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Selected elements in fruits of *Sorbus aucuparia* in the Tatra Mountains and urbanized areas of its foreland

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Abstract. *Sorbus acuparia* is an important pioneer tree for the ontogeny of forest stands, and its fruits can be an important food source for animals during periods of scarcity of their primary food. In the present work, we focused on different elements (trace and nutrient) in rowan fruits in 11 Tatra valleys. Fruits were also collected in urban areas around the Tatra Mountains. A total of 150 samples were collected and evaluated. We analyzed the relationship of element accumulation with altitude and compared sites and fruits from urban centers. The whole process may be influenced by anthropogenic human activities that increase these concentrations in the air. Clear representatives of such activities are enterprises and factories located in the adjacent parts of large cities such as Poprad, Liptovský Mikuláš, Ružomberok and others. Increased concentrations of metals such as Cl, Ca, and Hg were found in these cities and, conversely, metals such as S, Mn, Rb, and Pb were predominant in the mountains. When comparing the northern and southern parts of the valleys, it was the valley samples from the northern parts of the mountains that were more contaminated with pollutants than the southern ones. Finally, we also showed a relationship between the contaminated samples obtained along major roads and hiking trails.

Key words: Sorbus acuparia, fruits, elements, heavy metals, effect of elevation, Tatra Mountains

Introduction

Today, many ecosystems and natural environments are affected by heavy metal pollution. The need to measure, investigate and eliminate these sources of pollution are activities that are receiving increasing emphasis. The genus *Sorbus*, in the broad sense, is widespread in northern temperate regions, and includes almost 200 species in Europe alone (Sennikov and Kurtto 2017). *Sorbus aucuparia* is a small to medium-sized deciduous tree that usually grows to a height of 10 m in the lowlands to the upper tree line in the mountains of Europe. *S. aucuparia* grows well in harsh high mountain climates with high altitudes and thrives on both dry and moist soils. It is often used for reforestation of mountainous areas. Its timber is used for furniture, veneer, pulp production and as firewood. The fruits are popular and important food components for birds as well as for some mammals and play an important role, particularly during winter, or in mountainous areas (Chalupa 1979). The tree is propagated mainly by seeds, so it must be stratified for a long time (e.g., 5-7 months in moist sand) before germination. The *S. aucuparia* is a broad-leafed deciduous species with relatively large, fleshy and distinctly colored fruits, mainly dispersed by birds (Sernander 1901; Birger 1907). *S. aucuparia* as an indicator of air pollution is a tree that stands out for its ability to absorb metals in its fruits, bark, roots and leaves (Malá *et al.* 2007). It is also a good indicator because it grows in urbanized areas. The manifestations of damage on leaves of different tree species are different (Wohlgemuth *et al.* 2002; Vollenweider *et al.* 2003). *S. aucuparia*, for example, exhibited necrosis on the leaf blade. All these symptoms may be indicative of direct damage to leaf tissue by toxic concentrations of iron, manganese, nickel, and chromium (Markert *et al.* 2000). The absorption capacity of leaf discs is particularly high; large amounts of dust particles can settle on the surface and pollutants penetrate the leaf itself through the stomata (Mitchell *et al.* 2010). The mountain ecosystems in which these trees grow are very fragile and it is therefore essential to protect them. Nevertheless, their ecological importance is widely recognized, for example, as a substrate for lichens (Kuusinen 1994; Bendiksen *et al.* 2008; Holien and Prestø 2008; Hilmo *et al.* 2011). In addition, authors from Finland report that rowan berries are an important food source for fruit-eating birds in urban areas (Suhonen and Jokimäki 2015). The research and work that has been done in this area is often based on various indicators that reflect the true state of nature. Anthropogenic activities in urbanized areas of countries contribute significantly to discharge of heavy metals into the environment. These are mostly toxic metals that are hazardous to the health of fauna and flora

In this paper, we focus on one species, namely the rowan (*Sorbus aucuparia*), which is a typical representative of both high-altitude pollution and pollution in large cities. Significantly, we can clearly point out pollution of mountainous areas in a given territory through the trees that grow there.

These trees are not only able to grow in this environment, but also produce "fruit" that is saturated with heavy metals. Fruit production is higher in open spaces than in forests or borders (Kutsko *et al.* 1982). Through this material we can demonstrate, how much these areas are polluted in contrast to lowland areas. The discharge of pollutants causes extensive organic pollution, toxic pollution, and eutrophication, along with severe ecological destruction (Miao *et al.* 2012). It can also offer us information about how animals feed on these contaminated fruits and how these elements react to organisms and animals (or, for example, birds). Many factors also affect the diversity of the project, namely weather, altitude, humidity and other variables.

Increasing contamination of natural environments does not respect specially protected areas such as national parks. Due to their special importance for science, education, and recreation, anthropogenic factors that damage some elements of nature are investigated and characterized. The threat to national parks is related to increasing industrialization and the influence of larger cities in the Slovak Republic. Contemporary studies have shown that air pollution can shorten the life of those exposed to higher concentrations by 1 to 2 years (Brunekreef and Holgate 2002). Every year, the High Tatras are exposed to a large number of heavy metals captured by precipitation from the north and exposed to industrial emissions more so than the lowlands of Slovakia. We selected *S. aucuparia* as a bioindicator in this study. It covers the area up to the northern boundary of the forest and extends into the rhizosphere zone. In Scandinavia, *S. aucuparia* is common up to the subalpine birch-forest zone (Nilsson and Nilsson 1987) and small shrubs can be found high above the forest line (Lid 1979; Kullman 1986). On the other hand, rowan have also been studied at lower latitudes, directly in and around towns below the High Tatras. The proportion of rowan trees on sites and the intensity of their accumulation varied clearly with altitude (*S. aucuparia*) (L. var. *glabrata* Wimm). No bias was detected with respect to the aspect of unshaded sites, but on shaded sites young trees are recorded more frequently on north-facing slopes (Grime *et al.* 1988).

The objectives of this research are to analyse concentrations of heavy metals in rowan fruits. Furthermore, we are interested in determining the differences in heavy metal accumulation depending on environment and altitude, as well as to evaluate concentrations of heavy elements for animal and human health and development.

Material and Methods

The main part of our study area consisted of the Tatra National Park, the territory of which is divided into two regions of Slovakia, namely the Žilina and Prešov regions. We investigated 31 sites (Fig. 1), including sites of regional and district major towns as well as mountain settlements near the national park. Study areas included large industrial towns such as Žilina, Námestovo, Martin, Ružomberok, Liptovský Mikuláš, and Poprad, as well as mountain settlements including Východná, Štrbské pleso, Tatranská Lomnica, and Ždiar. Samples were collected in the Tatra Mountains along main valleys including Jamnická, Račkova, Bystrá, Kôprová, Mengusovská, Velická, Malá studená, Kežmarská Biela voda, Dolina Bielych plies, Predné and Zadné Meďodoly, Monkova, Javorová and Bielovodská (from west to east).

Samples of rowan fruits were collected consecutively from mid-September to November. The samples used in the experiment were fruits without pedicel, collected directly from the tree of a given individual. A total of one handful was collected for each sample per individual tree. In each valley, we collected between 4 and 15 samples according to length of the valley. The spacing between samples was approximately 150 m up to the elevation of the tree line. The last samples were also taken above the forest belt in the sub-alpine zone (covered by stands of *Pinus mugo*). Individual samples were placed in sterile plastic bags and stored in the laboratory refrigerator following field work. This survey contained a total of 150 samples from several locations.

Before processing, collected samples of rowan fruits were washed in de-ionized water, as the expected evaluation focused on accumulated ele-

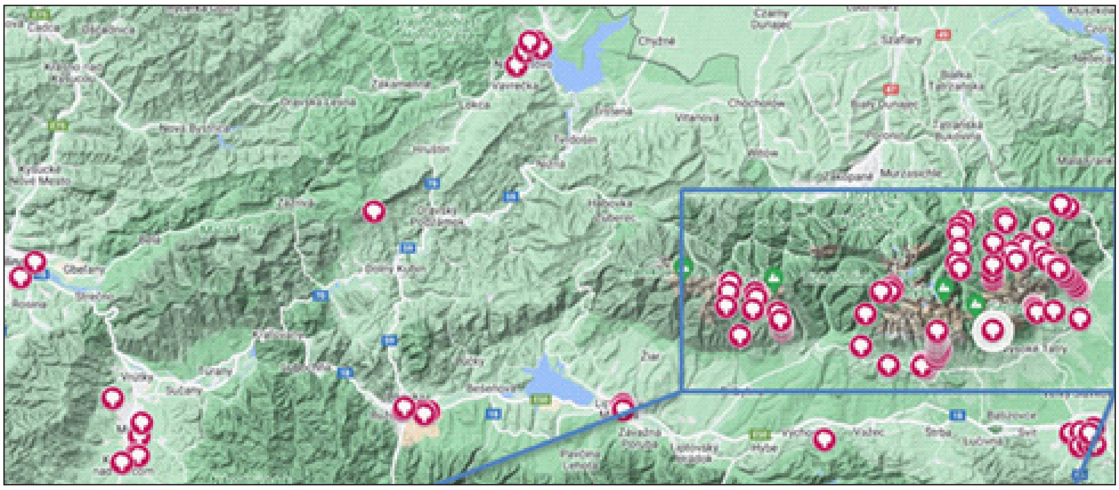


Fig. 1. Study sites where *Sorbus aucuparia* berries were sampled. (Source: Google maps database, 2022).

ments in rowan fruits. Next, they were placed in petri dishes and dried at 30% humidity and 30° C for 3-4 weeks, to prevent evaporation of the elements (especially Hg). After drying, the material was crushed into a fine powder using a CryoMill (Retsch, Germany). The fine powder of rowan fruits was consequently analyzed by X-ray fluorescence using a DELTA CLASSIC (Olympus, USA) hand-held XRF spectrometer with portable workstation. Samples of fine powder were analyzed in plastic vials filled with powder to 15 mm. The XRF spectrometer used a multiple beam technique in which each measurement consists of three beams emitted for a few seconds, repeated three times and then averaged. Initially, we tested randomized samples to variations of measurements in different time intervals per one beam. In total, three beams were emitted, resulting in variations of nine measurements. With a setting time of 110 seconds per beam we achieved the lowest variations for individual measurements below 10%. Therefore, our samples were measured on Default mode at 110 seconds per beam, measured three times and then averaged. Calibration of the device was conducted before each measurement, with a standard calibration coin included with the equipment. The resulting values were measured in units of ppm. Using this process, we measured and evaluated the following elements: S, Cl, K, Ca, Cr, Mn, Rb, Mo, Ba and Pb. After XRF measurement, the samples (same powder) were analyzed for precise mercury levels by a Direct Mercury Analyzer DMA-80 (Milestone, Italy).

The measured data were exported from the measuring devices into a simple matrix, which was supplemented with other descriptive information such as elevation, location (coordinates), name of the collection site, and sample identification between investigated groups. The data were split between natural and urban sites, samples collected along hiking trails and roads in TANAP, and data collected from southern and northern valleys. Urban sites included: Žilina, Martin, Liptovský Mikuláš, Poprad, Tatranská Lomnica, Ždiar and Štrbské pleso. Natural sites included samples collected in all investigated valleys. Northern valleys included: Javorová, Bielovodská and Predné Meďodoly. Southern valleys included: Jamnická, Račkova, Bystrá, Kôprová, Mengusovská, and Kežmarská Biela voda.

The data was further evaluated in Statistica 8 (Statsoft, USA). We did not exclude outliers. According to the Shapiro-Wilks test, data on element concentrations obtained from measurements were not normally distributed, except for S, K, and Mo. Therefore, prior to examination of differences between groups, we tested normality in each group. Elements with normal distribution were then assessed by t-test and elements with abnormal distribution were evaluated by the Mann Whitney U test. We also compared differences between selected valleys; Jamnická, Račkova, Bystrá, Kôprová, Mengusovská, Kežmarská Biela voda, Javorová and Bielovodská. In this comparison we used the Kruskal Wallis H test.

Results

Out of a total of 32 elements that the delta instrument is capable of measuring, we successfully measured 10 (S, Cl, K, Ca, Cr, Mn, Rb, Mo, Ba and Pb) in *Sorbus aucuparia* fruits. The highest measured element in *S. aucuparia* fruit was potassium (15402 ppm) and the lowest measured element was mercury (0.0043 ppm), measured additionally by a direct mercury analyzer (Table 1). These elements were present in varying degrees depending on where the tree was located. Both more and less polluted sites were compared. Generally, element concentrations in the fruits followed this order: K> Ca>Cl>S>Mn>Rb>Ba>Cr>Pb>Mo>Hg.

The urban samples represent samples collected in urbanized areas (i.e., cities and municipalities) within a respective distance of the High Tatras. There were 38 of these samples. An additional 112 samples were evaluated as Natural from

All	Valid N	Mean	Median	Minimum	Maximum	SD	SE
Elevation	150	1123.86	1260.00	370.00	1725.00	395.413	32.285
S	150	326.73	324.00	197.00	555.00	69.595	5.682
Cl	150	502.46	481.00	352.00	1492.00	129.041	10.536
K	150	15,402.17	15,286.00	6240.00	30,681.00	3900.908	318.508
Ca	150	3105.57	2883.50	1302.00	7216.00	1195.300	97.596
Cr	150	11.84	10.50	3.20	35.00	5.067	0.414
Mn	150	121.57	76.00	15.90	680.00	119.639	9.769
Rb	150	44.54	37.30	9.90	145.00	27.576	2.252
Mo	150	5.15	5.10	3.30	7.50	0.678	0.055
Ba	150	30.01	27.00	11.00	88.00	12.632	1.031
Pb	150	10.80	10.80	6.60	18.00	2.105	0.172
Hg	150	0.0043	0.0036	0.0012	0.0183	0.0026	0.0002

Table 1. Descriptive statistics for elements measured in samples of rowan fruits and for elevations of samples (all samples). It provides information on the number of valid values, mean, median, minimum and maximum values, standard deviation (SD), and standard error (SE) of the mean values.

natural and low human-impact areas. The results (Table 2, Fig. 2a, b) show that significantly higher concentration of elements, including S, Mn, Rb, and Pb were measured in rowan fruits collected from natural areas. In urban areas, higher concentrations of Cl, Ca, and Hg were found. The most abundant elements at both sites were potassium (K), followed by calcium (Ca).

Another group of selected samples consisted of samples that were collected close to main roads (N = 61) and samples that were located close to hiking trails in valleys (N = 89). The fruits of *S. aucuparia* in places near hiking trails had significantly higher concentrations of S, K, Mn, Rb, and Pb than along the main roads. Along the main roads, significantly higher concentrations of Cl and Ca were measured (Table 3, Fig. 3a, b).

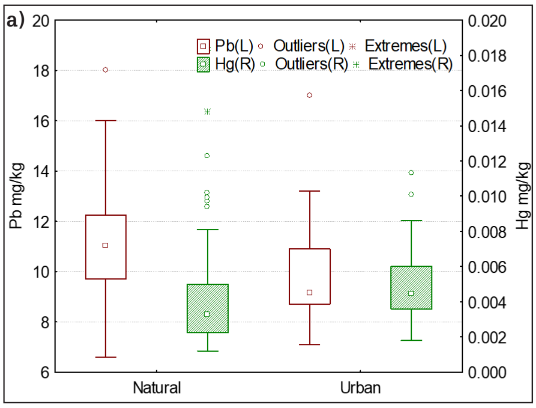
To compare the accumulation of the elements in rowan fruits on the windward side (north) and leeward side (south) of Tatra Mountains, we selected samples from the eastern Tatra Mountains and divided them into two groups. The north group were

Elements	Area	N	Mean (SE)	p
S	nature	112	333.32 (6.71)	**0.0459**
	urban	38	307.29 (10.06)	
Cl	nature	112	479.53 (4.74)	**0.0480**
	urban	28	570.05 (37.42)	
K	nature	112	15713.33 (368.50)	0.0936
	urban	38	14485.08 (617.63)	
Ca	nature	112	3046.63 (122.12)	**0.0288**
	urban	38	3279.32 (135.83)	
Cr	nature	112	12.10 (0.48)	0.1354
	urban	38	11.08 (0.78)	
Mn	nature	112	142.38 (11.56)	**0.0001**
	urban	38	60.21 (14.05)	
Rb	nature	112	53.09 (2.54)	**0.0001**
	urban	38	19.37 (0.76)	
Mo	nature	112	5.11 (0.06)	0.2781
	urban	38	5.25 (0.11)	
Ba	nature	112	30.35 (1.26)	0.8357
	urban	38	29.03 (1.64)	
Pb	nature	112	11.11 (0.19)	**0.0006**
	urban	38	9.89 (0.30)	
Hg	nature	112	0.004 (0.0003)	**0.0006**
	urban	38	0.005 (0.0003)	

Table 2. Differences in element accumulations between urban and natural environment (differences computed by M-W U test, for S, K and Mo by t-test). The significant values are in bold.

Elements	Area	N	Mean (SE)	p
S	trail	89	343.43 (7.35)	**0.0005**
	road	61	302.36 (8.05)	
Cl	trail	89	479.39 (5.01)	**0.0077**
	road	61	536.11 (24.33)	
K	trail	89	16044.24 (420.75)	**0.0264**
	road	61	1465.39 (464.76)	
Ca	trail	89	3019.35 (140.98)	**0.0328**
	road	61	3231.38 (123.22)	
Cr	trail	89	12.06 (0.54)	0.4306
	road	61	11.53 (0.63)	
Mn	trail	89	145.62 (13.52)	**0.0005**
	road	61	86.48 (12.52)	
Rb	trail	89	51.71 (2.89)	**0.0001**
	road	61	34.06 (3.14)	
Mo	trail	89	5.10 (0.07)	0.2761
	road	61	5.22 (0.08)	
Ba	trail	89	30.20 (1.46)	0.7552
	road	61	29.74 (1.37)	
Pb	trail	89	11.05 (0.22)	**0.0446**
	road	61	10.42 (0.25)	
Hg	trail	89	0.004 (0.0003)	0.0638
	road	61	0.004 (0.0003)	

Table 3. Differences in element accumulations between sites close to roads or hiking trails (differences computed by M-W U test, for Cl, Mo and Pb by t-test). The significant values are in bold.



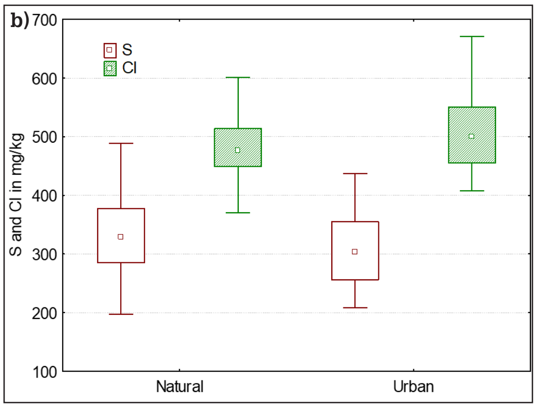


Fig. 2. Differences of element accumulations a) Pb and Hg; b) S and Cl in rowan fruits between urban and natural environment (Median; Box: 25%-75%; Whisker: Non-Outlier Range).

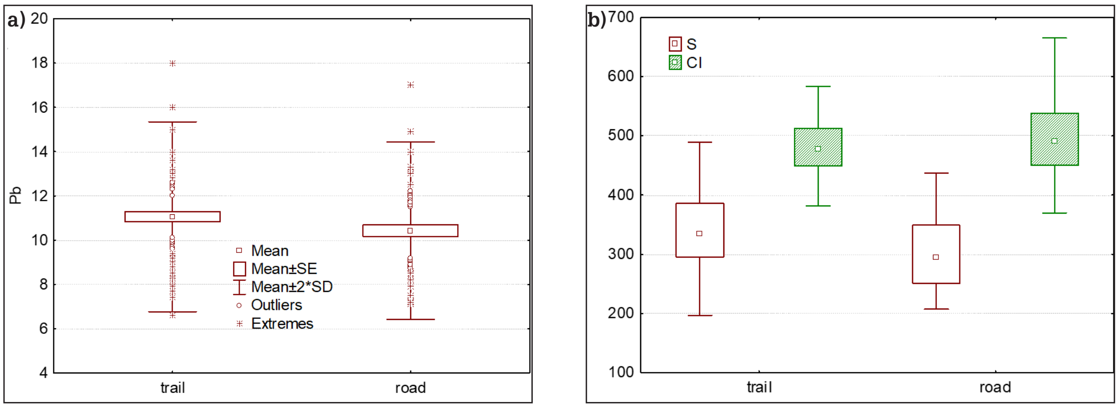


Fig. 3. Differences of element accumulations a) Pb; b) S and Cl in mg/kg in rowan fruits between sites close to roads and hiking trails (Median; Box: 25%-75%; Whisker: Non-Outlier Range).

associated with northern valleys including Javorová dolina, Bielovodská dolina, Predné Meďodoly. The southern group were associated with southern valleys including Jamnická, Račkova, Bystrá, Kôprová, Mengusovská, and the valley of the Kežmarskej Bielej vody. The differences in element accumulations on the northern and southern sides were almost insignificant (Table 4). On the northern side, only S and Ca were significantly higher in rowan fruits (Fig. 4).

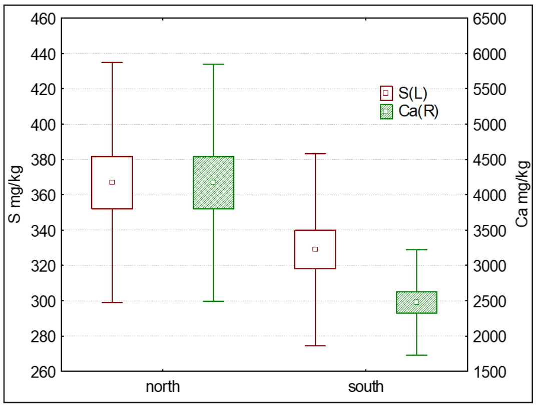


Fig. 4. Differences of S and Ca accumulations in rowan fruits between north and south sides of the Tatra Mountains (Median; Box: 25%-75%; Whisker: Non-Outlier Range).

In this section we compared the main Tatra Mountains valleys (Jamnická, Račkova, Bystrá, Kôprová, Mengusovská dolina, Dolina Kežmarskej Bielej vody, Javorová dolina and Bielovodská dolina). Of all the valleys, rowan fruits collected from Javorová dolina contained higher values of almost all elements except Mn and Hg (Table 5). Concentrations of Cl, K, Ca, Cr, and Ba were the highest there. On the other hand, the lowest concentrations of elements were measured in Jamnická dolina. The highest values of heavy elements such as Hg and Pb were observed in rowan fruits collected from Dolina Kežmarskej Bielej vody. However, significant differences between valleys were confirmed for Ca, Mn, and Rb. The levels of Ca were significantly higher in Javorová dolina (Fig. 5). In addition, levels of Mn and Rb were significantly lowest in Bielovodská dolina (Fig. 6 and 7).

Discussion

This study assessed and determined the extent of accumulation of trace elements and some heavy metals in rowan fruits grown in high-altitude eco-

Elements	Side	N	Mean (SE)	p
S	north	21	366.86 (14.81)	**0.0412**
	south	25	328.92 (10.88)	
Cl	north	21	499.33 (11.50)	0.2075
	south	25	482.64 (7.06)	
K	north	21	17686.23 (945.42)	0.1309
	south	25	15593.24 (739.44)	
Ca	north	21	4170.52 (366.52)	**0.0002**
	south	25	2474.60 (149.96)	
Cr	north	21	15.28 (1.52)	0.0834
	south	25	11.77 (0.79)	
Mn	north	21	162.67 (31.90)	0.1074
	south	25	110.88 (18.39)	
Rb	north	21	55.05 (6.73)	0.7575
	south	25	50.96 (6.64)	
Mo	north	21	5.21 (0.15)	0.7778
	south	25	5.27 (0.11)	
Ba	north	21	38.52 (4.42)	0.0916
	south	25	28.32 (2.12)	
Pb	north	21	11.85 (0.54)	0.5293
	south	25	11.43 (0.39)	
Hg	north	21	0.0037 (0.005)	0.1148
	south	25	0.0051 (0.007)	

Table 4. Differences in element accumulations between sites on windward side (north) and leeward side (south) of Tatra Mountains (differences computed by M-W U test, for Pb). The significant values are in bold.

Valleys	Jamnická dolina	Račkova dolina	Bystrá dolina	Kôprová dolina	Mengusovská dolina	Dolina Kež. Bielej vody	Javorová dolina	Bielovodská dolina	K-W H p value
Valid N	6	4	16	6	15	14	8	6	
S	341	329	380	321	296	317	361	348	0.0901
Cl	457	496	490	470	489	494	499.	480	0.8493
K	17055	12718	16562	13891	14732	16064	18428	16454	0.1970
Ca	2640	2092	2728	3534	3318	2478	5257	3786	**0.0015**
Cr	10.8	9.7	12.0	11.7	13.5	13.4	16.5	15.5	0.4349
Mn	133	263	172	265	130	106	142	88	**0.0416**
Rb	57.7	63.9	52.0	57.0	63.4	50.5	63.3	26.4	**0.0150**
Mo	4.6	5.1	4.9	5.0	5.4	5.5	5.3	5.1	0.0611
Ba	24.7	25.3	30.8	35.7	30.6	33.6	52.9	31.3	0.1062
Pb	10.3	10.9	11.1	10.4	11.8	12.0	11.8	10.8	0.1673
Hg	0.002	0.004	0.004	0.003	0.004	0.006	0.003	0.005	0.1587

Table 5. Mean values of elements accumulated in rowan fruits from selected valleys in the Tatra Mountains. The significant values are in bold.

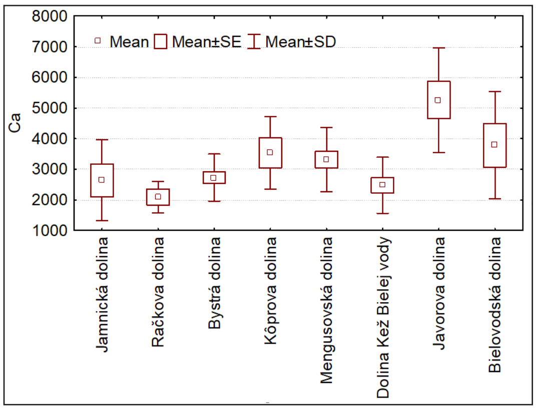


Fig. 5. Comparison of calcium accumulation across eight valleys. The valleys are shown at the bottom of the graph, the element values are on the left.

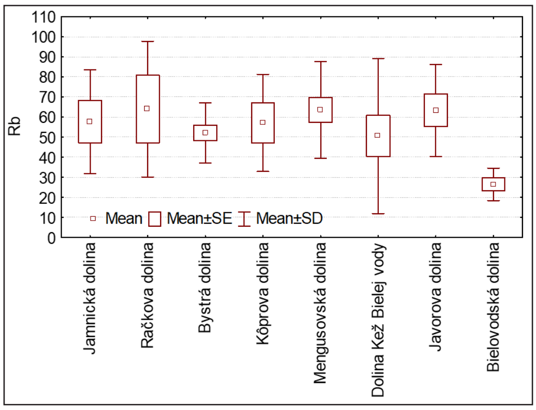


Fig. 7. Comparison of rubidium accumulatio across eight valleys. The valleys are shown at the bottom of the graph, the element values are on the left.

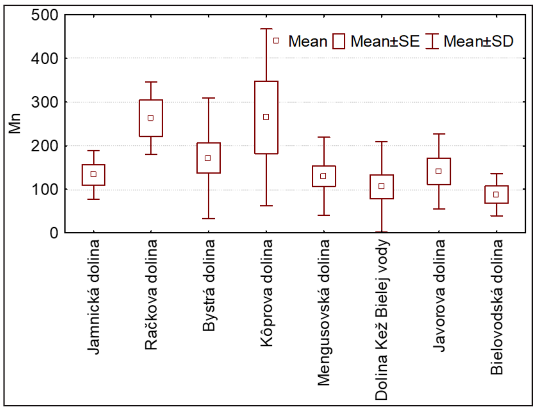


Fig. 6. Comparison of eight valleys by manganese. The valleys are shown at the bottom of the graph, the element values are on the left.

systems. These elements can bind to particles and transport them thousands of kilometers by air flow, where they are deposited again through dry or wet deposition, ultimately resulting in high environmental burden concentrations (Janhäll 2015; Li *et al.* 2017; Lazo *et al.* 2018). Overall elements/pollution load were compared between sites in urbanized environments, where people have a large impact on the surrounding environment and the natural environment compared to higher up in the mountains where lower levels of pollution should be evident. We also compared samples of *Sorbus aucuparia* fruits for sites close to major roads, where there is a higher concentration of cars and motor emissions at the site. Finally, areas in the north and south of the High Tatras were also surveyed. Slightly higher up in the valleys, we also surveyed pollution levels along hiking trails and nearby neighborhoods as we know that on the windward side of the Tatra Mountains, where precipitation rate is higher, higher concentrations of long-range emissions may be deposited. The difference between natural and urban environments is quite large, not only in terms of the concentration of people but also in the intensity of production activity. The greatest sources of pollution originate directly from urban areas. Conversely, in the fragile forest ecosystem of the high mountains, these pollutants should be present to a lesser extent since they are not directly within the affected area and are at varying altitudes. Metals can also occur in this environment without human intervention. Natural heavy metal concentrations in soils are closely related to soil type (Kabata-Pendias and Pendias 2001). Therefore, we began by examining the fruits of *S. aucuparia* in both natural and urban environments. Elements like sulphur were found in greater quantities in the natural environment (where they occur naturally), whereas the source of pollution comes from nearby cities that produce these compounds in large quantities. They are transported long distances by wind and precipitated into the soil at higher altitudes. Chlorine and chlorinated paraffins are another set of elements that significantly pollute the environment, particularly in cities and larger agglomerations. They are widely used in industrial applications, such as extreme pressure lubricant additives, flame retardants, plasticizers, and coating additives (Wei *et al.* 2016). In this environment, they are formed through activities such as the manufacture of plastics, fuel mixtures, households that use chlorine as a cleaning agent, landfill sites, and chlorinated air conditioners emitting chlorine into the air, as well as in the water industry, where chlorine is added to water and swimming pools. Under the influence of strong vapor and water vapor, these compounds are released into the air and dispersed throughout the environment.

Further, we observed a higher proportion of calcium in urban environments, in which *S. aucuparia* samples were also subjected to investigation. We assume that this result is mainly due to urban activities such as large-scale construction and demolition of buildings, where lime plasters are often used, as well as in transport where calcium dust may be released during braking and tire wear, and in the use of lime or lime compounds for disinfection of drinking water. Furthermore, elements such as manganese and rubidium show values three times higher in natural environments compared to urban zones. This significant increase comes from natural phenomena such as rock weathering, tectonic faults, and general geological changes in the soil. Minerals containing manganese and rubidium also contribute significantly, as does soil erosion, which subsequently washes down the mountain slopes. However, some elements are necessary for plants and trees for growth and proper photosynthesis.

Zn, Cu, Fe, and Cr, at trace levels, are all essential metals required for biochemical reactions in the living body of plants. At higher concentrations, they are all potentially toxic (Goyer 1996). Lead and mercury are the most serious elements. While lead primarily increases in natural settings, mercury levels rise more prominently in urban environments. Lead, being a toxic metal, poses a significant environmental burden and is hazardous to human and animal life. This metal can originate from geological processes of the earth but is also transported into the mountains by wind, tourism, waste incineration sites, and lead cables. The severity of mercury contamination in the environment is also alarming, particularly in urban settings where it is primarily caused by coal combustion and emissions from industrial plants such as glassworks, power stations, and cement plants. Furthermore, mercury deposition may increase in high-altitude regions due to high precipitation rates in mountainous areas and the cold condensation process, which causes volatile migrated compounds such as organic contaminants and gaseous elemental mercury to move toward cooler high-altitude and high-latitude regions (Schindler 1999; Susong *et al.* 1999; National Park Service 2002). These elements affect fauna and flora differently, but to a significant extent. According to the results, rowan fruits in natural environments are more affected by environmental pollution and show higher values of the elements compared to urban environments. The higher limits of elements were observed for seven out of eleven elements in natural settings and four out of eleven elements in urban areas. The evaluation of two sets of data posed some complexity due to the unspecified distance of fruit collection from these locations, assumed as potential transfer points for pollution affecting plant species, particularly *S. aucuparia*. Common sources of contamination along hiking trails include soil erosion, garbage, trail construction, and the use of heavy machinery and chemicals, as well as trail marking materials. For roads and heavily trafficked sections, pollution primarily arises from combustion engine emissions, asphalt road construction, signage, guardrails, oil spills, salt dispersion, and parking areas. The analysis revealed that rowan fruits near hiking trails were more contaminated, particularly with sulphur, manganese, rubidium, and lead. However, potassium, primarily occurring naturally, was not classified among the heavy metals (Barrows *et al.* 2018; Parolini *et al.* 2021). Analysis of sulphur levels along hiking trails suggests tourism activities as a primary contributor, with frequent trail usage and amenities like mountain huts using solid fuel for heating. Additionally, footwear, clothing, and mountaineering gear involving adhesives and chemicals also contribute to sulphur accumulation in natural environments. Similar relationships apply to other elements found in higher concentrations near trails, indicating anthropogenic pollution.

On roads, chlorine and calcium were notably present at elevated levels. Road salt emerges as the primary source, accumulating near roads after application. Other factors include geological conditions, soil disturbance, mineral leaching, vehicle emissions, and wastewater runoff into streams and rivers within the area. However, heavy metal removal from soil near roads poses challenges due to irreversible immobilization within various soil components (Gülser and Erdoğan 2008). The research examined pollution on both the windward (north) and leeward (south) sides of the Tatra Mountains, considering valley distribution in relation to these locations. Various studies highlight the dependency of atmospheric chemical cycles on weather conditions, terrain, and particle size distribution (Dossi *et al.* 2007; Siudek *et al.* 2011). Climatic conditions differed slightly between the two sides. While the northern side faced prevailing winds from industrial areas in western and northern Europe, the southern side was shielded from this influence but more affected by emissions from nearby urban centers. Nevertheless, the northern side experienced prolonged snow cover, potentially impacting *S. aucuparia* fruit. Calcium and sulphur levels indicated significant environmental pollution on the northern slopes. Our findings suggest heavier metal concentrations on the northern slopes compared to the southern ones, implying greater anthropogenic pollution affecting the entire mountain ecosystem. Manganese and barium contamination also exhibited notable disparities between the two sides. Based on our results, we attribute the higher pollution levels on the northern side of the High Tatras to neighboring countries. The deposition of heavy metals in the Tatras is associated with the automotive industry, particularly on the northern side, where there is a noticeable influence of transboundary air pollutants from Poland, particularly from Katowice. In the highest ridge positions devoid of terrain barriers, northwesterly convection predominates (Konček *et al.* 1973). Wet deposition significantly affects contamination and heavy metal uptake by plants on this side of the mountains. The correlation between orography, wet deposition volume, and precipitation composition is well-established (Fowler *et al.* 1993). However, the rate of atmospheric element deposition in mountainous regions can vary markedly over short distances. While precipitation generally increases with elevation in small mountainous areas (Zechmeister 1995), precipitation patterns are influenced by various geographic factors. Moreover, Gerdol and Bragazza (2006) discovered that elemental concentrations vary with elevation, even in the absence of elevation-related precipitation patterns. Urban and industrial environments pose more potential sources of contamination with harmful substances, including heavy metals, compared to natural settings. The issue of heavy metal toxicity is compounded by their ability to accumulate in seemingly healthy plant species at levels posing risks to human health if ingested (Harris *et al.* 1997). Environmental geochemical phenomena, such as heavy metal concentrations in soil, often exhibit correlations due to the physicochemical properties of the elements and geochemical processes (Zhang and Selinus 1998). In our study, chlorine levels were elevated at both sampling sites, with even higher concentrations observed in urban environments compared to natural ones. Sulphur, on the other hand, exhibited lower levels but is essential for biological processes, being incorporated into various biomolecules crucial for life. Organisms within ecosystems have specific tolerance ranges to changes in their physical and chemical environment. When these thresholds are surpassed, even minor disruptions in homeostasis can trigger significant effects (Miller 1998). This phenomenon may explain sudden environmental problems, such as dying forests, declining fish populations, and various diseases affecting both humans and animals. Comparing natural and urban environments for metals like manganese and rubidium, we find higher concentrations in natural settings, while urban areas show levels well above the standard measurement range. Rubidium, naturally occurring as a by-product of the Earth's crust, is transported to higher elevations where it deposits on soil surfaces. Studies conducted worldwide, including in Europe, indicate that the Alps, alongside other European mountainous regions are impacted by air pollutants originating from industrialized lowland areas (Mosello *et al.* 1993). These pollutants have significant impacts on lakes, streams, and the valleys they traverse. Mountain valleys, known for their saturation and high humidity, serve as reservoirs where soil absorbs and traps water along with associated pollutants. Metals pose a potential hazard due to their tendency to accumulate in biota, particularly on water surfaces where low pH values increase heavy metal solubility and toxicity (Goodyear and McNeill 1999; DeForest *et al.* 2007; Murray 1991). This underscores the likelihood of heightened contamination in valleys supporting delicate ecosystems. The presence of aluminum originates from both anthropogenic sources and terrestrial dust (Ljung *et al.* 2006). Direct metal application, coupled with deposition of acidic compounds, facilitates metal mobility within soil, leading to their eventual export to surface waters. Weathering processes play a crucial role in heavy metal levels, especially in areas characterized by highly soluble rock formations within the catchment (Borg *et al.* 2001).

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