SM_5C	*Paxillus involutus* (Batsch.) Fr.	Paxillaceae	Inedible	Saprotrophic	Lawn	15–25 m	9
	SM_6C	*Tricholoma equestre* (L.) P. Kumm.	Tricholomataceae	Inedible/edible?	Mycorrhizal	Roadside pine forest	30–40 m	7
Tree-growing mushrooms	TM_1OC	*Auricularia auricula-judae* (Bull.) Quél.	Auriculariaceae	Edible	Saprotrophic/facultative parasitic	*Sambucus nigra* L.	30–40 m	18
	TM_1C	*Auricularia auricula-judae* (Bull.) Quél.	Auriculariaceae	Edible	Saprotrophic/facultative parasitic	*Acer negundo* L. *Alnus glutinosa* (L.) Gaertn.	25–35 m	29
	TM_2C	*Cerioporus squamosus* (Huds.) Quél.	Polyporaceae	Inedible	Parasitic	*Acer platanoides* L.	15–40 m	4
	TM_3C	*Flammulina velutipes* (Curtis) Singer	Physalacriaceae	Edible	Saprotrophic	*Acer negundo* L. *Tilia cordata* Mill.	30–40 m	43
	TM_4C	*Ganoderma applanatum* (Pers.) Pat.	Polyporaceae	Inedible	Parasitic/saprotrophic	*Fagus sylvatica* L. *Aesculus hippocastanum* L.	25–40 m	6
	TM_5OC	*Ganoderma resinaceum* Boud	Polyporaceae	Inedible	Parasitic/saprotrophic	*Aesculus hippocastanum* L. *Fagus sylvatica* L	5–40 m	3
	TM_6OC	*Laetiporus sulphureus* (Bull.) Murrill	Laetiporaceae	Edible/young fruit bodies	Parasitic	*Robinia pseudoacacia* L.	10–20 m	32
	TM_6C	*Laetiporus sulphureus* (Bull.) Murrill	Laetiporaceae	Edible/young fruit bodies	Parasitic	*Robinia pseudoacacia* L.	10–15 m	19
	TM_7OC	*Pholiota aurivella* (Batsch.) P. Kumm.	Strophariaceae	Edible	Saprotrophic/facultative parasitic	*Fagus sylvatica* L. *Populus alba* L.	30–40 m	32
	TM_8OC	*Fomitopsis betulina* (Bull.) B.K. Cui, M.L. Han & Y.C. Dai.	Fomitopsidaceae	Inedible	Parasitic	*Betula pendula* Roth.	25–30 m	13
	TM_9OC	*Pleurotus ostreatus* (Jacq.) P. Kumm.	Pleurotaceae	Edible	Saprotrophic/facultative parasitic	*Populus nigra* L. *Fraxinus excelsior* L. *Fagus sylvatica* L.	30–45 m	29
	$TM_{10}C$	*Sparassis crispa* (Wulfen) Fr.	Sparassidaceae	Edible	Parasitic	*Pinus sylvestris* L	35–40 m	3

n – total amount of fruit bodies collected from all sampled sites.

CRM S-1 – loess soil; CRM 667 – estuarine sediments; CRM 405 – estuarine sediments and CRM NCSDC (73349) – bush branches and leaves. The recovery (80–120%) was acceptable for most of the elements determined. For non-certified elements, the recovery was defined in the standard addition method.

2.3. Statistical analysis

All statistical analyses were performed using both STATISTICA 13.3 software (StatSoft, USA) and agricolae, heatmaps, factoextra, hclust packages (R, Bell Laboratories). One-dimensional analysis of variance (ANOVA), and finally, the multiple comparison Tukey's HSD test were applied to show the existence of uniform groups of objects (soils, trees and mushrooms, separately) ($\alpha = 0.05$). For a better presentation of the objects, heatmaps were prepared separately for tree-growing and soil-growing mushroom species and also for both these groups of objects jointly (Galili, 2015). To show the existence of significant differences between the content of particular elements in all soils, trees and mushrooms separately, collected from the city and beyond, a *t*-test was performed. Additionally, to show differences between mushroom species regarding the content of all elements jointly, a rank-sum was performed.

3. Theory/calculation

The dynamically growing demand for mushrooms, especially wild-growing species, has led to a need for a broader assessment of their chemical composition than before. These species are most often collected close to roads, both inside and outside cities.

Increased traffic intensity suggests that urban mushrooms will contain higher concentrations of trace elements originating from transport. Nevertheless, it is not inevitable that the fruit bodies collected in such places will pose a threat to human health and life, in spite of their location (urban or rural environments).

4. Results

4.1. Concentration of elements in soil and soil-growing mushroom species

All 37 determined element concentrations in the following text are given as median values expressed as mg kg^{-1} DW. The characteristics of the ranges of element concentration in soils collected under the mushroom species are presented in Table S1 in the Supplementary material. Determined values for soils outside the city were similar to the geochemical background of the Wielkopolska region. No obvious anomalies were recorded. The same was observed for city soils. Comparing soils, significantly higher concentrations of Ca and Sr ($p < 0.001$), Ba and Bi ($p < 0.01$) and also Hg, Pb, Sb, W and Zr ($p < 0.05$) were found in the city soils than in those outside the city (Fig. 2). There were no significant differences between the concentration of the rest of the elements in soils from the city and outside it.

Medians of the element contents determined in soil-growing mushroom species were significantly different (Table 2).

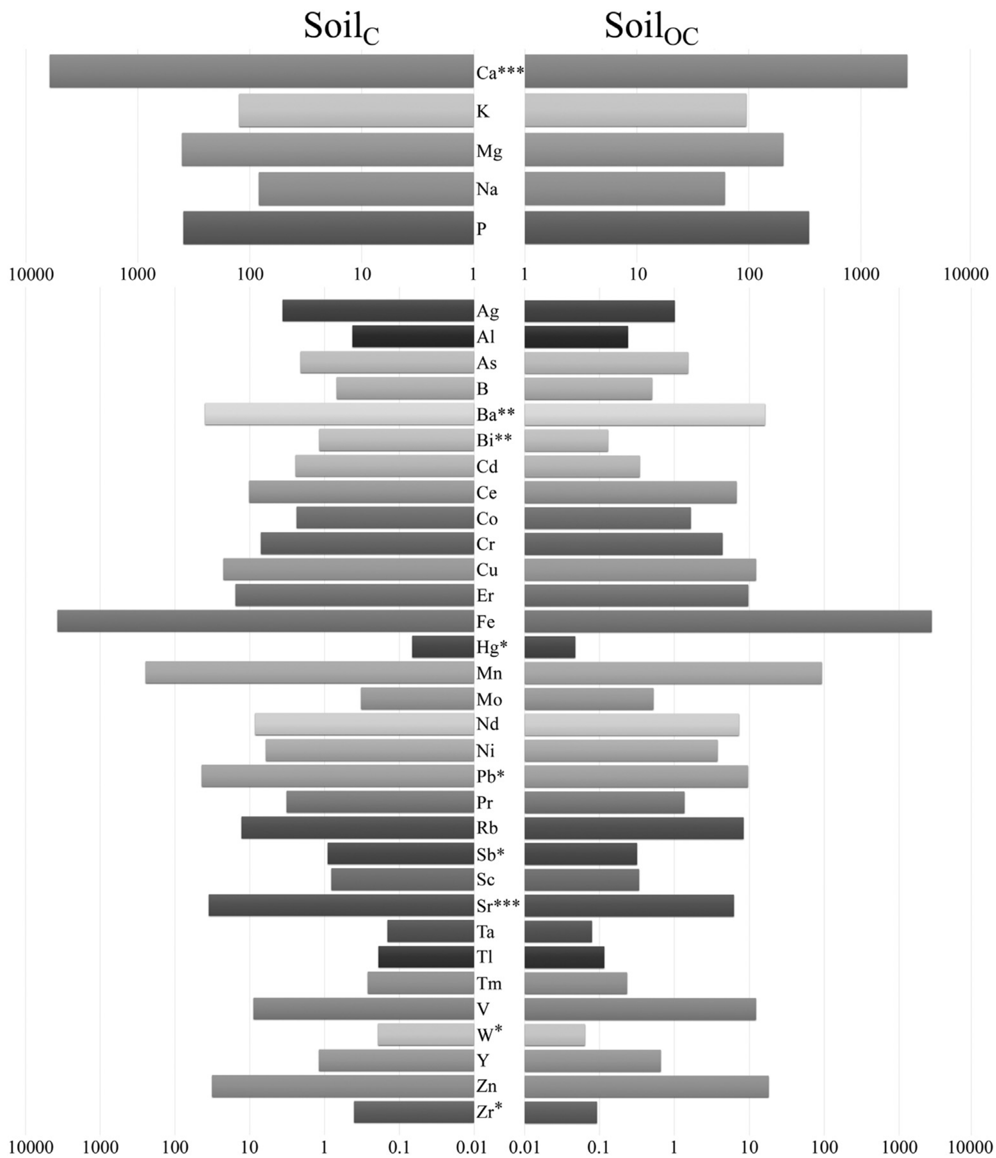

Fig. 2. Medians and differences in element concentration [mg kg^{-1} DW] in soils collected from the city (C) and outside the city (OC).
*** <0.001, ** <0.01, * <0.05.

The highest median values of the element contents in mushrooms collected in the city were: SM$_1$C – Mg, Na, P, Ag, Cd, Ni, Rb, Sb, Ta, Tl, Tm and W (737; 171; 6840; 5.69; 6.00; 1.57; 25.7; 1.83; 5.89; 0.498; 0.452 and 7.94 mg kg^{-1}, respectively); SM$_4$C – Ce, Er, Tl, Y and Zr (0.219; 0.226; 0.529; 0.098 and 0.521 mg kg^{-1}, respectively); SM$_6$C – K, Mg, Al, As, B, Ba, Bi, Co, Cr, Cu, Fe, Nd, Pb, Sc, V and Zn (41000; 674; 493; 14.6; 15.5; 73.1; 1.57; 5.71; 8.89; 64.5; 252; 2.53; 8.49; 0.425; 2.09 and 95.2 mg kg^{-1}, respectively) and SM$_5$C – Ca, K, Mg, Na, Fe, Hg, Mn, Mo, Pr, Rb and Sr (2140; 42200; 712; 184; 248; 0.519; 33.4; 6.20; 0.922; 27.0 and 9.51 mg kg^{-1}, respectively).

In mushrooms collected outside the city, the highest medians were as follows: SM$_1$OC – K, Mg, P, B, Ba, Er, Fe, Ni, Sb, Sr and Tm (37600; 743; 3480; 11.5; 25.5; 0.155; 81.1; 1.38; 1.03; 3.51 and 0.259 mg kg^{-1}, respectively); SM$_3$OC – Na, Ag, Al, As, Bi, Cd, Ce, Co, Cr, Mo, Nd, Pb, Pr, Sc, W and Zr (80.2; 2.50; 72.0; 0.589; 1.17; 1.69; 0.833; 0.866; 3.53; 0.332; 0.384; 4.32; 0.632; 0.176; 0.565 and 0.324 mg kg^{-1}, respectively); SM$_3$OC – Ca, Na, Cu, Fe, Mn, Rb, Sb, Ta, Tl, V, Y and Zn (2280; 74.4; 6.09; 87.2; 6.56; 22.5; 1.05; 5.70; 0.399; 0.091; 0.036 and 23.6 mg kg^{-1}, respectively) and SM$_4$OC – Bi, Hg and Zr (1.20; 0.088 and 0.309 mg kg^{-1}, respectively).

To compare the content of major, trace and all elements jointly in the studied soil-growing mushroom species collected in the city and outside the city, a rank sum was calculated (Fig. 3). The element contents in soil-growing mushroom species from the city decreased in the following order: SM$_1$C > SM$_6$C > SM$_5$C > SM$_4$C (major); SM$_5$C > SM$_1$C > SM$_6$C > SM$_4$C (trace) and SM$_1$C > SM$_5$C > SM$_6$C > SM$_4$C (all elements), while in the mushrooms outside the city: SM$_1$OC > SM$_3$OC > SM$_4$OC > SM$_2$OC (major) and SM$_2$OC > SM$_3$OC > SM$_1$OC > SM$_4$OC (both for trace and all elements).

4.2. Content of elements in tree and tree-growing mushroom species

Similarly to soils, the ranges of the determined elements content in the sampled trees are presented in Table S1 to better characterise differences between the plants. The studied tree species contained different amounts of elements depending both on the plant distance from the road and its species. When comparing the content of the elements in all studied tree species, significantly higher contents of Ag, Bi, Ce, Co, Mn, Mo, Nd, Pr, Ta, Tm and W were observed in the plants growing in

Table 2
Median values of element concentrations [mg kg^{-1} DW] in soil- and tree-growing mushroom species collected from the city (C) and beyond (OC).

Mushroom	Ca	K	Mg	Na	P	Ag	Al	As	B	Ba	Bi	Cd	Ce
Soil-growing mushroom species													
SM_1C	961^{c}	28400^{b}	737^{a}	171^{a}	6840^{a}	5.69^{a}	269^{b}	0.910^{d}	0.912^{c}	51.0^{b}	1.03^{b}	6.00^{a}	0.174^{b}
SM_4C	970^{c}	31800^{b}	522^{b}	48.9^{c}	1620^{c}	2.88^{d}	37.4^{d}	2.31^{c}	2.28^{c}	7.21^{c}	0.998^{c}	1.32^{d}	0.219^{a}
SM_5C	2140^{a}	42200^{a}	712^{a}	184^{a}	4170^{b}	4.63^{b}	94.0^{c}	9.26^{b}	10.5^{b}	49.3^{b}	0.877^{c}	3.43^{c}	0.157^{c}
SM_6C	1710^{b}	41000^{a}	674^{a}	92.7^{b}	4320^{b}	4.08^{c}	493^{a}	14.6^{a}	15.5^{a}	73.1^{a}	1.57^{a}	4.02^{b}	0.139^{c}
SM_1OC	986^{b}	37600^{a}	743^{a}	62.4^{b}	3480^{a}	0.935^{bc}	49.6^{b}	0.236^{d}	11.5^{a}	25.5^{a}	0.028^{c}	1.40^{b}	0.134^{c}
SM_2OC	572^{c}	10600^{d}	459^{b}	80.2^{a}	1910^{c}	2.50^{a}	72.0^{a}	0.589^{a}	0.027^{c}	14.8^{b}	1.17^{a}	1.69^{a}	0.833^{a}
SM_3OC	2280^{a}	32100^{b}	379^{c}	74.4^{a}	2300^{b}	0.836^{c}	29.5^{c}	0.411^{c}	0.374^{c}	11.9^{c}	0.970^{b}	0.852^{c}	0.152^{c}
SM_4OC	727^{c}	27300^{c}	482^{b}	47.0^{c}	1880^{c}	1.06^{bc}	31.3^{c}	0.511^{b}	1.92^{b}	3.70^{d}	1.20^{a}	0.876^{c}	0.423^{b}
Tree-growing mushroom species													
TM_1C	953^{b}	30100^{a}	637^{b}	68.3^{e}	2560^{f}	5.35^{b}	225^{bc}	1.66^{d}	19.5^{a}	45.4^{a}	1.02^{b}	1.07^{e}	0.572^{a}
TM_2C	756^{c}	19900^{c}	477^{c}	222^{b}	5190^{c}	1.12^{d}	241^{c}	1.17^{e}	4.21^{d}	23.8^{d}	0.572^{e}	2.53^{c}	0.313^{b}
TM_3C	1270^{a}	18100^{c}	794^{a}	158^{c}	3470^{e}	10.1^{a}	252^{c}	0.356^{f}	2.24^{e}	39.4^{b}	0.842^{c}	1.43^{de}	0.167^{de}
TM_4C	1210^{a}	10200^{e}	514^{c}	156^{c}	4270^{d}	2.06^{c}	313^{b}	2.10^{c}	8.76^{c}	46.6^{a}	0.716^{cd}	1.76^{d}	0.135^{de}
TM_6C	750^{c}	24800^{b}	616^{b}	108^{d}	6530^{b}	2.04^{c}	245^{c}	3.21^{a}	12.0^{b}	32.2^{c}	0.629^{de}	4.51^{b}	0.179^{cd}
$TM_{10}C$	1040^{b}	15000^{d}	405^{d}	802^{a}	7300^{a}	5.81^{b}	371^{a}	2.58^{b}	7.50^{c}	41.7^{ab}	1.46^{a}	5.04^{a}	0.216^{c}
TM_1OC	814^{b}	21300^{ab}	540^{b}	62.9^{c}	4920^{a}	1.66^{b}	79.9^{a}	1.06^{a}	8.94^{a}	26.8^{a}	0.040^{c}	2.61^{a}	0.232^{d}
TM_5OC	878^{b}	8160^{d}	412^{c}	83.2^{b}	4390^{b}	0.448^{e}	72.0^{a}	0.716^{b}	3.96^{b}	21.3^{b}	1.40^{a}	2.15^{b}	0.093^{e}
TM_6OC	851^{b}	23300^{a}	650^{a}	75.3^{b}	2340^{d}	1.91^{a}	28.6^{c}	0.737^{b}	0.044^{d}	9.67^{b}	0.012^{c}	0.653^{e}	0.432^{b}
TM_7OC	1020^{a}	20100^{b}	417^{c}	47.5^{d}	2010^{d}	1.07^{d}	59.8^{b}	0.305^{c}	1.04^{c}	17.6^{b}	0.047^{c}	1.67^{c}	0.119^{e}
TM_8OC	793^{b}	15100^{c}	558^{b}	61.3^{c}	3240^{c}	1.25^{c}	51.9^{b}	0.236^{c}	8.52^{a}	26.3^{a}	0.861^{b}	0.930^{d}	0.525^{a}
TM_9OC	864^{b}	20000^{b}	632^{a}	104^{a}	3290^{c}	0.134^{f}	73.1^{a}	0.813^{b}	4.19^{b}	28.0^{a}	0.024^{c}	0.551^{e}	0.291^{c}

$n = 3$; identical superscripts (a, b, c) denote non-significant differences between means in columns (separately for particular mushrooms collected from city and beyond) according to the post-hoc Tukey's HSD test; TM, tree-growing species; SM, soil-growing species.

the city than in those growing outside (Fig. 4). There were no significant differences for medians calculated for either all major elements or for the rest of the trace elements.

For tree-growing mushroom species from the city, the highest medians of the elements content were: TM_1C – K, B, Ba, Ce, Co, Cr, Fe, Nd, Ta, Tl, Tm, V, Zn and Zr (30100; 19.5; 45.4; 0.572; 5.24; 9.42; 382; 1.80; 5.76; 0.495; 0.476; 7.33; 79.5 and 0.296 mg kg^{-1}, respectively); TM_3C – Ca, Mg, Ag, Hg, Pb and Sr (1270; 794; 10.1; 0.489; 13.2 and 12.6 mg kg^{-1}, respectively); TM_4C – Ca, Ba, Fe, Mn and Sb (1210; 46.6; 401; 45.0 and 1.23 mg kg^{-1}, respectively); TM_6C – As, Co, Cu, Sc and W (3.21; 4.82; 14.8; 0.357 and 2.19 mg kg^{-1}, respectively) and $TM_{10}C$ – Na, P, Al, Bi, Cd, Er, Mo, Ni, Pr, Rb and Y (802; 7300; 371; 1.46; 5.04; 0.279; 1.92; 2.74; 0.956; 62.6 and 0.057 mg kg^{-1}, respectively) (Table 2).

In tree-growing mushrooms collected outside the city, the highest medians of the elements content were as follows: TM_1OC – P, Al, As, B,

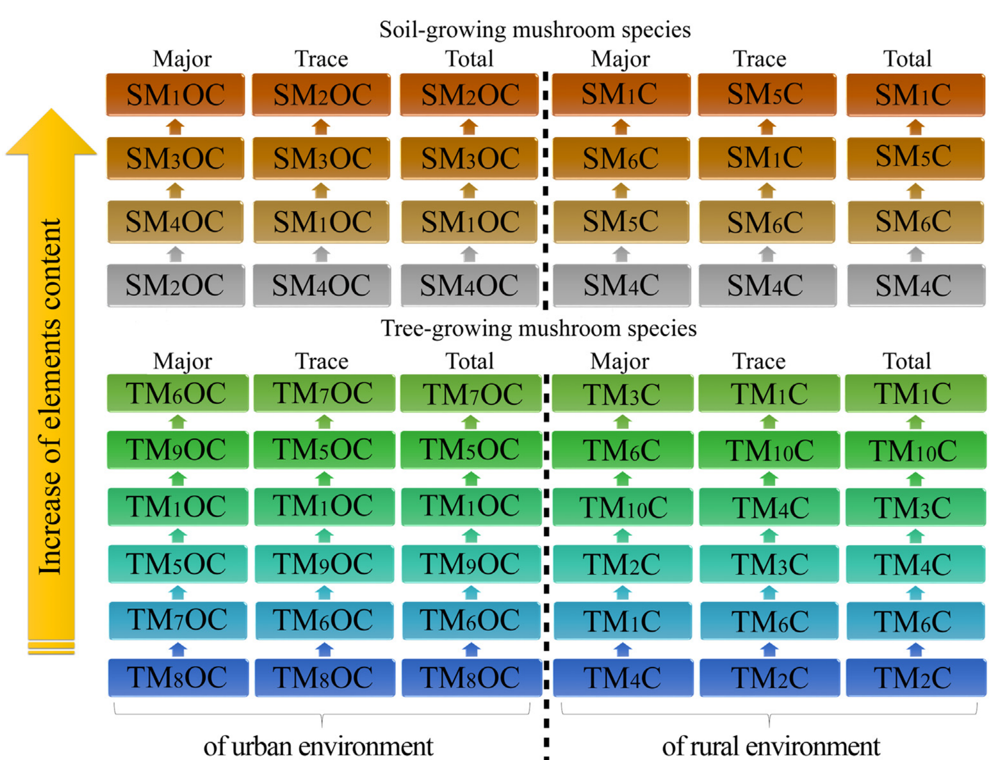

Fig. 3. The rank sum calculated for major, trace and all elements jointly determined in particular soil- and tree-growing mushroom species collected from the city (C) and out of the city (OC).

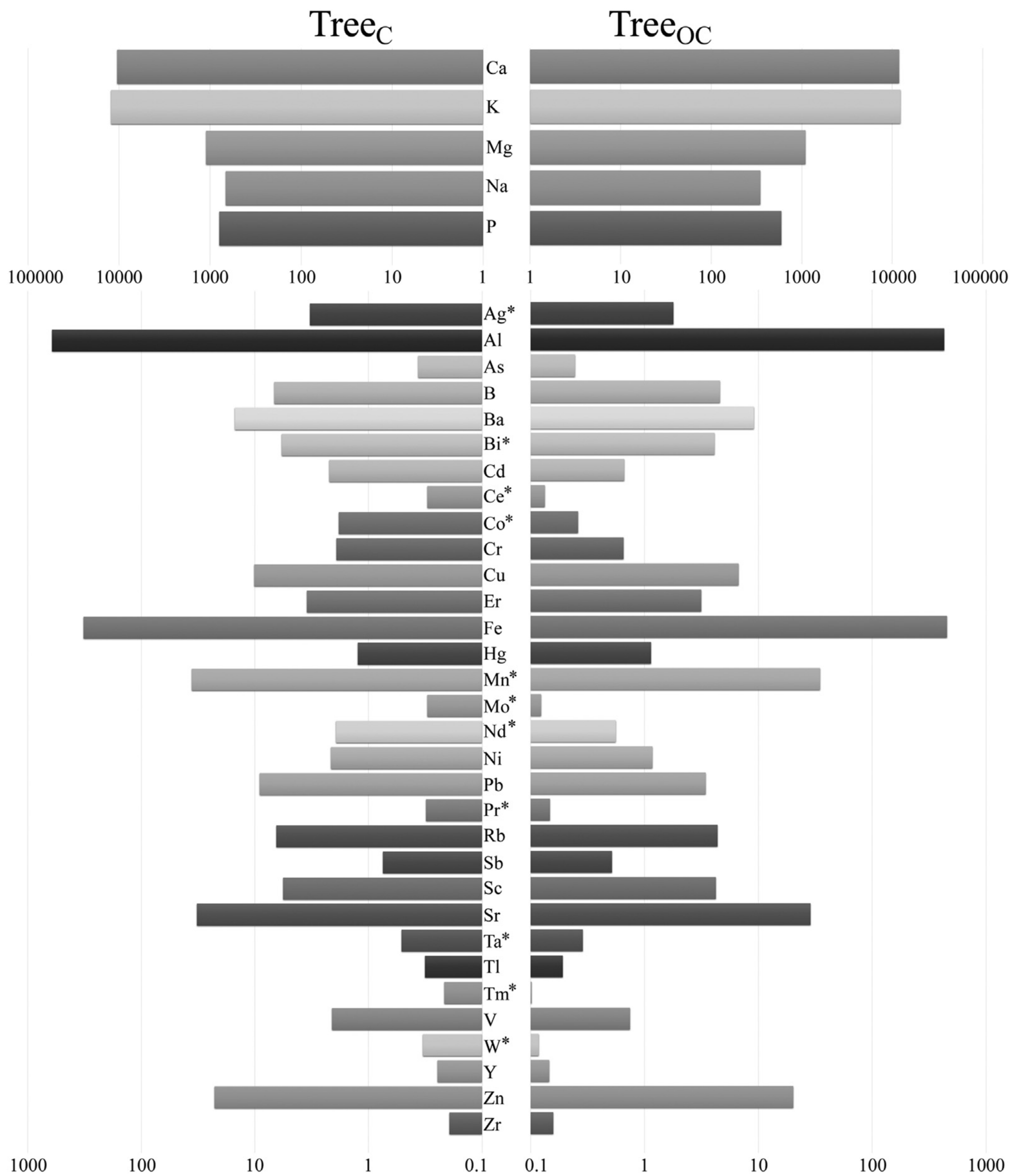

Fig. 4. Medians and differences in element concentration [mg kg^{-1} DW] in trees collected from the city (C) and outside the city (OC).
* <0.05.

Ba, Cd, Hg, Rb and Tm (4920; 79.9; 1.06; 8.94; 26.8; 2.61;0.081; 39.4 and 0.609 mg kg^{-1}, respectively); TM$_5$OC – Al, Bi, Fe, Mn, Nd, Ni, Tl and Y (72.0; 1.40; 139; 18.8; 0.640; 0.983; 0.372 and 0.063 mg kg^{-1}, respectively); TM$_6$OC – K, Mg, Ag, Cr, Hg, Pr, Sr, W and r (23300; 650; 1.91; 3.43; 0.087; 0.630; 3.50; 1.09 and 0.227 mg kg^{-1}, respectively); TM$_7$OC – Ca, Co, Cu, Er, Mo, Pb, Pr, Sb, Ta, Tl and Zn (1020; 0.960; 8.53; 0.127; 1.21; 4.53; 0.637; 1.80; 4.36; 0.339 and 32.2 mg kg^{-1}, respectively); TM$_8$OC – B, Ba, Ce and V (8.52; 26.3; 0.525 and 0.810 mg kg^{-1}, respectively) and TM$_9$OC – Mg, Na, Al, Ba, Mo, Nd and Sc (632; 104; 73.1; 28.0; 1.27; 0.638 and 0.205 mg kg^{-1}, respectively) (Tables 3 and 4).

A rank sum showed that the medians of major, trace and all determined element concentrations in tree-growing mushroom species from the city decreased in the following order: TM$_3$C > TM$_6$C > TM$_{10}$C > TM$_2$C > TM$_1$C > TM$_4$C (major); TM$_1$C > TM$_{10}$C > TM$_4$C > TM$_3$C > TM$_6$C > TM$_2$C (major) and TM$_1$C > TM$_{10}$C > TM$_3$C > TM$_4$C > TM$_6$C > TM$_2$C (all elements), while for the mushrooms collected outside the city: TM$_6$OC > TM$_9$OC > TM$_1$OC > TM$_5$OC > TM$_7$OC > TM$_8$OC (major) and TM$_7$OC > TM$_5$OC > TM$_1$OC > TM$_9$OC > TM$_6$OC > TM$_8$OC (both trace and all elements) (Fig. 3).

4.3. Similarities and differences between mushrooms from the city and those from outside

Heatmaps were prepared as a graphical presentation of the obtained results, showing similarities/differences between mushrooms collected inside and outside the city. In soil-growing mushroom species, two groups of objects can be differentiated: i) SM$_6$C, SM$_1$C and SM$_5$C sites and ii) SM$_2$OC, SM$_4$OC, SM$_4$C and also SM$_1$OC and SM$_3$OC sites (Fig. 5a). It is worth underlining that the presence of L. *fumosum* from and outside the city (SM$_4$C and SM$_4$OC, respectively) included in the same group of mushrooms points to a high similarity, irrespective of differences in the concentration of elements in the respective soils.

For tree-growing mushroom species, two groups of mushrooms with a similar content of all elements jointly were also indicated: i) with TM$_3$C, TM$_4$C, TM$_6$C, TM$_1$C and TM$_{10}$C, ii) with TM$_1$OC, TM$_9$OC, TM$_8$OC, TM$_2$C, TM$_5$OC, TM$_7$OC and TM$_6$OC (Fig. 5b). The second group

Table 3
Median values of element concentrations [mg kg^{-1} DW] in soil- and tree-growing mushroom species collected from the city (C) and beyond (OC).

Mushroom	Co	Cr	Cu	Er	Fe	Hg	Mn	Mo	Nd	Ni	Pb	Pr
Soil-growing mushroom species												
SM$_1$C	1.39^{c}	7.34^{b}	29.0^{b}	0.192^{b}	163^{b}	0.247^{c}	22.2^{b}	4.55^{b}	0.319^{b}	1.57^{a}	5.95^{b}	0.822^{b}
SM$_4$C	1.01^{c}	2.66^{c}	8.75^{d}	0.226^{a}	80.1^{c}	0.165^{d}	14.2^{c}	3.98^{c}	0.377^{b}	0.546^{c}	2.74^{c}	0.696^{c}
SM$_5$C	4.20^{d}	2.44^{c}	18.1^{bc}	0.169^{b}	248^{a}	0.519^{a}	33.4^{a}	6.20^{a}	0.398^{b}	0.398^{d}	2.78^{c}	0.922^{a}
SM$_6$C	5.71^{a}	8.89^{a}	64.5^{a}	0.039^{c}	252^{a}	0.334^{b}	19.4^{b}	1.87^{d}	2.53^{a}	0.920^{b}	8.49^{a}	0.341^{d}
SM$_1$OC	0.371^{d}	0.134^{d}	3.16^{c}	0.155^{a}	81.1^{a}	0.036^{d}	4.55^{b}	0.170^{c}	0.176^{c}	1.38^{a}	2.50^{b}	0.451^{b}
SM$_2$OC	0.866^{a}	3.53^{a}	4.95^{b}	0.098^{c}	61.8^{b}	0.061^{c}	3.93^{c}	0.332^{a}	0.384^{a}	0.257^{c}	4.32^{a}	0.632^{a}
SM$_3$OC	0.674^{b}	1.19^{b}	6.09^{a}	0.094^{c}	87.2^{a}	0.071^{b}	6.56^{a}	0.262^{b}	0.067^{d}	0.618^{b}	2.39^{c}	0.455^{b}
SM$_4$OC	0.560^{c}	0.611^{c}	2.75^{c}	0.125^{b}	39.5^{c}	0.088^{a}	2.13^{d}	0.157^{c}	0.224^{b}	0.305^{c}	2.07^{c}	0.367^{c}
Tree-growing mushroom species												
TM$_1$C	5.24^{a}	9.42^{a}	9.79^{c}	0.193^{b}	382^{a}	0.306^{d}	8.86^{d}	1.65^{b}	1.80^{a}	1.91^{b}	9.39^{c}	0.303^{c}
TM$_2$C	2.77^{b}	3.15^{d}	4.26^{e}	0.068^{d}	167^{c}	0.221^{e}	9.63^{d}	0.518^{c}	1.01^{b}	1.86^{b}	8.00^{e}	0.336^{c}
TM$_3$C	2.91^{b}	5.27^{c}	7.37^{d}	0.087^{d}	288^{b}	0.489^{a}	40.4^{b}	0.657^{c}	0.594^{c}	1.72^{b}	13.2^{a}	0.608^{b}
TM$_4$C	1.46^{c}	7.76^{b}	5.41^{e}	0.163^{c}	401^{a}	0.365^{c}	45.0^{a}	1.58^{b}	0.335^{d}	0.991^{c}	11.6^{b}	0.234^{d}
TM$_6$C	4.82^{a}	1.72^{e}	14.8^{a}	0.067^{d}	134^{c}	0.425^{b}	13.8^{c}	0.237^{d}	0.602^{c}	0.907^{c}	9.02^{cd}	0.141^{d}
TM$_{10}$C	2.60^{b}	8.10^{b}	13.1^{b}	0.279^{a}	308^{b}	0.337^{d}	14.8^{c}	1.92^{a}	0.552^{c}	2.74^{a}	6.99^{e}	0.956^{a}
TM$_1$OC	0.454^{d}	2.64^{b}	4.55^{cd}	0.065^{d}	91.5^{c}	0.081^{a}	3.64^{c}	0.295^{c}	0.147^{b}	0.380^{b}	1.27^{d}	0.236^{c}
TM$_5$OC	0.731^{b}	1.93^{c}	7.13^{b}	0.092^{c}	139^{a}	0.068^{b}	18.8^{a}	0.659^{b}	0.640^{a}	0.983^{a}	3.71^{b}	0.383^{b}
TM$_6$OC	0.487^{d}	3.43^{a}	0.958^{e}	0.041^{e}	50.9^{de}	0.087^{a}	1.78^{d}	0.406^{c}	0.098^{bc}	0.181^{d}	3.89^{b}	0.630^{a}
TM$_7$OC	0.960^{a}	2.76^{b}	8.53^{a}	0.127^{a}	42.4^{e}	0.053^{c}	3.05^{c}	1.21^{a}	0.065^{c}	0.236^{d}	4.53^{a}	0.637^{a}
TM$_8$OC	0.620^{c}	2.20^{c}	3.84^{c}	0.099^{bc}	107^{b}	0.049^{c}	8.85^{b}	0.292^{c}	0.137^{b}	0.084^{e}	2.92^{c}	0.385^{b}
TM$_9$OC	0.237^{e}	1.01^{d}	5.07^{c}	0.105^{b}	61.3^{d}	0.051^{c}	8.56^{b}	1.27^{a}	0.638^{a}	0.318^{c}	3.10^{c}	0.393^{b}

n = 3; identical superscripts (a, b, c) denote non-significant differences between means in columns (separately for particular mushrooms collected from city and beyond) according to the post-hoc Tukey's HSD test; TM, tree-growing species; SM, soil-growing species.

also included fruit bodies from the city and beyond, similar in the total content of elements, but this time of different species (*C. squamosus* – TM$_2$C, *A. auricula-judae* – TM$_1$OC, *F. betulina* – TM$_8$OC or *P. ostreatus* – TM$_9$OC).

Based on the described similarities, a comparison was performed for all soil- and tree growing mushroom species from inside and outside the city (Fig. 6). From the obtained results, two homogeneous groups were found, the first of which consisted of fruit bodies collected inside the city and the second those collected outside the city. The only exception was the previously mentioned L. *fumosum* (SM$_4$C), similar to mushrooms collected outside the city.

Soil-growing mushroom species collected from the city were characterised by significantly higher contents of Ag ($p < 0.01$), Fe, Hg, Mn, Mo, Sr, Y and Zn ($p < 0.05$) than mushrooms collected outside the city (Fig. 7). In tree-growing mushroom species from the city, significantly higher contents of Al, Hg and Pb ($p < 0.001$), Ba, Fe and Ni ($p < 0.01$), As, Cr, Sr, Ta and Zn ($p < 0.05$) were observed than in the fruit bodies collected from the rural area (Fig. 8).

5. Discussion

There is a decided common view of the cleanliness of the urban environment that leaves no illusions, clearly defining harmful anthropogenic activity using, e.g. the Air Quality Life Index. Air pollution in particular has contributed to the distribution of pollution, especially in cities near industrial plants (Strosnider et al., 2017; Hołtra and Zamorska-Wojdyła, 2020). Chemical analysis of the urban environment and areas located outside cities shows considerably higher

Table 4
Median values of element concentrations [mg kg^{-1} DW] in soil- and tree-growing mushroom species collected from the city (C) and beyond (OC).

Mushroom	Rb	Sb	Sc	Sr	Ta	Tl	Tm	V	W	Y	Zn	Zr
Soil-growing mushroom species												
SM$_1$C	25.7^{a}	1.83^{a}	0.013^{c}	5.98^{b}	5.89^{a}	0.498^{a}	0.452^{a}	0.220^{c}	7.94^{a}	0.045^{c}	86.4^{b}	0.246^{c}
SM$_4$C	14.9^{d}	0.381^{d}	0.384^{b}	2.92^{c}	4.31^{b}	0.529^{a}	0.267^{b}	0.161^{c}	0.995^{c}	0.098^{a}	31.9^{d}	0.521^{a}
SM$_5$C	27.0^{a}	0.739^{c}	0.038^{c}	9.51^{a}	1.53^{d}	0.423^{b}	0.148^{c}	1.09^{b}	6.64^{b}	0.044^{c}	66.7^{c}	0.085^{d}
SM$_6$C	18.1^{c}	1.14^{b}	0.425^{a}	5.72^{b}	2.98^{c}	0.415^{b}	0.310^{b}	2.09^{a}	0.171^{d}	0.063^{b}	95.2^{a}	0.315^{b}
SM$_1$OC	15.2^{b}	1.03^{a}	0.034^{d}	3.51^{a}	0.659^{c}	0.140^{c}	0.259^{a}	0.027^{c}	0.347^{c}	0.019^{b}	15.8^{b}	0.196^{b}
SM$_2$OC	12.1^{c}	0.543^{b}	0.176^{a}	1.57^{b}	0.835^{c}	0.308^{b}	0.097^{d}	0.083^{b}	0.565^{a}	0.013^{c}	17.2^{b}	0.324^{a}
SM$_3$OC	22.5^{a}	1.05^{a}	0.049^{c}	0.696^{c}	5.70^{a}	0.399^{a}	0.201^{b}	0.091^{a}	0.260^{d}	0.036^{a}	23.6^{a}	0.051^{c}
SM$_4$OC	9.60^{d}	0.539^{b}	0.125^{b}	0.931^{c}	2.44^{b}	0.151^{c}	0.173^{c}	0.030^{c}	0.415^{b}	0.019^{b}	17.4^{b}	0.309^{a}
Tree-growing mushroom species												
TM$_1$C	32.0^{c}	0.616^{c}	0.089^{d}	3.39^{e}	5.76^{a}	0.495^{a}	0.476^{a}	7.33^{a}	0.067^{e}	0.011^{e}	79.5^{a}	0.295^{a}
TM$_2$C	24.4^{d}	0.882^{b}	0.111^{c}	5.82^{d}	2.42^{d}	0.326^{b}	0.269^{d}	0.140^{b}	0.362^{c}	0.024^{d}	19.1^{e}	0.055^{de}
TM$_3$C	13.9^{e}	0.633^{c}	0.265^{b}	12.6^{a}	4.28^{b}	0.254^{c}	0.030^{e}	0.030^{b}	0.361^{c}	0.030^{c}	42.2^{cd}	0.246^{b}
TM$_4$C	11.5^{e}	1.23^{a}	0.026^{e}	10.3^{b}	2.88^{d}	0.350^{b}	0.358^{c}	0.244^{b}	1.40^{b}	0.032^{c}	51.7^{b}	0.069^{de}
TM$_6$C	44.5^{b}	0.590^{c}	0.357^{a}	3.34^{e}	1.74^{e}	0.164^{d}	0.334^{c}	0.097^{b}	2.19^{a}	0.042^{b}	36.0^{d}	0.131^{c}
TM$_{10}$C	62.6^{a}	0.794^{b}	0.016^{e}	8.84^{c}	3.76^{c}	0.269^{c}	0.421^{b}	0.170^{b}	0.220^{d}	0.057^{a}	48.8^{bc}	0.042^{e}
TM$_1$OC	39.4^{a}	0.455^{cd}	0.024^{cd}	3.04^{b}	0.746^{c}	0.182^{d}	0.609^{a}	0.055^{cd}	0.297^{c}	0.025^{cd}	9.58^{e}	0.050^{d}
TM$_5$OC	29.4^{bc}	0.524^{c}	0.035^{bc}	1.24^{d}	1.29^{b}	0.372^{a}	0.552^{b}	0.183^{b}	0.111^{d}	0.063^{a}	9.12^{e}	0.160^{c}
TM$_6$OC	12.6^{e}	1.45^{b}	0.018^{d}	3.50^{a}	1.57^{b}	0.225^{c}	0.351^{d}	0.068^{c}	1.09^{a}	0.022^{d}	29.5^{b}	0.227^{a}
TM$_7$OC	30.2^{b}	1.80^{a}	0.043^{b}	3.10^{b}	4.36^{a}	0.339^{a}	0.419^{c}	0.045^{cd}	0.421^{b}	0.028^{c}	32.2^{a}	0.209^{b}
TM$_8$OC	25.7^{c}	0.403^{cd}	0.024^{cd}	2.48^{c}	0.439^{d}	0.187^{cd}	0.117^{e}	0.810^{a}	0.124^{d}	0.046^{b}	26.9^{c}	0.039^{d}
TM$_9$OC	18.0^{d}	0.336^{d}	0.205^{a}	3.15^{b}	0.928^{c}	0.272^{b}	0.306^{d}	0.040^{d}	0.265^{c}	0.025^{cd}	14.5^{d}	0.051^{d}

n = 3; identical superscripts (a, b, c) denote non-significant differences between means in columns (separately for particular mushrooms collected from city and beyond) according to the post-hoc Tukey's HSD test; TM, tree-growing species; SM, soil-growing species.

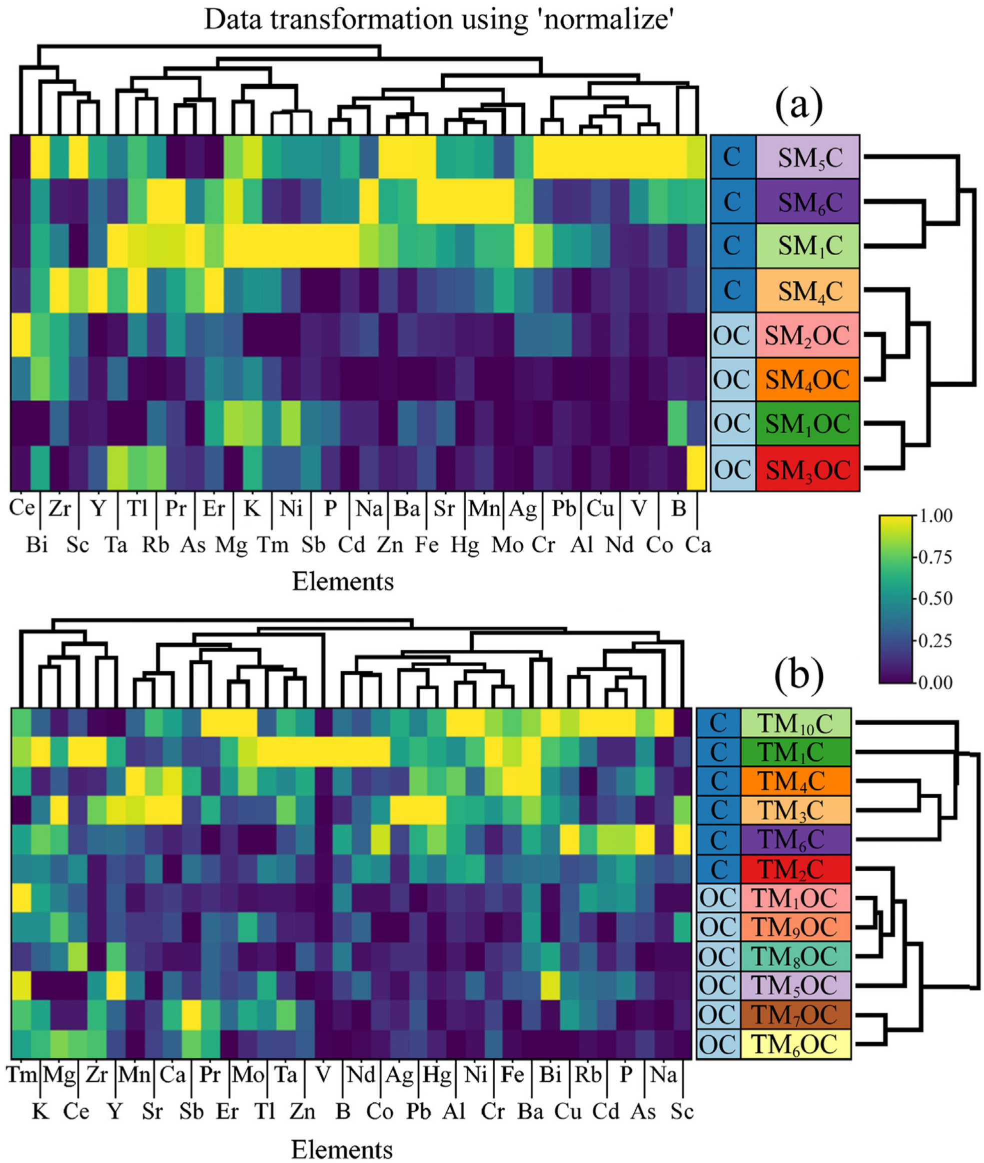

Fig. 5. Correlations between particular soil-growing (a) and tree-growing (b) mushroom species separately, concerning the content of all elements jointly (Heatmap) in median values with the presentation of a hierarchical tree plot.

concentrations of elements in the former (Reimann et al., 2017). The high concentration of toxic elements in soil and/or other urban environment components and especially the constant exposure to their presence may cause serious health issues (Tume et al., 2020). Nevertheless, parks, squares and lawns are still associated with greenery, and therefore appear to be a relatively clean area that inspires confidence. Such a psychological mechanism is not surprising but may have little to do with reality, which is especially the case in the proximity of roads as a consequence of road dust migration (Li et al., 2018). The presence of roads is of particular importance in the absence of acoustic screens placed on roads with significant traffic intensity (Różański et al., 2017). Unfortunately, in both urban and rural areas, soil- and tree-growing mushrooms also grow close to roads (Işiloğlu et al., 2001; Mleczek et al., 2016).

In these studies, significantly higher median values for Ca, Ba, Bi, Hg, Pb, Sb, Sr, W and Zr were found in the city soils compared to those found outside the city (Table S1). In soil-growing mushroom species from the city, significantly higher contents of Ag, Fe, Hg, Mn, Mo, Sr, Y and Zn were observed (Fig. 7). This suggests that higher concentrations of Hg and Sr in the soil caused a variation between these metal levels in fruit bodies, which was not found for the other elements. On the other hand, it may suggest that higher concentrations of elements in urban soils do not necessarily mean that their content in fruit bodies will be significantly higher than in areas outside the city, and vice versa. After all, the accumulation of elements by fungi depends on many different factors, including, in particular, soil chemistry (Melgar et al., 1998). An important factor stimulating or inhibiting the accumulation of elements by fungi may be the pH of the soils (Lalotra et al., 2016). In the examined soil samples from the city, pH ranged between 6.91 and 7.85 with a median of 7.33, while pH of soils outside the city was between 4.22 and 6.30 with a median of 4.78. This may explain the observed differences in the enrichment of fruit bodies with elements or not. Lower pH values of rural soils with a significantly lower concentration of selected elements could result in their higher accumulation due to their greater availability. The same alkaline pH of soil may be a significant factor limiting element availability and finally, accumulation in mushrooms, which for Cd in oyster mushrooms was clearly described by Yang et al. (2005). It should be emphasised that it is not only pH that can modify the accumulation of elements by fruit bodies; other parameters, such as dissolved organic carbon, can also affect element accumulation (Hernandez-Soriano and Jimenez-López, 2012), although they were not analysed in our studies.

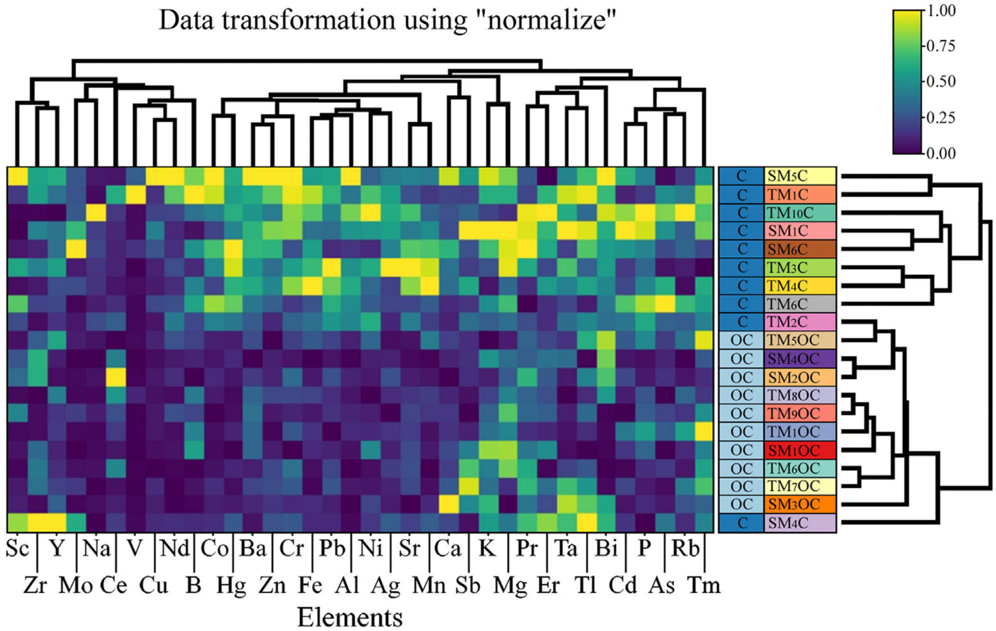

Fig. 6. Correlations between all soil-growing and tree-growing mushroom species concerning the content of all elements jointly (Heatmap) in median values with the presentation of a hierarchical tree plot.

An explanation for the observed discrepancies in tree-growing mushroom species is much more difficult due to the presence of different tree species that provide a source of elements for them. In this case, differences in soil pH were clearly diverse (between 6.88 and 7.62 with median 7.07 for samples from the city and between 3.97 and 5.97 with median 4.56 for soils outside the city). Moreover, these differences may directly influence metal phytoextraction by trees (Sheoran et al., 2016). According to Javed et al. (2013), a high soil pH may be correlated with a high concentration of organic acids which may acidify the rhizosphere. This could decisively limit metal phytoextraction. It is most likely that for this reason, despite the significantly higher median values for Ag, Bi, Ce, Co, Mn, Mo, Nd, Pr, Ta, Tm and W concentration in the city tree species, only Ta had a significantly higher content in tree-growing mushroom species. On the other hand, significantly higher Ba, Hg, Pb, and Sr concentrations in city soils were reflected in a significantly higher content of these metals in city tree-growing mushrooms. This may suggest that mushrooms can regulate the number of accumulated elements, and trees are more a reservoir of elements than a component that regulates the amount of elements transported to the fruit bodies (Falandysz and Borovička, 2013).

The obtained results clearly divide the studied mushrooms into two groups depending on their place of origin, which suggests that regardless of their form of growth (soil/tree), city mushrooms contain higher total element contents than those from rural areas.

Adequate Intakes (AIs) are estimated for the reference body weights for men and women (68.1 and 58.5 kg, respectively) (EFSA NDA Panel, 2013). For several elements determined in this study, AIs have been established (mg per day): Ca (950), K (3500), P (550), Cu (1.6), Fe (11), Mn (3.0), Mo (0.065) and Zn (11.7) (EFSA, 2017). Taking as a starting point one meal a day of 200 g of fresh mushrooms, which approximately corresponds to 20 g of dried matter, the ranges being the lowest and the highest percentage share of metal in AIs, for city soil-growing mushroom species they were as follows: 1.9–4.7, 14.8–25.6, 2.7–4.4, 5.8–25.7, 10.1–91.6, 11.7–45.5, 7.9–23.0, 55.5–214 and 5.0–19.3% for Ca, K, Mg, P, Cu, Fe, Mn, Mo and Zn, respectively. The presented data give evidence that only Mo was present in amounts exceeding the established value of AIs. The only exception was *T. equestre*, characterised by a relatively high content of Mo (median 6.37 mg kg^{-1}). Due to limited data on the Mo content in this species, the determined content appears high when compared with the studies of Turfan et al. (2018), where its mean content in *Tricholoma terreum* was barely 0.43 mg kg^{-1}. A number of questions have arisen concerning the toxicity of this species, although Rzymski and Klimaszyk (2018) have suggested it should not be considered a toxic mushroom. Thus, the intake of this mushroom species from the city is not associated with a serious risk to human health or life with respect to Mo content. Moreover, it is not significantly higher than the suggested AIs value.

In the soil-growing mushroom species collected outside the city, ranges for the elements mentioned above were: 1.1–5.1, 5.9–22.7, 2.0–4.1, 6.3–12.7, 3.4–8.1, 6.3–15.7, 1.3–4.6, 5.1–9.6 and 2.5–4.0%, respectively, clearly indicating that the content of these elements accumulated by these mushroom species is significantly lower than the AIs for all these elements.

Unfortunately, the studied fruit bodies also contain other elements, including toxic heavy metals, for which there are still no relevant legal regulations; existing regulations are limited to only some heavy metals. The maximum level for Cd, Hg and Pb (by categorising them into food supplements) in foodstuffs such as mushrooms is 1.0, 0.1 and 3.0 mg kg^{-1} DW, respectively (EC, 2008). This indicates that an intake of 200 g of fresh mushrooms is not related with any potential risk for humans, independently of the place in which the fruit bodies were collected. A similar situation for Tolerable Daily Intake (TDI) found at 2.8 μg kg^{-1} bw was observed for Ni (Efsa, 2015) or 7 mg kg^{-1} DW of rare earth elements (SAC, 2012). For numerous other elements, it is difficult to discuss high or low contents due to the present lack of scientific opinion on their effects on human health.

6. Conclusions

The results obtained in this paper clearly show differences in the content of several elements between soil- and tree-growing mushroom species collected inside and outside the city. The content of elements determined in both groups of mushrooms was lower than the reference values of Adequate Intakes. It was unequivocally stated that the influence of the city and the pollutants migrating within it might be related to a higher content of certain elements in the fruit bodies. However, those collected from the city area showed a significantly higher content

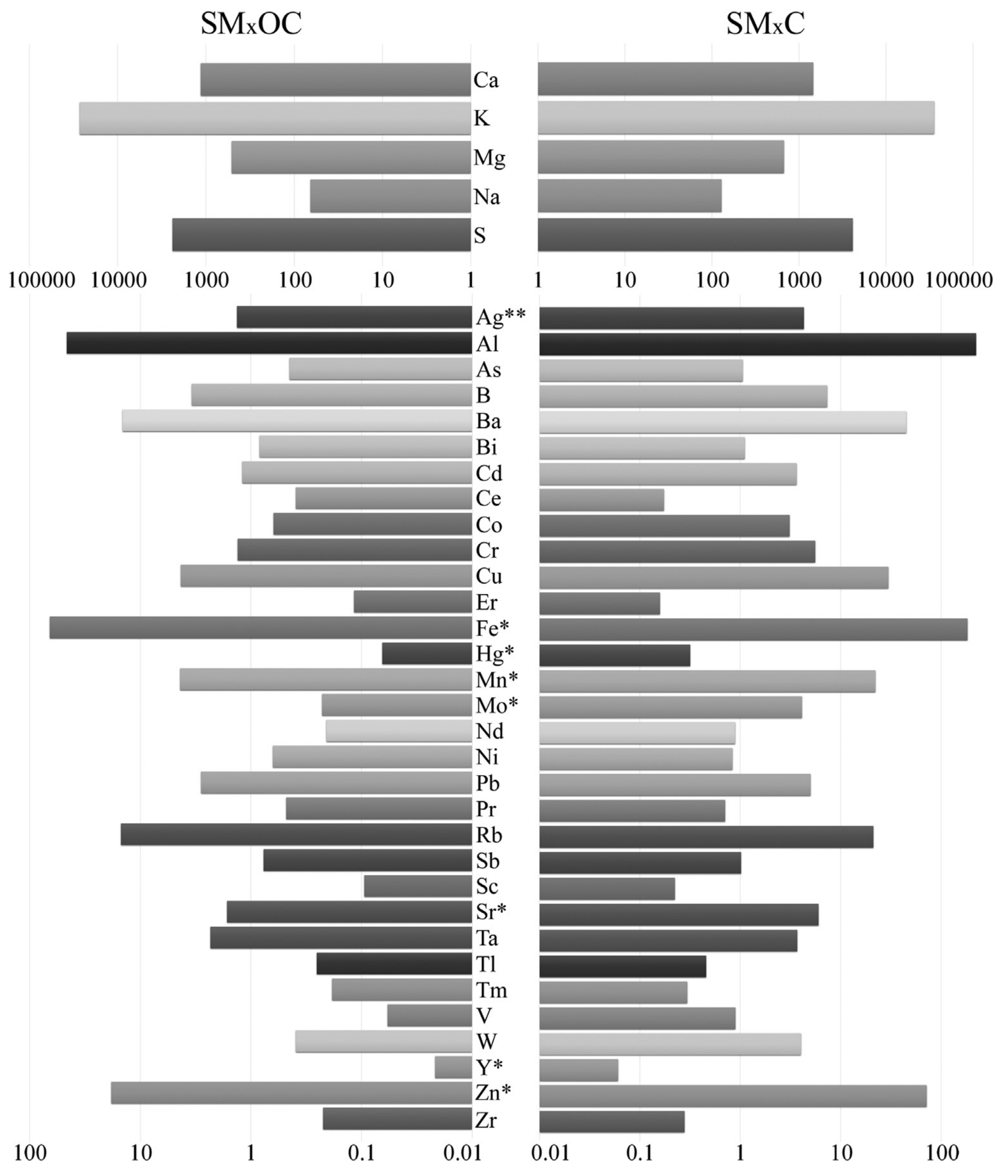

Fig. 7. Medians and differences in element concentration [mg kg^{-1} DW] in soil-growing mushroom species collected from the city (SM_xC) and outside the city (SM_xOC). ** <0.01, * <0.05.

in the case of most of the other metals/metalloids (arsenic). It should be remembered that the mineral composition of mushrooms is a derivative of many different environmental factors, but it is also influenced by anthropogenic activity. Although the results of this study reliably reflect the existing relationships, anomalies may occur. These can be related both to the presence of parent rock, rich in elements, as well as to a significantly higher intensity of road traffic, which is a significant source of toxic elements.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.151162.

CRediT authorship contribution statement

Mirosław Mleczek: Conceptualization, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Anna Budka:** Data curation, Visualization. **Marek Siwulski:** Conceptualization, Formal analysis, Funding acquisition, Supervision, Writing – original draft. **Sylwia Budzyńska:** Conceptualization, Formal analysis, Investigation. **Pavel Kalač:** Supervision, Writing – original draft. **Zbigniew Karolewski:** Funding acquisition, Writing – original draft. **Marta Lisiak-Zielińska:** Data curation, Visualization. **Natalia Kuczyńska-Kippen:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Przemysław Niedzielski:** Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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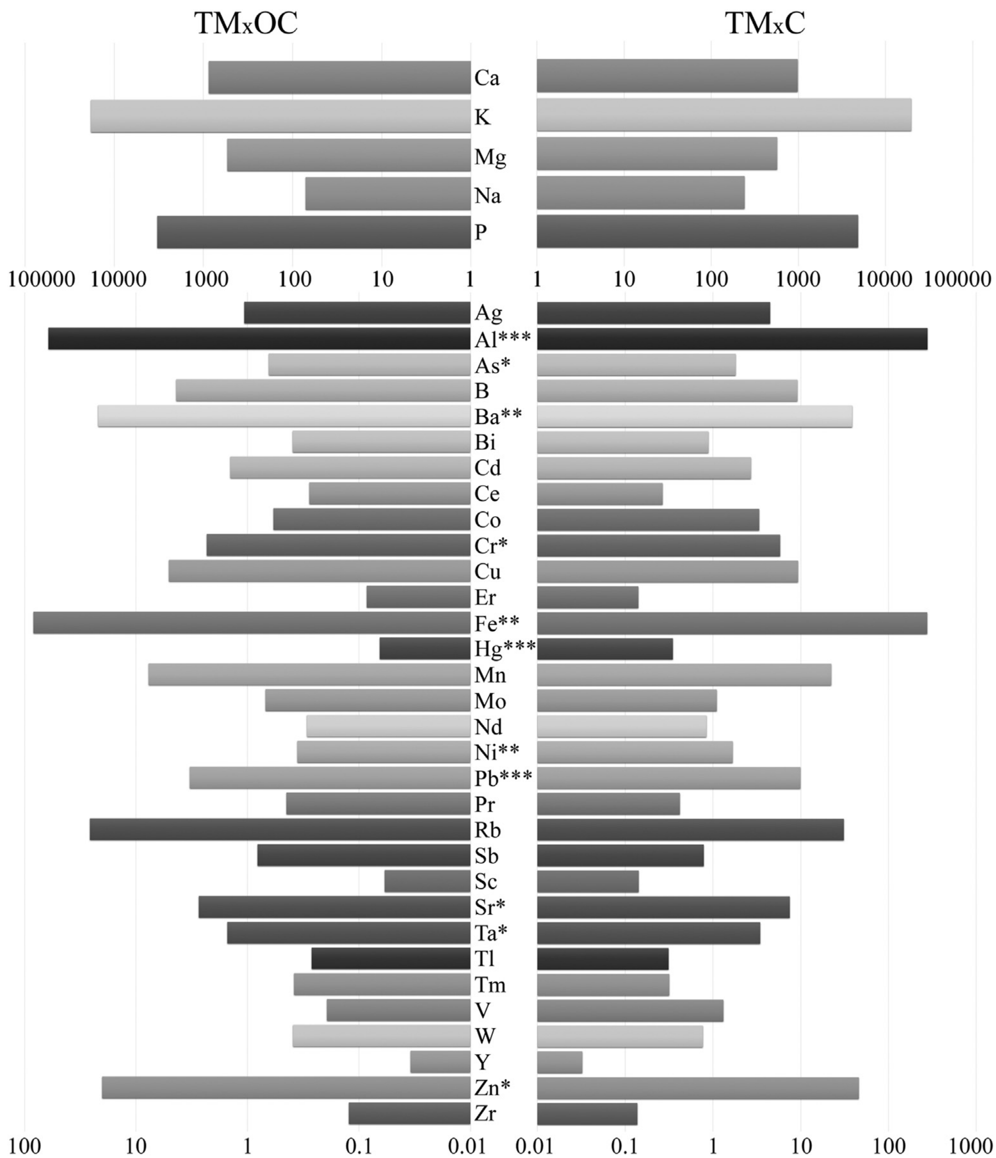

Fig. 8. Medians and differences in element content [mg kg^{-1} DW] in tree-growing mushroom species collected from the city (TM_xC) and outside the city (TM_xOC). *** <0.001, ** <0.01, * <0.05.

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