EVALUATING THE CAPABILITY OF WOODY PLANTS TO CAPTURE ATMOSPHERIC HEAVY METALS IN BUDAPEST

A BUDAPESTI FAFAJOK KÉPESSÉGÉNEK ÉRTÉKELÉSE A LÉGKÖRI NEHÉZFÉMEK MEGKÖTÉSÉRE

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Abstract

Urban green infrastructure planning plays an essential role in aspects of pollution reduction, such as heavy metal trapping. However, the reduction effects are both influenced by the different pollution conditions in each city and the species-specific interaction of trees and pollution. Herein, we investigated three common urban woody plants (Acer platanoides L., Fraxinus excelsior L. Westhof's Glorie, and Tilia tomentosa Moench) in Budapest to compare their heavy metal trapping abilities from the airborne in leaf dust deposits and leaves. All samples were deconstructed by a wet digestion method. Four traffic-related heavy metal elements (Zn, Cu, Pb, and Ni) were determined by using an atomic absorption spectrometer (AAS). The investigated results showed that the relevant concentration of all measured elements was constant in all species, namely Zn < Cu < Pb < Ni. Although the total heavy metal content in the dust deposit increased towards the end of one vegetation period, the highest percentage of total metal concentration was in the summer season as the particulate matter sources varied in each season. These indicate that woody plants are ideal candidates for pollution monitoring. All of the evaluated elements were loaded highest in the dust deposit of T. tomentosa during all sampling times, followed by A. platanoides, and the least in F. excelsior. A significant correlation between metal contents in the dust deposit and leaf was found in T. tomentosa (0.926 at a p<0.01 level). Therefore, we suggest T. tomentosa, which has better atmospheric trace element capturing capacity than A. platanoides and F. excelsior and thus it is a better option for pollution reduction in the urban area.
Keywords: *particulate matter, heavy metals, tilia tomentosa, woody plant*

Összefoglaló

A városi zöld infrastruktúra tervezése alapvető szerepet játszik a környezetszennyezés csökkentésében, mint például a nehézfémek megkötésében. A csökkentési hatásokat azonban egyaránt befolyásolják az egyes városok eltérő szennyezési feltételei, valamint a fák és a szennyezés specifikus kölcsönhatásai. Munkánk során Budapesten három közönséges városi fás szárú növényt (Acer platanoides L., Fraxinus excelsior L. Westhof's Glorie és Tilia tomentosa Moench) vizsgáltunk, hogy összehasonlítsuk nehézfém megkötő képességüket a levelekre kiülepedett porban és a levelekben is. Az összes mintát nedves roncsolással készítettük elő. Négy közlekedési eredetű nehézfém (Zn, Cu, Pb és Ni) meghatározása atomabszorpciós spektrométer (AAS) segítségével történt. A vizsgált eredmények azt mutatták, hogy az összes mért elem

releváns koncentrációja minden vizsgált fajban állandó, nevezetesen Zn < Cu < Pb < Ni. Bár a teljes nehézfém-tartalom a porlerakódásban a vegetációs periódus vége felé nőtt, a teljes fémkoncentráció legnagyobb százaléka a nyári szezonban volt kimutatható, mivel a szállópor források évszakosan változtak. Ezek azt mutatják, hogy a fás szárú növények ideális jelöltek lehetnek a szennyezés monitorozására. A vizsgált elemek mindegyike a T. tomentosa porlerakódásában volt a legnagyobb az összes mintavételi idő alatt, ezt követte az A. platanoides, a legkevésbé pedig a F. excelsior. Szignifikáns korrelációt találtunk a porlerakódás és a levél fémtartalma között a T. tomentosaban (0,926 p<0,01). Ezért javasoljuk a T. tomentosat, amely jobb légköri nyomelem-megkötő képességgel rendelkezik, mint az A. platanoides és a F. excelsior, így jobb választás a városi szennyezés csökkentésére.
Keywords: *particulate matter, nehézfém, tilia tomentosa, fás szárú növény*

Introduction

Particulate matter (PM) is one of the significant pollutions in the urban environment. Over 94% of the urban population in Europe was exposed to more $PM_{2.5}$ than the World Health Organization (WHO) recommends according to a research from the European Environment Agency (EEA, 2022). Industrial, urban construction, and traffic emissions are the primary sources that contribute significantly to PARTICULATE MATTERS levels in the air (ANTISARI et al., 2015; BENÍTEZ et al., 2019; JEANJEAN et al., 2016). The main ingredients of particulate matter include carbon-containing compounds, water-soluble ions, earth's crust elements, and trace elements (WANG et al., 2019a). Fine particulates are suspended in the air and last longer than larger particulates (DZIERŻANOWSKI et al., 2011). Because of its small particle size and large specific surface, $PM_{2.5}$ has a high adsorption capacity, contributing to its complex composition and sources (WANG et al., 2019a; YING et al., 2018). Heavy metals are typically found in lower concentrations of $PM_{2.5}$, but they endanger human health by causing problems with the pulmonary, cardiac, vascular, and neurological systems (NOWAK et al., 2018; WANG et al., 2019b). Although some are required for the growth and well-being of living organisms, excessive amounts are likely to cause toxic effects.

Urban woody plants, because of seasonal changes and their sizes, shapes, and colors, are the most prominent elements of city decoration. The ideal ally trees must accommodate ever-increasing requirements, withstand shade, drought, poor soil, continuous root and branch pruning, injury, air pollination, salt, and dog urine. Moreover, their wounds recover quickly, they are not susceptible to rot, they do not cause allergies, and their flowers, leaves, and fruits do not litter (SZALLER et al., 2014). Pine species (such as, *Pinus mugo* and *Pinus sylvestris),* deciduous tree species spruce (such as, *Betula pendula, Pinus mugo, Pinus sylvestris, Robinia pseudoacacia, Salix cinerea, Skimmia japonica, Stephanadra incisa* and *Tilia tomentosa)* are the most planted urban trees in Europe that are used in air quality improvement initiatives to reduce pollution (KOSIOREK et al., 2016; SÆBØ et al., 2012). Some species such as *B. pendula* and *R. pseudoacacia* are considered as bio-monitors in the urban environments because of their high hardiness, pollution tolerance and characteristic as pioneer species (DADEA et al., 2017). Conifers are more effective in particulate matter accumulation than broad-leaved species due to the thick epicuticular wax layer on their needles; however, they are less tolerant of high traffic-related pollution, especially if salt is used for road de-icing during the winter, making them unsuitable as companion trees (DZIERŻANOWSKI et al., 2011; SERBULA et al., 2013).

Being directly exposed to air contaminants leaves passively collect dust on their surface and absorb gaseous and particulate matter pollution (MOLNÁR, 2016). Dust trapping ability is determined by species-specific leaf's morphological and anatomical parameters such as trichomes and epicuticular waxes, which distinguishes one species from another

(DZIERŻANOWSKI et al., 2011; SERBULA et al., 2013; SIMON et al., 2014; TOMAŠEVIĆ et al., 2004). Planting woody plants in urban areas is a novel, efficient, eco-friendly, and low-cost technology for pollution reduction. However, both species and location of pollution sources are critical in determining effectiveness (MORI et al., 2015; YIN et al., 2019). Thus, applying plants to the aspect of pollution reduction should be adapted to the local conditions. Besides industrial emissions and residential heating, road traffic is also considered an uncontrolled and significant source, accounting for 19% of total $PM_{2.5}$ in Hungary (FERENCZI et al., 2021).

PM concentrations are a primary environmental issue that requires immediate action to reduce air pollution. Many attempts have been made to quantify the effectiveness of urban trees in capturing particulate matters (LIANG et al., 2016). However, the different pollution conditions in each city and the species-specific interaction of trees and pollution, both influence reduction effects. We are encountering extreme circumstances in urban areas with rising stress from anthropogenic activities. Hence, this study was carried out in Budapest to investigate the interaction between the trees and ambient PM pollution. The features of particulate matter in Budapest and the capacity of woody plants to capture fine particulate matter were evaluated, which will provide useful information for future urban environmental planning and management.

Material and Method

Study area

Budapest is the capital city of Hungary, located on both sides of the Danube River and with about 2 million inhabitants (HROTKÓ et al., 2021; PROBÁLD, 2014). It has a temperate climate with impacts from the oceanic climate and the Mediterranean climate (PROBÁLD, 2014). The annual mean temperature is 11.3 °C. The annual average of total sunshine is 2010 hours and annual rainfall is about 516 mm, which falls mainly from May to June and autumn, with large temporal variability in each year (mean of 30 years 1981-2010) (MET, 2023). As Hungary's economic center and most populated city, Budapest is overburdened with anthropogenic activities (PROBÁLD, 2014). Despite the significant improvements in air quality since the wave of heavy industry closures in 1990, the increase in roadside traffic in Budapest contributes to serious air pollution (ALFÖLDY et al., 2007).

The study area, Buda Arboretum (47°28' LN; 19° 2' LE, 120 m above sea level) is a suburban park located on the south slope of Gellért-Hill, Budapest (Figure 1). It was initiated in the winter of 1893/94 with a cultivation area of 7.5 hectares and approximately 1900 species of woody plants (SCHMIDT and SÜTÖRI-DIÓSZEGI, 2013).

Acer platanoides L. (Norway maple), *Fraxinus excelsior* L. Westhof's Glorie (common ash), and *Tilia tomentosa* Moench (silver linden) are common deciduous urban trees in East-Central European cities and are among the most frequently planted species in Budapest (Szaller et al., 2014). They are different in leaf surface structure (Figure 2). The *A. platanoides* leaf is bright green, glabrous, and lustrous beneath, bearded in the axis of the veins. *F. excelsior* has glabrous compound leaves with villous along the midrib beneath. The *T. tomentosa* leaf, on the contrary, is slightly pubescent above and with white tomentose beneath (CZAJKOWSKA and KIELKIEWICZ, 2002).

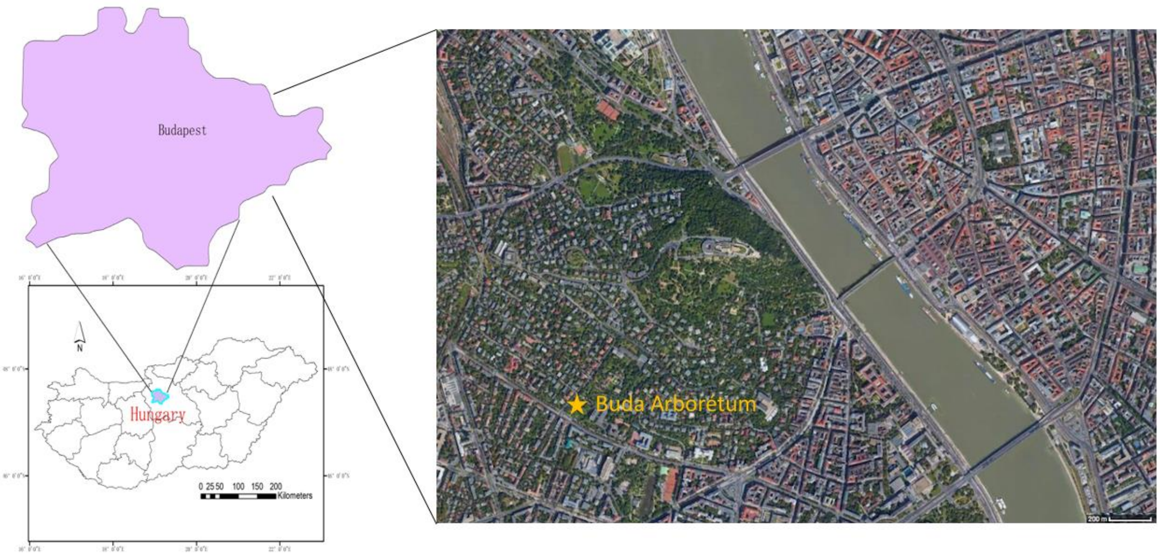

Figure 1. Sampling site: location of Buda Arboretum.

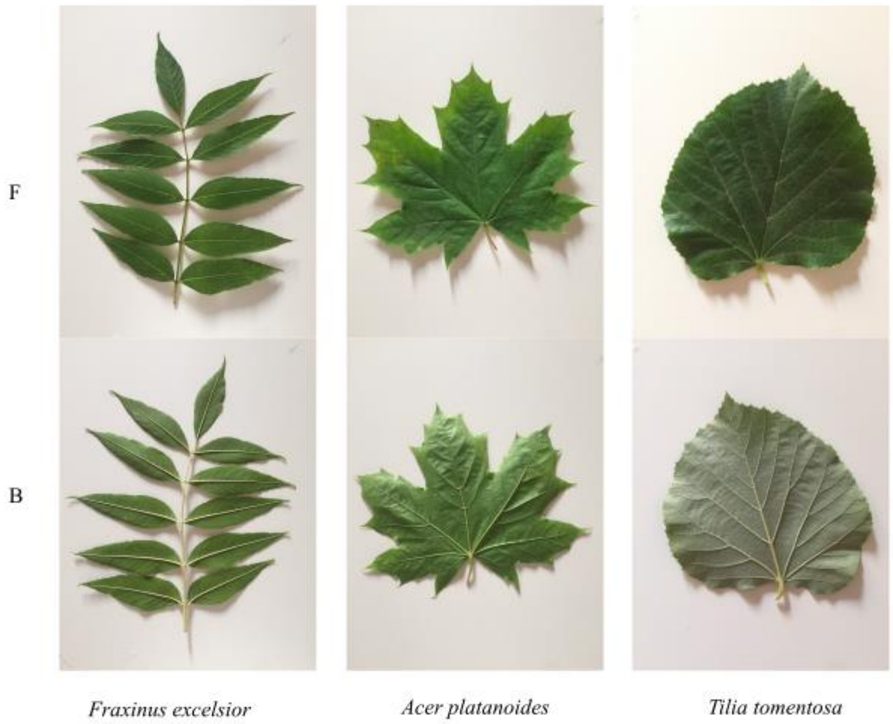

Figure 2. Leaf morphologies of *A. platanoides*, *F. excelsior*, and *T. tomentosa* (F=Front side, B=Back side)

Sampling and sample analysis

The sampling times were May 2019, July 2019, and October 2019. Each sampling day was after a period of rainless days. To have a similar integration time of pollution, sampling trees are of similar age (20years old), height (8-10m), and trunk diameter (12-13cm). We collected fully developed leaves with no spots or abnormal appearances. 45 leaves were sampled from 2-3 m height of the canopy, 2 trees from each species. All the samples were put carefully in paper bags and brought to the laboratory for further processing.

Each sample, 25 leaves were measured by a leaf area meter AM350 (ADC BioScientific Ltd, UK). We calculated the average leaf area of each species in square meters (m^2). Another 20 leaves were separated into two subsamples, soaked in 250 ml of distilled water for 20 hours and shaken in an ultrasonic cleaner (UC005AJ1 TESLA) for 10 minutes. The solution is filtered by filter paper (pore size 2-4 μm). Then the fine particulate-containing suspension was evaporated to a constant weight. After washing off dust residues, leaves were naturally dried to a constant weight and grounded. All samples were chemically digested using 4ml of 65% concentrated nitric acid for 1 hour at room temperature, then adding 2ml of 30% hydrogen peroxide and let stand still. After deconstruction, the dust solution was diluted to 30ml and leaf solutions were diluted to 100ml. The Zn, Cu, Pb, and Ni contents of all samples were determined by an atomic absorption spectrometer (AURORA AI 1200-AURORA Instruments Ltd, Canada). The heavy metal content of the dust deposit was calculated at mg/m^2 of the leaf area and mg/kg of the leaf dry weight.

Data analysis

We used the IBM SPSS 25 software package (SPSS Inc., Chicago, IL, USA) and Excel (Microsoft, Redmond, WA, USA) for statistical analysis. The dataset was firstly processed by the normality test. The normality of various was accepted as absolute values of Skewness and Kurtosis less than 2. The homogeneity of variances was tested by the Levene test. Based on data distribution, the dataset was standardized. Then the metal concentrations were compared by Multivariate ANOVA. If MANOVA was significant, we followed up Univariate-ANOVA with Bonferroni correction. Finally, Tukey's HSD post hoc tests were used if there was a significant difference. SPSS, ArcGIS 10.7 (ESRI, USA), and Origin (OriginLab Corporation, Massachusetts, USA) were used in creating figures.

Result and Discussion

Physicochemical properties of the dust residue

Table 1 shows the descriptive analysis of Zn (0.9 - 4.62 mg/cm^2), Cu (1.33 -9.46 mg/cm^2), Pb (3.92 -18.82 mg/cm^2), and Ni (5.03 -26.38 mg/cm^2) concentrations in the leaf $PM_{2.5}$ deposit. The trend of element concentration is Zn < Cu < Pb < Ni. It corresponds to our previous study, which measured heavy metals in foliar dust deposits from 2015 to 2016 in Budapest (HROTKÓ et al., 2021). Furthermore, the relevant abundance of the tested elements in the leaf dust deposits is the same in all examined species, as shown in Figure 2. Thus, we can conclude that woody plant leaves are good indicators of air contamination and can characterize the air quality in urban areas since they are exposed directly to and accumulate pollutants (ANIČIĆ et al., 2019; SIMON et al., 2011). Similarly, ANIČIĆ et al. (2019); KRUTUL et al. (2014); and ŢENCHE-CONSTANTINESCU et al. (2015) also stated that *A. platanoides, F. excelsior, and T.* tomentosa are suitable to use as bioindicators, but their capacities differ from one another.

Table 1. Descriptive statistics of leaf dust heavy metal contents (mg/m^2)

Element	Minimum	Maximum	Range	Mean±S.D
Zn	0.90	4.62	3.73	2.20±0.94
Cu	1.33	9.46	8.14	4.84±2.60
Pb	3.92	18.33	14.41	10.09±4.56
Ni	5.03	26.38	21.35	14.28±6.85
Sum	14.08	64.08	42.98	32.42±14.48

Note: S.D is standard deviation.

In our study, Zn was in the lowest concentration, averaging of 2.20 mg/m^2 in all species. The content of Cu, an average of 4.84 mg/m^2, is also lower than Pb and Ni contents. This is because Zn and Cu have a similar source in the urban environment; they are ascribed to the metallic parts of cars, tire treads, tire dust, and engineer wear (SIMON et al., 2014). Furthermore, both of them are water-soluble elements and are easily washed off by rain (CATINON et al., 2008). In contrast, Ni and Pb were at a higher concentration (Table 1) and they also shown enriched in all three species (Figure 3). Since foliar dust is the most precise and direct indicator of the concentration of heavy metals in the atmospheric particulate matter and the quality of the air (LI et al., 2022). This can address the pressure from Pb and Ni in Budapest's air pollution. Although leaded petrol was prohibited in Hungary after 1999, car exhaust is still the main source of Pb and Ni in the atmosphere (SIMON et al., 2014). In line with the findings of ŚWIETLIK et al., (2013), we found that Ni and Pb emissions were very similar, with slightly less Pb than Ni. In the urban environment, Ni originates not only from fossil fuel combustion, stationary sources, the corrosion of cars, and motor vehicle parts but also from waste incineration (SIMON et al., 2014). Between 2010 and 2019, Hungary's total number of cars increased dramatically, from 208,571 to 498,158 (OIAT, 2023). FERENCZI and BOZÓ, (2017) also stated that traffic emissions are one of the main factors determining the air quality of Budapest. There is no doubt that the mounting traffic nowadays in Budapest consequently raises the Pb and Ni content in the atmosphere. Furthermore, because Pb is a non-essential element and Ni is only a trace nutrient, they can both accumulate in leaf dust deposits.

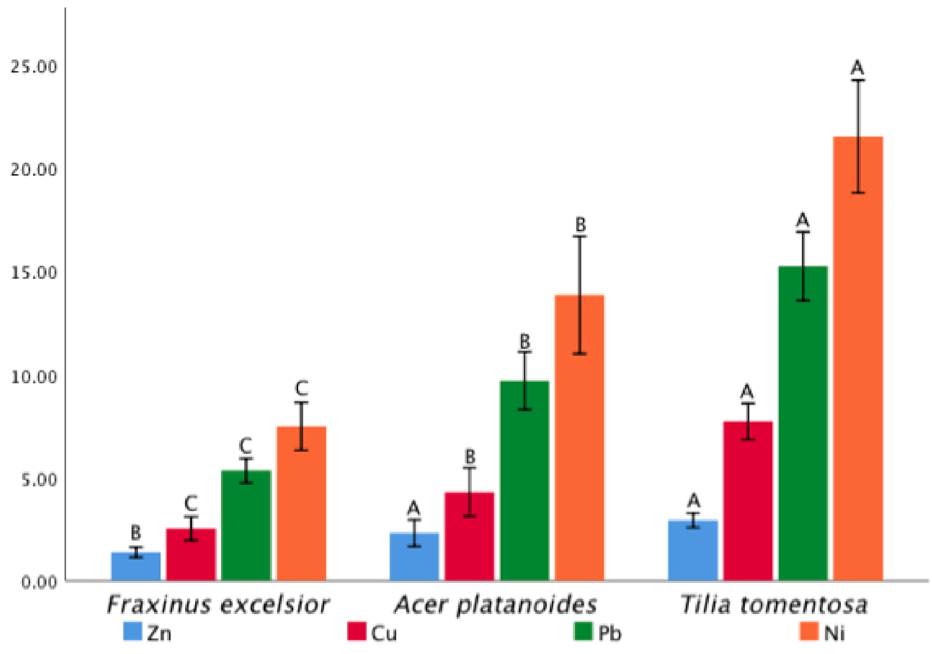

Figure 3. The mean content of heavy metals in leaf dust deposits (mg/m^2)

PM is mainly made of water-soluble ions, elemental carbon, organic carbon, and inorganic elements (MCDONALD et al., 2007). Inorganic elements including earth crust elements (Al, Fe, Si, etc.), metal elements (Zn, Cu, Pb, Mn, Ni, V, As, Cr, etc.), and rare elements (La, Ce, Nd, etc.) (WANG et al., 2019a). WANG (2020) investigated 32 elements in $PM_{2.5}$ in Xiamen, China, and found the total elements were making up 1.37-16.15% of $PM_{2.5}$. In our study, the total percentage of four elements ranged between 0.28% and 2.37%. The average percentage of total heavy metal content of dust deposition is shown in Figure 4, where it is lower in autumn than in summer, despite the fact that total dust deposits were highest in the autumn season across all species (Figure 5). The element percentage shows a decreasing trend from spring towards autumn in *F. excelsior*, while *A. platanoides* and *T. tomentosa* show the highest percentage in the summer season. WANG (2020) also concluded that the total metal element concentration in $PM_{2.5}$ was higher in the summer than in the spring, autumn, and winter seasons. Because local resources, such as residential heating and traffic emissions, as well as meteorological conditions, influence PM2.5 concentrations in the air (FERENCZI and BOZÓ, 2017). Therefore, the main determining factors in the autumn season are heating combined with unfavorable weather conditions. Also, under humid and foggy weather conditions, water-soluble compounds comprise a higher percentage of the total PM (LIANG et al., 2016; WANG. 2020). In the summer season, traffic emissions are the key factor. Road traffic emissions, which can account for up to 66% of PM2.5, are one of the main sources of air pollution in urban areas (JEANJEAN et al., 2016; SUNDVOR et al., 2012). Thus, woody plants are proper candidates to indicate PM pollution characteristics and sources (CHEN et al., 2017; MCDONALD et al., 2007).

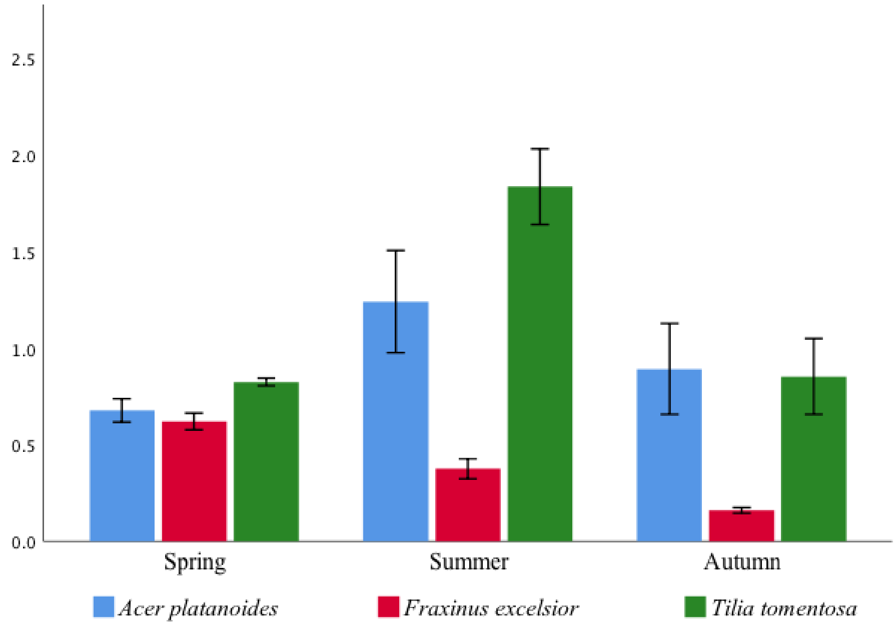

Figure 4. The mean percentage of heavy metals of dust deposit (%)

Dust trapping by different woody plants

Figure 5 lists comparisons in all sampling terms of the total element content in the dust deposits of different woody plants in Budapest. *T. tomentosa* contained the highest total heavy metal concentration in the dust deposit in each sampling term, significantly higher than the other species. Followed by *A. platanoides*, and the lowest is found in *F. excelsior*. In spring, *A. platanoides* showed no significant difference from *F. excelsior*. The biggest difference was in summer, when *T. tomentosa* captured 3.65 times more heavy metals in the leaf dust than *F. excelsior*. The statistical analysis revealed that the capture of atmospheric $PM_{2.5}$ by urban trees varied significantly by species and season (CHEN et al., 2017). The performance of total metal content in leaf dust deposits also confirms the data of HROTKÓ et al. (2021). *T. tomentosa's* leaf surface has the highest ability to capture dust from the ambient, followed by *A. platanoides*, and then *F. excelsior*. Similarly, some studies have considered *T. tomentosa* as a future tree because of the great accumulative capacity of its leaves and the stronger tolerance to pollution marked it suitable as air pollution biomonitor and metal accumulation plant (HOODAJI et al., 2012; SEVIK, 2019; ŢENCHE-CONSTANTINESCU et al., 2015).

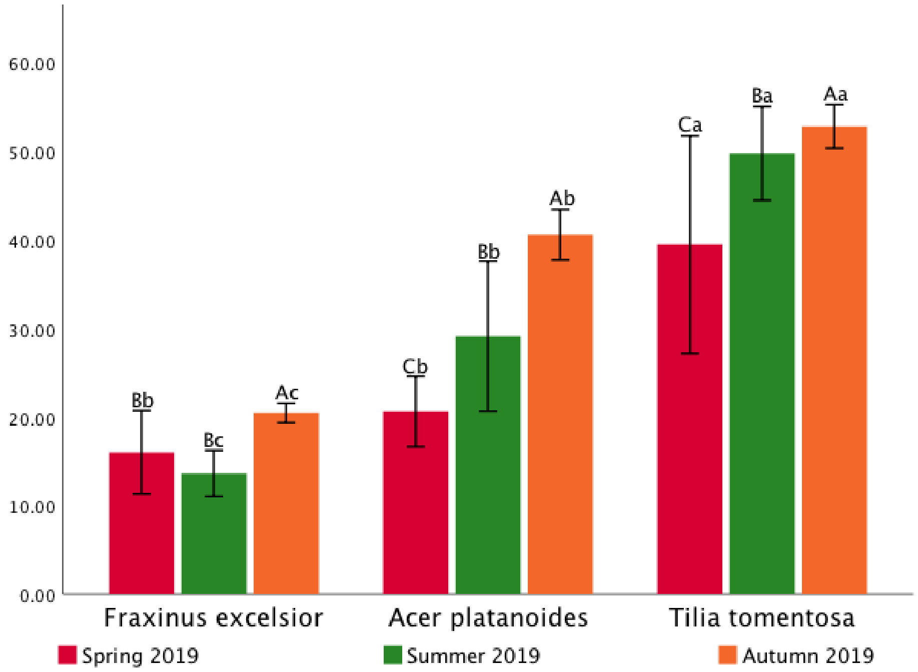

Figure 5. Total metal element contents of the leaf dust deposition (mg/m^2)

Note: Different letter represent significantly difference between groups (Tukey's HSD p<0.05). Lower cases are for comparison in species. Upper cases are for comparison in sampling time.

Moreover, meteorological changes also generate impacts on woody plants and $PM_{2.5}$ interactions in several ways. The weather in Budapest in autumn 2019 was calm and clear, anticyclonic, with wind speeds over 1 m/s at 1.5 m above ground, which is assumed to have a highly negative impact on the dust deposit on green vegetation (DIMOUDI and NIKOLOPOULOU, 2003; FERENCZI et al., 2021; PROBÁLD, 2014) However, SOUDEK et al. (2012) and WANG et al. (2019) discovered a lower temperature day normal as well as higher PM in the air. It is because a cold period increased the intensity of communal heating and led to a larger emission of PM (HROTKÓ et al., 2021). In our study, the autumn term may have been impacted by habitat heating.

We did not find a constant accumulation pattern by the factor of species, sampling time, and element (Figure 6). Even when exposed to similar sources and under similar environmental conditions, metal-accumulating plants are governed by individual species characteristics (CAPUANA, 2011; KWON et al., 2020). However, they accumulated higher amount in autumn season than in spring season. In the comparison of the relevant abundance of each element, *T. tomentosa* always has the highest concentration, followed with *A. platanoides*, and the lowest in the *F. excelsior*, but the differences ranged differently. The smallest difference was found in Zn among all the terms and species, in autumn season, 3.42 mg/m^2 in *A. platanoides* and 3.44 mg/m^2 in *T. tomentosa*. This can because of the emission sources and also plants are hard to trap Zn related particles. The biggest difference was found in the content of Ni in the summer season between *T. tomentosa* (23.57 mg/m^2) and *F. excelsior* (6.55 mg/m^2). Thus, based on the aforementioned results, we can conclude that *T. tomentosa* has a higher capacity in entrapping HM on the leaf surface than the other two species.

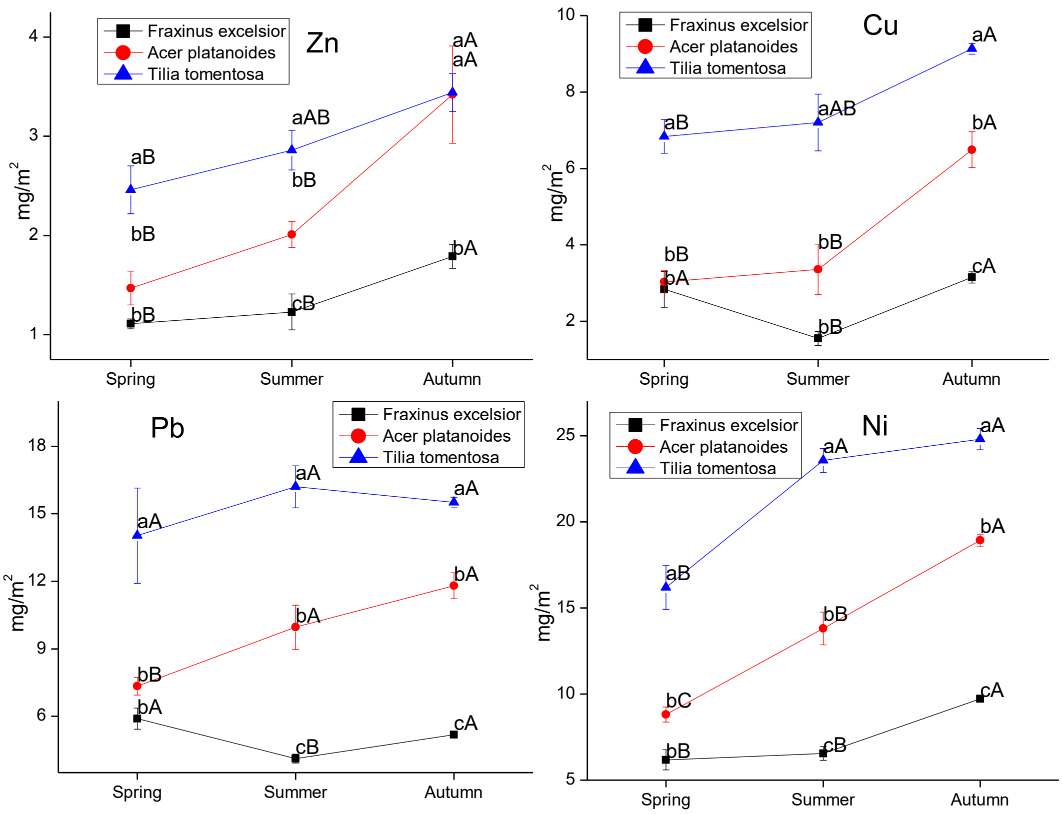

Figure 6. The course of HM content of the dust deposits from woody plant leaves surface

Note: Different letter shows significantly difference between groups (Tukey's HSD p<0.05). Lower cases are comparison in species. Upper cases are comparison in sampling time.

Corresponding to the PM accumulation species selection study, SÆBØ et al. (2012) also clustered *A. platanoides* in intermediate PM accumulation capacity group and *F. excelsior* in the lowest level. The leaves of woody plants in the urban area are highly exposed to atmospheric pollutions, their capacity in retaining dust also depends on several physiological factors. Trichomes on the leaf surface, size of stomata, and stomatal density are the most influential factors in dust trapping (SIMON et al., 2014). As the surface of the leaves gets rougher, the elements' accumulation is increased due to their greater ability to trap particles. Also, EMAMVERDIAN et al., (2015) demonstrated that trichomes functioned as metal storage. In the comparison of these three species, the leaf of *T. tomentosa*, with its branched hairy surface, big and stellar trichomes, retained the highest amount of dust on the surface (ANIČIĆ et al., 2011; CZAJKOWSKA and KIELKIEWICZ, 2002). And the larger size and high density of stomata *A. platanoides* contribute to its dust trapping capacity, while the smooth leaf surface and lower density of stomata on *F. excelsior* result in the lowest dust capture on the leaf surface (SIMON et al., 2011).

ANIČIĆ et al., (2019) described that the amount of PM captured by deciduous woody plants was significantly increased during the vegetation period from spring (May) to autumn (September), which also corresponds to our study for *A. platanoides* and *T. tomentosa*. The total heavy metal content doubled in the deposited dust on the leaves of *A. platanoides*. The changes in *T. tomentosa* was not as huge as in *A. platanoides* but they increased from the spring to the autumn. As the leaf surface geometry is highly related to the PM interaction, the smooth leaf surface of *F. excelsior* may contribute to the decrease (16.03 -13.64 mg/m^2) in summer of element content by rain wash off or by wind blow.

In conclusion, different elements function differently for plant growth, and different physical characteristics as well as the air pollutant source are contributing to the accumulation of trace elements in the dust. Also, air pollutants, instead of remaining confined near the source of emission, spread over distances depending upon the topography and meteorological conditions, especially wind direction, wind speed, and vertical and horizontal thermal gradients (HOODAJI et al., 2012). Nevertheless, leaves with trichomes and rough or epicuticle wax on the surface have higher potentials for capturing dust (DZIERŻANOWSKI et al., 2011; SERBULA et al., 2013).

The content of heavy metals in leaves

Statistics analysis results showed no significant differences for each element between species (Table 2). Woody plants accumulate heavy metals in the leaf through leaf absorption and uptake from the soil as well (EL-AMIER and ALGHANEM, 2018; STANKOVIC et al., 2009). The high concentrations of Pb and Ni are, to a large extent, the consequence of atmospheric deposition of particles and absorbed pollution (STANKOVIC et al., 2009). In plants, the inorganic Pb is poorly absorbed while the organic compounds of Pb emitted from automobile exhaust are absorbed well and quickly, transported through the intercellular spaces of the leaves, and accumulated in the plant (EL-AMIER and ALGHANEM, 2018; STANKOVIC et al., 2009). Also, SERBULA et al., (2013) reported that branches and leaves of *Tilia spp.* were better biomonitors of airborne pollution with Pb than the other plant species. We also analyzed the correlation of the heavy metal content in the leaf and in the dust deposit, and results showed stronger correlations of each element and the total concentration in *T. tomentosa* (Table 2). Although it is hard to determine their accumulating ability only by the concentration in the leaf because plant species, heavy metal concentrations in the environment, other environmental factors, and the plant physiological conditions could collectively influence the concentration of trace elements in plants. Nonetheless, based on the findings, we can conclude that the *T. tomentosa* leaf strongly interaction with atmospheric $PM_{2.5}$ pollution.

Table 2. Heavy metal concentrations in leaves of woody plants (mg/kg)

Species	Zn	Cu	Pb	Ni	Total HM
Fraxinus excelsior	4.93±0.90	1.29±0.96	10.51±1.81	12.63±4.44	36.34±8.03
Acer platanoides	5.20±2.96	1.57±0.85	10.51±1.39	12.20±4.83	35.32±4.74
Tilia tomentosa	3.81±0.47	1.00±0.89	10.35±1.79	11.92±4.42	32.14±3.88

Table 3. Relationship of dust deposit-leaf heavy metals of woody plants

Leaf	Zn	Cu	Pb	Ni	Total HM
Fraxinus excelsior	0.837**	-0.687**	0.176	0.840**	0.523*
Acer platanoides	0.440	-0.688**	0.475	0.849**	0.711**
Tilia tomentosa	0.877**	-0.629**	0.548*	0.956**	0.926 **

*Note: Pearson correlation coefficient **. Correlation is significant at p<0.01 level (2-tailed). *. Correlation is significant at p<0.05 level (2-tailed).*

Conclusion

Intensive anthropogenic activities are increasing air pollution in urban areas, which is threatening human health. Woody plants are important elements of urban environments and contribute to human wellbeing in several ways. However, ideal urban trees have to meet more and more requirements, such as bearing shade, resisting drought, reducing air pollution, etc. We studied the interaction of urban woody plants' foliar and ambient heavy metal pollution through the investigation of heavy metal content in the leaf dust residue and in the leaves of three common woody plant species in Budapest. Results revealed that woody plants are suitable for atmospheric pollution monitoring and particulate matters source analysis. A similar trend of heavy metal concentrations was found in all species, indicating these three woody plant species are suitable indicators for atmospheric heavy metal pollution. The total heavy element concentration, which comprised the highest percentage of the total fine particulate matters deposit on the leaf, was investigated in the summer, demonstrating the sources of fine particulate matters in the summer were mainly from traffic emissions. Among the three examined woody plant species, *T. tomentosa* showed a higher capacity for accumulating all measured heavy metals on the leaf surface and stronger interaction with the leaf element content than *A. platanoides* and *F. excelsior*. Therefore, we suggested *T. tomentosa* as a better option for future urban landscape planting in Budapest. Nevertheless, since numerous factors can influence the interaction effects, further studies should be conducted to provide more accurate information and to discover the interaction mechanisms.

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Declarations
The authors declare that they have no conflict of interest.

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