Use of trees for reducing particulate matter pollution in air

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Adverse health effects of environmental pollution is a frequent subject of medical and veterinary studies. One of the most dangerous air contaminants is particulate matter (PM). Planting trees as biological filters is considered as a valuable way of reducing number of particles in air. However, there is not enough research on selecting the most efficient plant species/varieties for accumulation of these pollutants. In this study, five commonly cultivated tree species were compared: silver birch, Simon's poplar, callery pear 'Chanticleer', northern red oak and Swedish whitebeam, to identify the differences in accumulation levels of PM on leaf surface. Results showed that all of the tested species accumulated high amounts of PM. Whitebeam and birch were most effective in capturing particles, while lowest levels were found on oak.

Keywords: air contamination, PM, phytoremediation, coarse particles, urban forest.

Introduction

Particulate matter (PM) is present in air as an atmospheric aerosol where solid and liquid, mineral and organic substances are suspended in mixture of gases [1]. It has various sources like natural volcano eruptions, forest fires and sandstorms to anthropogenic vehicle exhausts and processing industries, for instance cement or fertilizers production [2]. Number of toxic compounds like heavy metals and PAHs (polycyclic aromatic hydrocarbons) condensate on the particle surface [3]. PM demonstrates adverse health effects on humans, depending on chemical composition, size and concentration in ambient air. These include respiratory and cardiovascular symptoms like CORD (chronic obstructive respiratory disease), asthma, lung cancer, atherosclerosis and heart failure and thus increased mortality [4–8]. These health harming effects increase with decreasing particle size, described as particle diameter which ranges from 1 nm to 100 μm [3] and only PM_{10} (fraction of particles with diameter of 10 microns and lower) is considered as highly dangerous in view of public health. European law define limit values of PM_{10} concentration in ambient air as annual average of 40 μg m^{-3} [9]. However, concentration on many sites in Poland, e.g. Niepodległości Avenue in Warsaw, permanently exceed permissible level [10].

Plants possess an ability to filter the contaminants from air and retain them on leaves [11]. Leaves of some species are equipped with specific morphological features like trichomes (leaf hair) that may increase the number of captured particles [12]. Epicuticular wax layer, its thickness and composition are important factors for PM accumulation as well, because some particles penetrate inside wax layer and are deposited there [13, 14]. Due to greater leaf area index, trees are able to capture more PM than other vegetation while using the same ground area [15]. Although, this property is widely known, there is limited evidence on effectiveness of this process and differences among plant species. In UK research [11, 16] trees captured significant quantities of particulate matter and Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville) was most effective. Authors indicated the best choice for pollution-control plantings are coniferous tress and those from broad-leaved species that have rough leaf surfaces like hairy-leaved common whitebeam (*Sorbus aria* (L.) Crantz). Research conducted in Beijing (China), where air pollution is very high, showed that trees in city center accumulated 772 tones of PM_{10} during one year [17], while in similar research in Chicago (USA) urban trees, which occupy 11% of city area, removed about 234 tons of PM_{10} [18]. In whole USA, urban trees and shrubs remove 215 kilotons of PM_{10}

a year [19]. McDonald et al. stated that planting trees on one forth of available urban area may reduce PM_{10} concentration by 2–10% [20].

The aim of this study was to evaluate the effectiveness in accumulating airborne particles on foliage by trees commonly planted on road sites in Poland.

Materials and methods

Plant material, study area and sample collecting procedure

The study area was localized in vicinity of Warsaw University of Life Sciences — SGGW campus in Ursynów district, Warsaw, Poland. Leaf samples were collected from trees of five species growing along Ciszewskiego, Rodowicza 'Anody' and Rosoła streets. Following species were used in this study: *Betula pendula* Roth (silver birch), *Populus simonii* Corrière (simon's poplar), *Pyrus calleryana* Decne. 'Chanticleer' (callery pear), *Quercus rubra* L. (northern red oak) and *Sorbus intermedia* (Ehrh.)Pers. (Swedish whitebeam). Samples were collected in early November, at the end of vegetation season, few days before autumn defoliation in 3 growing seasons 2006, 2007 and 2008. In order to receive equalized samples, all leaves were collected from traffic-exposed crown side on height ranging from 1,5 m to 3 m above ground level, depending on tree structure. For each species four batches of 8–12 leaves (quantity depending on leaf area) were collected from four different trees and transported to laboratory in paper bags. In every year samples were collected from the same trees.

Quantitative analysis of PM and waxes

Every batch (sample) of leaves was placed into a glass container and rinsed with water for 60 seconds in order to wash off particles that are potentially washed off during rainfall. Water was then filtered using metal sieve with mesh diameter of 100 μm to eliminate bigger elements. Then, it was filtered using PALL filtering set with vacuum pump on pre-weighted Whatman paper filters with retention of 10 μm and then 2.5 μm to separate two fractions of particles: those with diameter 10–100 μm (less important in view of health problems) and those called coarse particles with diameter 2.5--10 μm (which are part of PM_{10} fraction). Filters were dried then and post-weighted to calculate the mass of each PM fraction in sample.

The same batch of leaves was then rinsed with chloroform for 40 seconds in order to dissolve the epicuticular wax layer from leaf tissue and wash out particles trapped by waxes. The filtering procedure was the same as for water-rinsed particles.

Waxes washed off from leaves was weighted as well after chloroform evaporation. Also leaf area of each sample was measured using Skye Instruments Image Analysis System, so that results are shown in micrograms of PM per square centimeter of leaf area (μg cm^{-2}).

Every batch of leaves (sample) was measured separately as a replicate for statistical analysis.

More detailed procedure is presented in paper under preparation [21].

Statistical analysis

Received data was analyzed using One-Way ANOVA or Multifactor ANOVA using STATGRAPHICS Plus 4.1 software. Significance of differences was estimated using Tukey's test at confidence level of 95%.

Results and discussion

Amounts of particulate matter deposited on leaf surface of five tree species is presented in Fig. 1. Although leaves of tested trees demonstrated high effectiveness in capturing airborne particles in view of average concentration in air, some significant differences between species were recorded. Birch, whitebeam and poplar were most effective, while oak demonstrated lowest levels of PM on leaves.

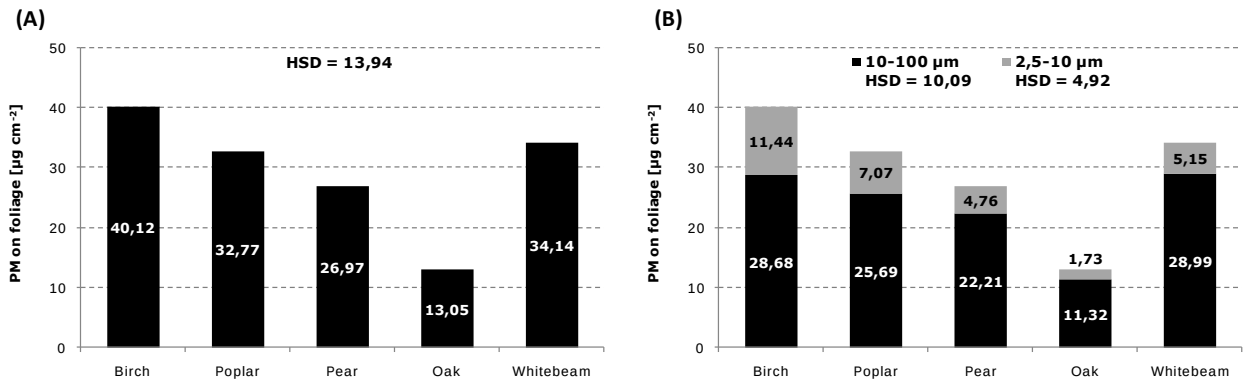

Fig. 1. The mass of whole measured PM with diameter 2.5–100 μm (A) and amounts of separated fractions 2.5–10 and 10–100 μm (B), captured on leaf surface of five tree species. Mean values from 3-year study (n = 8) with Tukey's HSD values at α = 0.05.

Amounts of bigger (10–100 μm in diameter) and smaller (2.5–100 μm in diameter) particles separated as respectively less and more health affecting fractions of PM are also shown in this figure. What is easily noticeable, major content in mass of all measured PM is the bigger fraction. Its weight is 82.5% of all PM on average, ranging from 71.45% for birch to 86.83% for oak. While in comparison of the bigger fraction accumulation, three best species mentioned above demonstrated even equal mass of captured particles, birch turned out to be the most effective in capturing smaller fraction within tested species, with more than sixfold more small PM on leaves than oak. In comparison with this, coniferous Corsican pine in other research [16] with accumulation of coarse particles at about 54 μg cm^{-2}, was more effective than any broad-leaved species. Common whitebeam, species with leaves similar to Swedish whitebeam but even more densely-haired, captured about 40 μg cm^{-2} of coarse fraction.

Data received in 3-year study demonstrated diversity also between years (Fig. 2). This may be caused by specific meteorological events during the vegetation period related to rainfalls and wind direction, especially directly before samples collection in each season, however collection was run rather before rain events, after as many dry days as possible in every season. Although these differences were significant, relations between species were usually maintained.

Comparative data about PM rinsed with different agents is presented in Fig. 3. Amounts of particles rinsed with water that can be washed off during heavy rainfalls and those rinsed with chloroform that were trapped in epicuticular waxes, deposited inside wax layer and therefore retained for longer period of time are displayed separately for both diameter fractions. For the water-rinsed particles, whitebeam demonstrated highest accumulation of bigger fraction followed by pear and poplar, while poplar and birch respectively captured most of smaller fraction. Regarding chloroform--rinsed particles, these may be considered as the most interesting. Particles which are trapped in wax are hydrophobic thus probably contain most harmful organic substances like e.g. aliphatic and aromatic hydrocarbons. In view of this, birch as the most effective

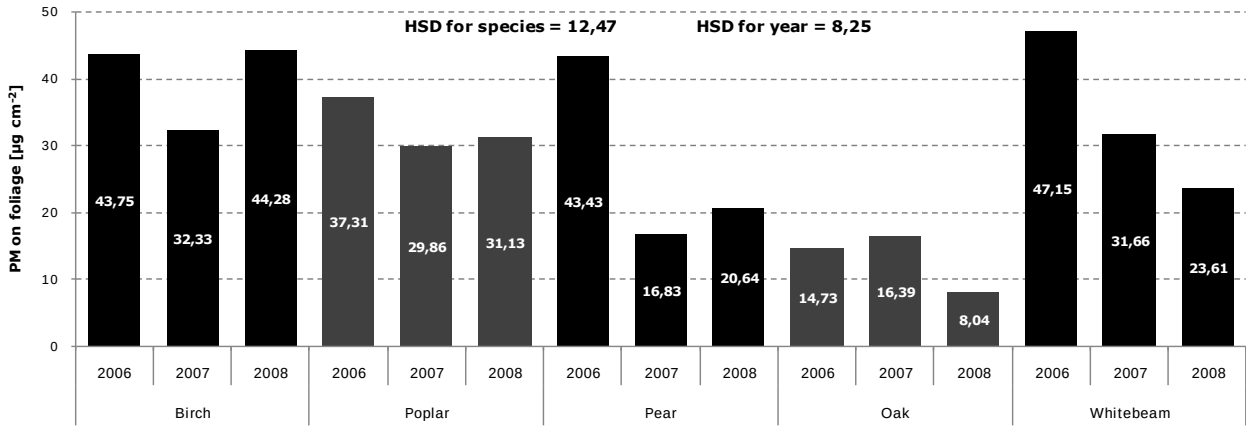

Fig. 2. The mass of total measured PM with diameter 2.5–100 μm captured on leaves of five tree species. Mean values from repeated 1-year studies (n = 4) with Tukey's HSD values at α = 0.05.

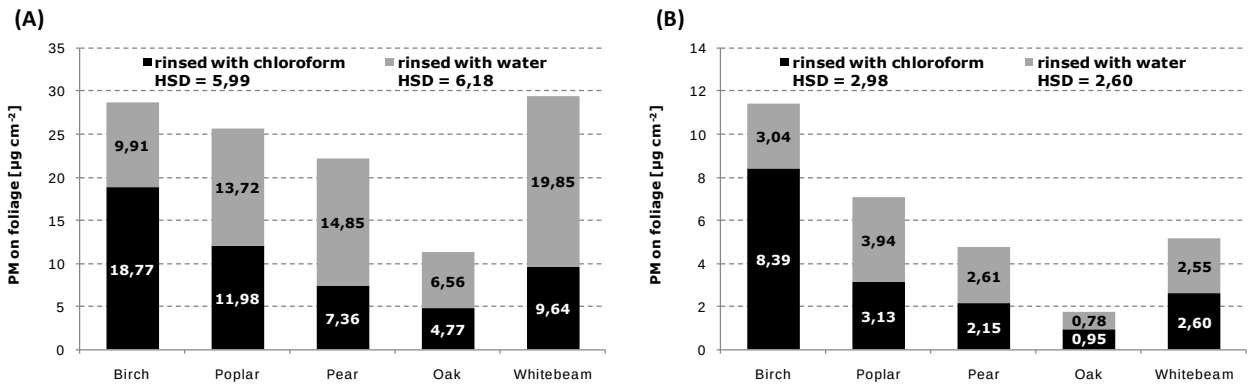

Fig. 3. The mass of PM with diameter 10–100 μm (A) and 2.5–10 μm (B), captured on leaves of five tree species separated by rinsing agent used. Mean values from 3-year study (n = 8) with Tukey's HSD values at α=0.05.

Table 1. Mass of epicuticular wax washed out from leaves of five tree species as mean values from 3-year study (n = 8) with Tukey's HSD value at α = 0.05 and Pearson correlation coefficients (r) for wax-related PM and wax.

Species	Birch	Poplar	Pear	Oak	Whitebeam	HSD
Epicuticular wax [μg cm^{-2}]	684,60	58,24	98,75	98,85	85,80	101,45
PM Ø 10-100 μg with wax (*r*)	-0,02	0,62	0,70	0,49	0,27	—
PM Ø 2,5-10 μg with wax (*r*)	0,19	0,24	0,72	0,12	-0,04	—

accumulator of wax-related PM seems to be the best species for traffic-related sites, where organic substances from vehicle exhausts are present in highest concentrations. Birch, as showed in Fig. 3(B), demonstrated three to over eightfold higher accumulation rate of smaller and wax-related PM than other tested species. In this study, oak, regardless of the fraction and rinsing-agent, was the least effective species.

Highest rates of PM assayed on leaves of silver birch are probably a result of thick epicuticular wax layer, characteristic for this species. There was over sixfold more waxes on birch leaves than on other species (Table 1). This advantage of silver birch was previously indicated by Popek et al. [22] in screening research amongst 16 commonly planted tree species. However, no significant correlation was found in present research between amount of waxes and wax-related particles, especially in birch leaves (Table 1). Pear demonstrated moderately strong correlation between PM fractions and wax content, while other species had moderately weak correlation or no-correlation between these parameters. This reaffirms, what was noticed in previous research [data not published], that not only amount of waxes is important for trapping PM. Probably chemical composition and structures of wax layer, which are a species-specific trait, are also essential.

Conclusions

Three-year study on PM accumulation on foliage of five tree species presented in this paper, allows to draw the conclusions as follows:

- Trees planted at road sites are able to improve the air by capturing particles and depositing them on leaves;
- There are significant differences in effectiveness between tested species;
- Species with densely-haired leaves (Swedish whitebeam) is more effective in capturing bigger particles (10–100 μm), especially those easily removable during rainfall;
- Species characterized for very thick layer of epicuticular waxes (silver birch) is much more effective in capturing smaller particles, especially wax-related ones that are deposited inside wax layer;
- The amount of particles inside epicuticular wax layer is not directly connected with amount of waxes;
- Among tested tree species, silver birch is most effective and northern red oak is less effective in improving ambient air via capturing the most health-affecting particles of diameter lower than 10 μm.

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