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Air pollution tolerance index and heavy metal bioaccumulation in selected plant species from urban biotopes

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HIGHLIGHTS

- Plantain, dandelion, black locust, birch may be used in heavy metal bioindication.
- The efficiency of heavy metal bioaccumulation depends on species and type of elements.
- The investigated plants may be useful in tackling atmospheric pollution.

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ABSTRACT

This research was carried out on plants *Taraxacum officinale, Plantago lanceolata, Betula pendula* and *Robinia pseudoacacia* growing in urban biotopes with different levels of heavy metal contamination in the city of Dąbrowa Górnicza (southern Poland). Based on the pollution index, the highest heavy metal contamination was determined in the site 4 (connected with industry emitters) and 6 (high traffic). The metal accumulation index (MAI) values ranged within the biotopes in Dąbrowa Górnicza between 7.3 and 20.6 for *R. pseudoacacia*, 4.71–23.1 for *P. lanceolata*, 4.68–28.1 for *T. officinale* and 10.5–27.2 for *B. pendula*. Increasing tendency in proline content in biotopes connected with high traffic was found in the leaves of investigated plants (except *R. pseudoacacia*). Similar tendency was observed for ascorbic acid content in the foliage of the plants as well as in *T. officinalle* in stands connected industrial emission. Non-protein thiols content increased especially in the leaves of *R. pseudoacacia* in biotopes with high traffic emissions as well as in *T. officinale* in stands connected with industry. The mean values of APTI (Air Pollution Tolerance Index) within the city of Dąbrowa Górnicza for investigated plants were found in the following ascending order *P. lanceolata* < *R. pseudoacacia* < *B. pendula* < T. *officinale*. Among the investigated plants *B. pendula* and *T. officinale* may be postulated as appropriate plants in urban areas with considerable soil and air contamination, especially with heavy metals. The results indicate that species deemed tolerant according to APTI are suitable plants in barriers areas to combat atmospheric pollution.

1. Introduction

In urban environments heavy metals such as Zn, Pb and Cd can originate from different sources, e.g. rubber tire wear, motor oil, auto workshops, electroplating industries and gasoline combustion. Leaded gasoline has been prohibited, yet much residual lead remains in the soil. Heavy metals are transferred to the biosphere constituents of airborne particles; nowadays more than 40 chemical elements are being measured in atmospheric particulate matter samples (Liu et al., 2007; Sawidis et al., 2012; Ugolini et al., 2013).

Concentrations of major and trace elements in plants depend on root uptake connected with bioavailability of elements in the soil or dry and wet deposition on outer plants organs (binding and solubility of particles deposited on leaf surfaces) (Tomašević et al., 2004; Norouzi et al., 2015). The heavy metals in adsorbing particulate matter (PM) from the atmosphere are able to enter and contaminate the soil therefore considering that metal uptake in

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higher plants take place through roots and leaves, it is difficult to distinguish whether the accumulated elements originate from the soil or from the air (Tomašević et al., 2004; Norouzi et al., 2015).

Plants effectively filter air by absorbing PM on their leaves, which can decrease air pollution (Shi et al., 2017). Moreover, Yin et al. (2011) demonstrated that particulate concentrations in the air decrease by 9.1% at distances of 50–100 m into a forest. Biodiversity of urban roadside plants acts as an eco-sustainable filter for air pollution (Rai, 2016a,b). Considerable species-specific differences in plant PM accumulation capacity depend mainly on the leaf characteristics such as trichomes, surface roughness, epicuticular wax layer (Shi et al., 2017). Green plants are widely recommended in the form of green belts and urban green spaces for air pollution mitigation (Pandey et al., 2016). Apart from pollution attenuation, urban green spaces can also beneficial for social well-being, as they may increase social cohesion and identifying with the local area. They can also influence health positively as they may lower negative emotions, e.g. after exposure to a natural environment in comparison to a more synthetic environment. Moreover, the perceived availability of nearby green space can help to alleviate noise annoyances (Bertram and Rehdanz, 2015).

Plants from urban environment exposed to pollutants demonstrated varied responses first of all in form of photosynthesis, respiration, enzymatic reactions, stomatal behavior as well as membrane disruption (Rai, 2016a,b). The varied physiological parameters can be used in defining the sensitivity or resistance of plants towards various air pollutant concentrations (Pandey et al., 2016). The leaf parameters such as chlorophyll content, ascorbic acid content, relative water content (RWC), and leaf extract pH can be combined to calculate the Air Pollution Tolerance Index (APTI). Thanks to the APTI indication, researchers can select plant species that are tolerant to the pollution in urban environments (Prajapati and Tripathi, 2008; Pathak et al., 2011; Sharma et al., 2013; Pandey et al., 2016). In APTI research, trees and shrubs are used (both deciduous and evergreen) as well as herbaceous plants (Priyanka and Dibyendu, 2009; Leghari et al., 2011; Sharma et al., 2013; Ogunkunle et al., 2015; Nadgórska-Socha et al., 2016).

The sensitivity and response of plants to air pollutants vary, with plant species that are more sensitive acting as bioindicators of air pollution, and the tolerant species according to APTI used for green belt development (Agbaire and Esiefarienrhe, 2009; Leghari et al., 2011; Ogunkunle et al., 2015). Deciduous tree species with good heavy metal accumulation include *Acer* sp., *Populus* sp., *Robinia* sp., *Salix* sp. and *Betula* sp. (Baycu et al., 2006; Unterbrunner et al., 2007; Monfared et al., 2013). This study examined two of them: *Robinia pseudoacacia* L. and *Betula pendula* Roth. Leaves from the *R. pseudoacacia* were used in an evaluation of physiological responses as well as APTI calculation in an earlier study of ours, which compared an urban industrial area and a potentially non-contaminated rural area on the outskirts of a nature reserve in southern Poland (Nadgórska-Socha et al., 2016). *Betula pendula* was also evaluated in a study of metal-accumulating woody species considered for phytoextraction at metal-contaminated sites, in an assessment of the suitability of the tree species for the production of biomass in soils contaminated with trace elements, as well as for the bioaccumulation of heavy metals by selected plant species at uranium mining dumps in the Sudety Mts., in the heavy metal contaminated town of Będzin (Poland). (Wisłocka et al., 2006; Unterbrunner et al., 2007; Nadgórska-Socha et al., 2011; Evangelou et al., 2012). Among herbaceous plants, the common dandelion (*Taraxacum officinale* Web) and narrow leaf plantain (*Plantago lanceolata* L.) have received attention as bioindicators, as well as in remediation projects, given its ability to uptake and store heavy metals in its aerial tissues (Kabata-Pendias and Dutka, 1991; Kos et al., 1996; Szarek-Łukaszewska and Niklińska, 2002; Bini et al., 2012; Nadgórska-Socha et al., 2013, 2015).

In this work we report the results of a study carried out on *Taraxacum officinale, Plantago lanceolata, Betula pendula* and *Robinia pseudoacacia* growing on stands with different degrees of pollution in an urban environment in the town of Dąbrowa Górnicza (southern Poland). The present study examines the biomonitoring potential of selected plant species and the patterns of heavy metal accumulation in urban areas. Thus the leaves of the four studied plant species were tested for bioaccumulation of the selected heavy metals; Zn, Pb, Cd, Cu, Mn and Fe. Accordingly, we investigated heavy metal uptake by common plants to develop a predictive foliar Metal Accumulation Index (MAI). We aimed to estimate the non-protein thiols (NP-SH), ascorbic acid and proline content as well as to calculate the APTI values for each of the studied species.

2. Materials and methods

2.1. Study area

Dąbrowa Górnicza is a city in the southern part of Poland in Śląskie province, a known industrialized region of the country. The city of Dąbrowa Górnicza lies in the eastern part of the Upper Silesia agglomeration. It covers a total geographical area of 188.8 sq km and is located between latitudes 50°17′25.7″–50°26′52.9″ and longitudes 19°09′16.6″–19°29′17.0″. The city is one of the most contaminated towns in the region and in the country. According to Silesian air monitoring data in 2013, the average levels of air pollutants in the city, when plant sampling occurred, were as follows: PM_{10} 40 μg m^{-3}, benzo(a)pyrene 5.18 ng m^{-3}, SO_2 13 μg m^{-3}, NO_2 24 μg m^{-3}, ozone 42 μg m^{-3} (http://monitoring.katowice.wios.gov.pl). The soil and plant sampling sites selected within the city were located by the biggest industrial plants: the ironworks Arcelor Mittal Poland, Coking Plant “Przyjaźń”, waste processing plant (sites 1, 2, 3, 4), as well as by main roads with heavy traffic (sites 5, 6 and 7), sites 8 and 9 in parks located in the city center, and site 10 located in the vicinity of a man-made water reservoir Pogoria III (green areas, strictly recreational) (Table 1).

2.2. Soil and plant sampling

The four plant species: two trees species *Robinia pseudoacacia* L., *Betula pendula* Roth and two herbaceous plants: *Plantago lanceolata* L. and *Taraxacum officinale* Web available in the study area (except *Betula pendula* at sites 7 and 8) were investigated. The sampling of plant species was performed in mid-June 2013. Three composite leaf samples were taken at each site from all species. Leaves from trees of about the same age were taken from the lower foliage, randomly from all sites and brought to the laboratory on ice for analysis. Soil samples were collected from the same sites. After removing any surface litter, three composite soil samples were sampled from a depth of 0–15 cm at each site.

2.3. Analysis of metal concentration in soil and plant samples

Soil samples were sieved through a 2 mm screen, air dried and used for pH, heavy metal and organic matter estimation. The metal content of the soil was estimated according to the method by Ostrowska et al. (1991) and previously described in detail (Nadgórska-Socha et al., 2013). Metals were extracted from the air-dried samples of soil using 2 M HNO_3 (extracted elements). The applied metal extraction process is recommended as a method in the estimation of contamination levels in industrial areas. Soil pH was measured in a 1:2.5 soil to water weight ratio. Organic matter content (expressed in %) was measured following the method by Ostrowska et al. (1991). The HNO_3-extractable fraction was obtained