PM$_{10}$ and PM$_{2.5}$ Dust-Retention Capacity and Leaf Morphological Characteristics of Landscape Tree Species in the Northwest of Hebei Province

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Abstract: This study aimed to explain the reasons for the differences in the PM$_{2.5}$ and PM$_{10}$ dust-retention capacity of different tree species. Ten typical landscape tree species with a strong ability to adsorb particulate matter and improve the quality of the atmospheric environment were selected in Zhangjiakou, and the leaves of each tree species were collected from April to October. The PM$_{2.5}$ and PM$_{10}$ dust-retention capacity of different tree species were measured using an aerosol regenerator. The differences in the leaf structure of different tree species were analyzed using an electron microscope. The results showed that the PM$_{10}$ and PM$_{2.5}$ per unit leaf area of 10 tree species ranged from 1.31 ± 0.68 to 2.64 ± 1.29 µg cm$^{-2}$ and from 0.28 ± 0.13 to 0.99 ± 0.34 µg cm$^{-2}$, and the PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per unit leaf area of coniferous trees was higher than that of broad-leaved trees. Further, the PM$_{10}$ dust-retention capacity per unit leaf area of each tree species in different months was the highest in October (3.17 ± 1.12 µg cm$^{-2}$) and the lowest in August (0.79 ± 0.56 µg cm$^{-2}$). The PM$_{2.5}$ dust-retention capacity per unit leaf area was the highest in October (0.99 ± 0.34 µg cm$^{-2}$) and the lowest in April (0.28 ± 0.13 µg cm$^{-2}$). The annual PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per hectare of *Pinus tabulaeformis* was the highest and that of *Ginkgo biloba* was the lowest. The conifer trees have rough leaves, and broad-leaved trees have smooth leaves. The leaves of *P. tabulaeformis* and *Picea asperata* have a widespread stomata distribution, and the leaf surface is not smooth, with a large number of grooves and bulges. The number of stomata on the leaf surface of *Salix babylonica* and *G. biloba* is less than that of *P. tabulaeformis* and *P. asperata*. When the dust-retention capacity of PM$_{2.5}$ per unit leaf area is high, the corresponding roughness is also significant, and a good logarithmic relationship exists between roughness and PM$_{2.5}$ per unit leaf area ($R^2 = 0.9504$). The results of this study might have an important reference value in terms of the selection of tree species with strong PM$_{10}$ and PM$_{2.5}$ dust-retention capacity and the improvement in ambient air quality in the northwest of Hebei Province.

Keywords: landscape tree species; leaf dust retention; leaf morphology; PM$_{10}$ and PM$_{2.5}$; Zhangjiakou

1. Introduction

Atmospheric aerosol is one of the core components in the study of climate and environment. It has a direct impact on human health, resulting in respiratory and cardiovascular diseases [1]. Epidemiological and toxicological studies showed that particles carrying a variety of chemicals could have a severe negative impact on human health [2]. Fine particulate matter (aerodynamic diameter <2.5 µm, PM$_{2.5}$) and coarse particulate matter (aerodynamic diameter 2.5–10 µm, PM$_{10}$) are important constituents of aerosol. As the main air pollutant in cities [3,4], atmospheric particulate matter has always been the focus of research in the field of an urban environment, as well as the main index reflecting ambient air quality. The diffusion of particulate matter in the atmosphere can significantly reduce visibility, leading to haze formation. Particulate matter can enter the human respiratory tract, increase the
risk of cardiopulmonary diseases, and cause significant harm to human health [5,6]. It also has negative effects on social economy and urban environment. According to their aerodynamic diameter, atmospheric particles can be divided into micron particles (diameter >1 µm), submicron particles (0.1–1 µm), and ultrafine particles (diameter <0.1 µm). PM$_{2.5}$ and PM$_{10}$ are the main components of particulate matter on the micron scale. PM$_{2.5}$ refers to particulate matter with a diameter of 2.5 µm or less, and PM$_{10}$ refers to particulate matter with a diameter of 10 µm or less. The smaller the particle size, the higher the optical absorption coefficient, resulting in lower atmospheric visibility [7]. As the host city of snow events for the 2022 Winter Olympic Games, the ambient air quality of Zhangjiakou has attracted public attention. According to the Statistical Bulletin of the National Economic and Social Development of Zhangjiakou in 2019 [8], the ambient air quality of the whole year reached the standard for 308 days in the central urban area, with a compliance rate of 84.4%; the comprehensive ambient air quality index of Zhangjiakou was 3.53, ranking first in the Hebei Province. In 2019, PM$_{2.5}$ and PM$_{10}$ were still the main pollutants in the province [9]. Therefore, measures to effectively reduce the concentration of PM$_{2.5}$ and PM$_{10}$ and improve the urban environment, and thereby retain a good image of Zhangjiakou City before the world, are of considerable significance. PM$_{2.5}$ and PM$_{10}$ concentrations can be reduced both by reducing pollution sources and through forest vegetation. Forest vegetation purifies the atmospheric environment and reduces the mass concentration of particulate matter in the atmosphere via stomata (dermis) absorption, leaf lag, and internal degradation so as to fully improve the environmental quality; this has been the topic of studies conducted globally [10]. The forest cover has increased from 3.6% to 8% in La Costa, and the mean concentration of PM$_{10}$ has reduced to 2% (removed 4 tons per year) [11]. Lu et al. [12] found that the PM$_{2.5}$ adsorption amount per unit leaf area was reduced by 23.25% as the altitude increased by 50 m. However, the existing studies cannot fully clarify the reasons for the differences in the dust-retention capacity of different tree species and the overdue particles of different tree species. Therefore, the purpose of this study was to explain the reasons for the difference of dust retention capacity between PM$_{2.5}$ and PM$_{10}$ of different tree species, and to analyze the mechanism of the difference in the amount of particles adsorbed by different tree species from the leaf morphology and roughness, we selected 10 typical landscape tree species in Zhangjiakou City, collected the leaves of each tree species from April to October, and used an aerosol regenerator to measure the PM$_{2.5}$ and PM$_{10}$ dust-retention capacity of the leaves of different tree species. The suitable tree species with strong fine particulate matter-retention capacity in Zhangjiakou City were pointed out. The results of this study might help improve the environment of northwest Hebei Province.

2. Materials and Methods

2.1. Selection of Tree Species

Zhangjiakou is in the northwest of Hebei Province. It has met the national environmental air quality standards due to the hosting of the Winter Olympic Games. Its anthropogenic air pollutant emission intensity is also at a low level, but the pollution exceeds the standard in winter on some days. PM$_{2.5}$ is added to Zhangjiakou’s environment via industrial, residential, transportation, agricultural, and power generation sources, contributing 34.5%, 29.7%, 15.7%, and 6.4%, respectively. The main types of pollution sources in Zhangjiakou are residential sources (17.6%), industrial sources (16.6%), and agricultural sources (8.8%) [13]. The study was conducted in Zhangjiakou People’s Park, the largest comprehensive park, with a total area of about 12.43 hm$^2$. The atmospheric and environmental conditions in the park are consistent, and the pollution sources are the same. The park was built in the early 19th century and is located on the west bank of the Qingshui River in the city center. A total of 10 common and typical tree species with similar forest ages in Zhangjiakou People’s Park were selected. These included P. tabulaeformis, P. orientalis, P. bungeana, Picea asperata, G. biloba, Salix babylonica, Populus, Fraxinus chinensis, Sophora japonica, and Acer mono. These 10 tree species, on average, accounted for more than 85% of the landscape tree species in the study area (Table 1).
Table 1. Basic information on different tree species.

| Tree Species            | Height (m, Mean ± SD) | Breast Diameter (cm, Mean ± SD) | Crown Width (m) |
|-------------------------|------------------------|---------------------------------|-----------------|
|                         |                        |                                 | East–West (Mean ± SD) | North–South (Mean ± SD) |
| Pinus tabulaeformis     | 7.85 ± 2.45            | 12.04 ± 3.54                    | 2.33 ± 0.45      | 2.58 ± 0.58 |
| Platycladus orientalis  | 7.04 ± 3.22            | 11.54 ± 2.87                    | 2.45 ± 0.47      | 2.54 ± 0.65 |
| Pinus bungeana          | 5.88 ± 2.12            | 10.24 ± 2.14                    | 2.68 ± 0.58      | 2.55 ± 0.45 |
| Picea asperata          | 6.58 ± 1.58            | 11.55 ± 2.54                    | 1.25 ± 0.33      | 1.35 ± 0.54 |
| Ginkgo biloba           | 9.88 ± 3.64            | 14.25 ± 3.54                    | 1.68 ± 0.24      | 1.85 ± 0.74 |
| Salix babylonica        | 10.85 ± 5.64           | 16.54 ± 4.14                    | 3.54 ± 1.02      | 4.55 ± 1.58 |
| Populus                 | 14.53 ± 6.54           | 22.54 ± 4.75                    | 4.12 ± 1.88      | 3.85 ± 1.68 |
| Fraxinus chinensis      | 12.53 ± 3.45           | 19.54 ± 3.25                    | 3.12 ± 1.42      | 2.57 ± 1.44 |
| Sophora japonica       | 11.33 ± 3.58           | 15.32 ± 3.54                    | 2.85 ± 2.01      | 3.02 ± 1.85 |
| Acer mono               | 7.85 ± 3.55            | 12.78 ± 2.47                    | 2.24 ± 1.02      | 2.64 ± 1.33 |

2.2. Foliage Collection Method

From April to October, three trees of different tree species were selected for field sampling (avoiding rainy days). The leaves of coniferous and broad-leaved tree species were collected at the upper, middle, and lower positions of the tree crown in the east, south, west, and north directions. All blades weighed more than 100 g. The leaves were collected three times a month. After the collection, the leaves were taken to the laboratory.

2.3. Determination of PM$_{2.5}$ and PM$_{10}$ Absorption Capacity of Tree Species

The aerosol regenerator (QRJZFSQ-II) was used to measure the particulate matter (PM$_{2.5}$) in leaves of different tree species. According to the method used by Zhang et al. [14] and Niu et al. [15], the particulate matter ($M$) of PM$_{2.5}$ and PM$_{10}$ per unit leaf area was calculated via Equation. The PM$_{2.5}$ and PM$_{10}$ dust-retention capacity per hectare of forest-land ($Q$) was calculated via Equation.

\[
M = \frac{m}{A}
\]

\[
Q = 0.1M \times LAI \times k
\]

where $M$ is the PM$_{2.5}$ and PM$_{10}$ dust-retention capacity of tree species per unit leaf area ($\mu g \cdot cm^{-2}$); $m$ is the residual amount of PM$_{2.5}$ and PM$_{10}$ ($\mu g$) in the leaves placed into the aerosol regenerator; $A$ is the leaf area ($cm^2$) of all the leaves placed in the aerosol regenerator cartridge; $Q$ is the PM$_{2.5}$ and PM$_{10}$ dust-retention capacity per hectare of forest land, kg/(hm$^2$·a); LAI is the leaf area index; 0.1 is the unit conversion coefficient; $k$ is the elution times per year. The amount and intensity of rainfall affected the cleaning of PM$_{2.5}$ and PM$_{10}$. The annual elution times of PM$_{10}$ and PM$_{2.5}$ were observed to be 18 and 12, respectively, based on the local rainfall data.

2.4. Roughness of Leaf Surface of Different Tree Species

In the laboratory, the fronts and backs of the leaves were washed with distilled water. The water on the surfaces of the leaves was carefully removed with absorbent paper. The relatively flat surface of the leaves was selected, trying to avoid the veins of the leaves and making it a sample measuring about 5 × 5 mm$^2$. At room temperature, the samples were scanned and photographed with a gold-coated Si$_3$N$_4$ probe using a scanning probe microscope (spi3800-spa-400, Seiko Instruments Inc., Chiba, Japan) in noncontact atomic force microscopy (AFM) analysis mode. The scanning rate was 0.5 Hz, the lateral resolution was 0.2 nm, the vertical resolution was 0.01 nm, and the maximum scanning range was 10 × 10 μm$^2$. All AFM images were in height mode, and no processing was performed on the images.
2.5. Leaf Surface Micromorphological Structure of Different Tree Species

An appropriate number of leaves were picked and immediately sealed in plastic paper to prevent the extrusion or damage of leaf hairs. The fresh leaves were cut into small cubes with a side length of about 5 mm in the middle of both sides of the vein and fixed immediately using 2.5% (volume fraction) glutaraldehyde solution. Then, the leaves were rinsed with phosphoric acid buffer solution three times, dehydrated with gradient ethanol, and divided into five gradients: 70%, 80%, 90%, 95%, and 100%. After the sample was sprayed with gold, the FEI Quanta 200 environmental scanning electron microscope (FEI Company, Eindhoven, The Netherlands) was used to observe the surface of the blade and select a suitable proportion for photographing.

3. Results and Analysis

3.1. Analysis of PM$_{10}$ Dust-Retention Capacity of Different Tree Species

The PM$_{10}$ dust-retention capacity per unit leaf area of 10 tree species ranged from $1.31 \pm 0.68$ to $2.64 \pm 1.29$ µg·cm$^{-2}$, and the PM$_{10}$ dust-retention capacity per unit leaf area of each tree species was greater than that of broad-leaved trees (Table 2). The average PM$_{10}$ dust-retention capacity per unit leaf area of coniferous trees was above $1.80$ µg·cm$^{-2}$, while that of broad-leaved trees was below $1.60$ µg·cm$^{-2}$. Hence, all four coniferous trees had high PM$_{10}$ dust-retention capacity, while all six broad-leaved trees had low PM$_{10}$ dust-retention capacity. The PM$_{10}$ dust-retention capacity per unit leaf area of *Platycladus orientalis* was the highest ($2.64 \pm 1.29$ µg·cm$^{-2}$), followed by *Pinus bungeana* ($2.56 \pm 1.08$ µg·cm$^{-2}$). Among the broad-leaved tree species, *Acer mono* ($1.58 \pm 0.55$ µg·cm$^{-2}$) and *Fraxinus chinensis* ($1.47 \pm 0.65$ µg·cm$^{-2}$) had the highest PM$_{10}$ dust-retention capacity per unit leaf area, while *Ginkgo biloba* ($1.31 \pm 0.68$ µg·cm$^{-2}$) had the lowest. The highest PM$_{10}$ dust-retention capacity was observed in October, followed by September and May, and the lowest capacity was in August. The PM$_{10}$ dust-retention capacity per unit area of each tree species in different months was in the order of October ($3.17 \pm 1.12$ µg·cm$^{-2}$) > September ($2.75 \pm 0.53$ µg·cm$^{-2}$) > May ($1.53 \pm 0.40$ µg·cm$^{-2}$) > July ($1.44 \pm 0.33$ µg·cm$^{-2}$) > June ($1.41 \pm 0.48$ µg·cm$^{-2}$) > April ($1.20 \pm 0.46$ µg·cm$^{-2}$) > August ($0.79 \pm 0.56$ µg·cm$^{-2}$). The value in October was 4.03 times that in August.

### Table 2. PM$_{10}$ dust-retention capacity of leaves of different tree species (µg·cm$^{-2}$).

| Tree Species          | April | May  | June | July | August | September | October | Mean ± SD |
|-----------------------|-------|------|------|------|--------|-----------|---------|-----------|
| *Pinus tabulaeformis* | 1.81  | 1.70 | 1.99 | 1.50 | 1.38   | 3.96      | 5.03    | 2.64 ± 1.29 |
| *Platycladus orientalis* | 1.86  | 1.62 | 1.59 | 1.32 | 0.94   | 2.69      | 3.77    | 1.97 ± 0.89 |
| *Pinus bungeana*      | 1.82  | 2.01 | 2.34 | 1.91 | 1.71   | 3.12      | 4.98    | 2.56 ± 1.08 |
| *Picea asperata*      | 1.21  | 2.15 | 1.18 | 1.60 | 0.28   | 2.99      | 3.79    | 1.89 ± 1.10 |
| *Ginkgo biloba*       | 0.79  | 1.33 | 1.05 | 1.27 | 0.25   | 2.20      | 2.28    | 1.31 ± 0.68 |
| *Salix babylonica*    | 1.16  | 1.67 | 1.11 | 1.02 | 0.37   | 2.11      | 2.54    | 1.43 ± 0.68 |
| *Populus*             | 0.76  | 1.10 | 1.02 | 0.95 | 0.17   | 2.93      | 2.43    | 1.34 ± 0.90 |
| *Fraxinus chinensis*  | 0.72  | 1.04 | 1.15 | 1.69 | 0.90   | 2.49      | 2.29    | 1.47 ± 0.65 |
| *Sophora japonica*    | 0.82  | 1.05 | 1.15 | 1.01 | 0.70   | 2.48      | 2.31    | 1.36 ± 0.67 |
| *Acer mono*           | 1.07  | 1.38 | 1.28 | 1.92 | 0.86   | 2.48      | 2.08    | 1.58 ± 0.55 |
| **Mean**              | 1.20 ± 0.46 | 1.53 ± 0.40 | 1.41 ± 0.48 | 1.44 ± 0.33 | 0.79 ± 0.56 | 2.75 ± 0.53 | 3.17 ± 1.12 | 1.75 ± 0.80 |

In addition, significant differences were found in the annual PM$_{10}$ dust-retention capacity per hectare of different tree species (Figure 1). The annual PM$_{10}$ dust-retention capacity per hectare of different tree species was still greater in coniferous than in broad-leaved trees, with *Platycladus orientalis* having the highest PM$_{10}$ dust-retention capacity, followed by *Pinus bungeana*. Among the broad-leaved tree species, *Acer mono* and *F. chinensis* had the highest PM$_{10}$ dust-retention capacity, while *Populus* and *G. biloba* had the lowest. The annual overdue PM$_{10}$ per hectare of different tree species was in the order of *P. tabulaeformis* (15.64 ± 1.71 kg/(hm$^2$-a)) > *P. bungeana* (15.18 ± 1.33 kg/(hm$^2$-a)) > *P. orientalis* (11.00 ± 1.02 kg/(hm$^2$-a)) > *P. asperata* (10.45 ± 1.38 kg/(hm$^2$-a)) > *A. mono*...
(7.12 ± 0.51 kg/(hm²-a)) > F. chinensis (6.88 ± 0.63 kg/(hm²-a)) > Salix babylonica (6.81 ± 0.84 kg/(hm²-a)) > S. japonica (6.37 ± 0.65 kg/(hm²-a)) > Populus (6.02 ± 0.84 kg/(hm²-a)) > G. biloba (5.66 ± 0.60 kg/(hm²-a)). The annual PM₁₀ dust-retention capacity of *P. tabulaeformis* was 2.76 times that of *G. biloba*.

![Figure 1](image_url)  
**Figure 1.** Annual PM₁₀ dust-retention capacity per hectare of different tree species.

### 3.2. Analysis of PM₂.₅ Dust-Retention Capacity of Leaves of Different Tree Species

The mean PM₂.₅ dust-retention capacity of leaves of different tree species from April to October was between 0.28 ± 0.13 and 0.99 ± 0.34 μg·cm⁻² (Table 3). The PM₂.₅ dust-retention capacity per unit leaf area of coniferous trees was higher than that of broad-leaved trees. The mean of PM₂.₅ dust-retention capacity per unit leaf area of coniferous trees was above 0.60 μg·cm⁻², while that of broad-leaved trees was below 0.50 μg·cm⁻². The top four species in terms of PM₂.₅ dust-retention capacity per unit leaf area were coniferous trees, while broad-leaved trees ranked among the bottom six. The PM₂.₅ dust-retention capacity per unit area of the leaves of *P. tabulaeformis* was the highest (0.80 ± 0.35 μg·cm⁻²), followed by *P. bungeana* (0.74 ± 0.33 μg·cm⁻²). Among the broad-leaved tree species, *S. babylonica* (0.54 ± 0.21 μg·cm⁻²) had the highest PM₂.₅ dust-retention capacity per unit leaf area, followed by *A. mono* (0.43 ± 0.16 μg·cm⁻²) and *F. chinensis* (0.42 ± 0.20 μg·cm⁻²); *G. biloba* (0.35 ± 0.21 μg·cm⁻²) had the lowest dust-retention capacity. The PM₂.₅ dust-retention capacity was the highest in October, followed by September and June, and the lowest capacity was observed in April. The PM₂.₅ dust-retention capacity per unit leaf area of different tree species ranged from 0.63 to 1.60 μg·cm⁻² in October, from 0.42 to 0.81 μg·cm⁻² in September, and between 0.09 and 0.54 μg·cm⁻² in April. The order of PM₂.₅ dust-retention capacity per unit area of each tree species in different months was in the order of October (0.99 ± 0.34 μg·cm⁻²) > September (0.65 ± 0.11 μg·cm⁻²) > June (0.54 ± 0.20 μg·cm⁻²) > July (0.51 ± 0.16 μg·cm⁻²) > May (0.39 ± 0.24 μg·cm⁻²) > August (0.33 ± 0.08 μg·cm⁻²) > April (0.28 ± 0.13 μg·cm⁻²). The dust-retention capacity per unit area was 3.50 times higher in October than in April.

The annual PM₂.₅ dust-retention capacity per hectare of different tree species was still greater in coniferous than in broad-leaved trees (Figure 2); it was the highest for *P. tabulaeformis*, followed by *P. bungeana*. Among the broad-leaved tree species, *S. babylonica* and *F. chinensis* had the highest PM₂.₅ dust-retention capacity, and *Populus* had the second-lowest and *G. biloba* had the lowest. The PM₂.₅ dust-retention capacity per hectare of different tree species was the highest in *P. tabulaeformis* (3.35 ± 0.98 kg/(hm²-a)) and the lowest in *G. biloba* (1.03 ± 0.42 kg/(hm²-a)). The PM₂.₅ dust-retention capacity per hectare of *P. tabulaeformis* was 3.24 times that of *G. biloba*. 
Table 3. PM$_{2.5}$ dust-retention capacity of leaves of different tree species (µg·cm$^{-2}$).

| Tree Species         | April | May   | June  | July  | August | September | October | Mean ± SD |
|----------------------|-------|-------|-------|-------|--------|-----------|---------|-----------|
| Pinus tabulaeformis  | 0.54  | 0.68  | 0.85  | 0.75  | 0.45   | 0.73      | 1.60    | 0.80 ± 0.35 |
| Platycladus orientalis | 0.42  | 0.78  | 0.81  | 0.56  | 0.36   | 0.73      | 1.24    | 0.70 ± 0.27 |
| Pinus bungeana       | 0.31  | 0.67  | 0.85  | 0.74  | 0.44   | 0.71      | 1.44    | 0.74 ± 0.33 |
| Picea asperata       | 0.41  | 0.46  | 0.45  | 0.60  | 0.37   | 0.81      | 1.32    | 0.63 ± 0.31 |
| Ginkgo biloba        | 0.09  | 0.16  | 0.34  | 0.33  | 0.24   | 0.64      | 0.68    | 0.35 ± 0.21 |
| Salix babylonica     | 0.32  | 0.38  | 0.39  | 0.24  | 0.23   | 0.66      | 0.84    | 0.54 ± 0.21 |
| Populus              | 0.24  | 0.14  | 0.32  | 0.31  | 0.23   | 0.59      | 0.77    | 0.37 ± 0.21 |
| Fraxinus chinensis   | 0.20  | 0.11  | 0.43  | 0.54  | 0.34   | 0.64      | 0.71    | 0.42 ± 0.20 |
| Sophora japonica     | 0.20  | 0.17  | 0.43  | 0.48  | 0.31   | 0.42      | 0.72    | 0.39 ± 0.17 |
| Acer mono            | 0.12  | 0.32  | 0.54  | 0.53  | 0.34   | 0.54      | 0.63    | 0.43 ± 0.16 |
| Mean                 | 0.28 ± 0.13 | 0.39 ± 0.24 | 0.54 ± 0.20 | 0.51 ± 0.16 | 0.33 ± 0.08 | 0.65 ± 0.11 | 0.99 ± 0.36 | 0.53 ± 0.16 |

Figure 2. Annual PM$_{2.5}$ dust-retention capacity per hectare of different tree species.

3.3. Relationship between Particulate Matter Dust-Retention Capacity and Leaf Morphological Characteristics of Different Tree Species

3.3.1. Relationship between Morphological and Leaf Surface Characteristics of Different Tree Species and Particulate Matter Dust-Retention Capacity

Four representative tree species (the coniferous and broad-leaved tree species with the highest and the lowest dust-retention capacity) were selected from the 10 tree samples: *P. tabulaeformis*, *P. asperata*, *S. babylonica*, and *G. biloba*. The leaf surface characteristics of different tree species at different times in April and October were described. The month of April was when the experiment began and it was the time of the early stage of tree growth. October was the last sampling month in this study, which was also the end stage of the growth of trees. A significant difference was found in leaf morphology in this period. Figure 3 shows that a large number of stomata were found on the leaves of *P. tabulaeformis* and *P. asperata* in April, and stomata were clearly visible. The leaf surface of *P. tabulaeformis* and *P. asperata* was not smooth, with a large number of grooves and bumps. In April, the number of stomata on the leaf surface of *S. babylonica* and *G. biloba* was lower than that of *P. tabulaeformis* and *P. asperata*. The leaf surface of *G. biloba* was very smooth, and the stomata distribution could hardly be seen. In October, a large number of particulate matter was present on the leaf surface of the four tree species, and the leaves were rougher. The number of particulate matter on the leaf surface of *P. tabulaeformis* and *P. asperata* was significantly higher than that of *S. babylonica* and *G. biloba*. The leaf surface roughness of *S. babylonica*
and *G. biloba* was also greater than that in April, and the stomata were full of particulate matter. The leaves of coniferous trees were rougher, while the leaves of broad-leaved trees were smoother.

**Figure 3.** Leaf morphological characteristics of typical tree species in April and October.
3.3.2. Relationship between Particulate Matter Dust-Retention Capacity and Leaf Roughness of Different Tree Species

Figure 4 shows the relationship between the PM$_{2.5}$ dust-retention capacity per unit leaf area of different tree species and the leaf roughness of the corresponding tree species. When the PM$_{2.5}$ dust-retention capacity per unit leaf area was high, the corresponding roughness was also significant. A good logarithmic relationship existed between the roughness and the PM$_{2.5}$ dust-retention capacity per unit leaf area: $y = 44.438 \ln(x) + 36.914$ ($R^2 = 0.9504$). For example, *G. biloba* had the lowest PM$_{2.5}$ dust-retention capacity per unit leaf area (only $0.35 \pm 0.21 \, \mu g \cdot cm^{-2}$); its corresponding roughness was lower ($35.68 \pm 8.54$ nm). The maximum PM$_{2.5}$ dust-retention capacity per unit leaf area was $0.80 \pm 0.35 \, \mu g \cdot cm^{-2}$. The corresponding roughness was also significant, which was $144.35 \pm 25.63$ nm. The leaf roughness of *P. tabulaeformis* was 4.05 times that of *G. biloba*. The leaf roughness of other tree species also showed basically the same result as PM$_{2.5}$ retention per unit leaf area.

Figure 5 shows the relationship between the PM$_{10}$ dust-retention capacity per unit leaf area of different tree species and the leaf roughness of the corresponding tree species. When the PM$_{10}$ dust-retention capacity per unit leaf area was high, the corresponding roughness was also significant, and a good logarithmic relationship existed between the roughness and the PM$_{10}$ dust-retention capacity per unit leaf area: $y = 43.101 \ln(x) + 38.934$ ($R^2 = 0.8941$). For example, the PM$_{10}$ per unit leaf area of *G. biloba* and *Populus* was only $1.31 \pm 0.68$ and $1.34 \pm 0.90 \, \mu g \cdot cm^{-2}$, respectively; the corresponding roughness was also lower, $35.68 \pm 8.54$ and $73.45 \pm 10.28$ nm, respectively. The PM$_{10}$ dust-retention capacity per unit leaf area of *P. bungeana* and *P. tabulaeformis* was the highest ($2.56 \pm 1.08$ and $2.64 \pm 1.29 \, \mu g \cdot cm^{-2}$, respectively), and the corresponding roughness was also significant ($135.88 \pm 22.45$ and $144.35 \pm 25.63$ nm, respectively). The leaf roughness of *P. tabulaeformis* was 4.05 times that of *G. biloba*. The leaf roughness of other tree species also showed the same result as PM$_{10}$ dust-retention capacity per unit leaf area.

![Figure 4. Relationship between PM$_{2.5}$ dust-retention capacity and leaf roughness of different tree species.](image)
4. Discussion

4.1. Analysis of the Differences in PM$_{10}$ and PM$_{2.5}$ Dust-Retention Capacities of Different Tree Species

The PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per unit leaf area of different tree species ranged from $1.31 \pm 0.68$ to $2.64 \pm 1.29$ µg·cm$^{-2}$ and $0.28 \pm 0.13$ to $0.99 \pm 0.34$ µg·cm$^{-2}$, respectively, with coniferous trees showing higher dust-retention capacity than the broad-leaved trees. The average PM$_{10}$ dust-retention capacity per unit leaf area of conifers was above $1.80$ µg·cm$^{-2}$, while that of broad-leaved trees was below $1.60$ µg·cm$^{-2}$. The coniferous trees exhibited the top four dust-retention capacities, and all six broad-leaved trees had comparatively lower dust-retention capacities. The PM$_{2.5}$ dust-retention capacity per unit leaf area of different tree species was the same as that of PM$_{10}$. This indicated that the fine particulate matter dust-retention capacity of coniferous trees was greater than that of broad-leaved trees. The highest fine particulate matter dust-retention capacity was observed in *P. tabulaeformis* and *P. bungeana* among conifers and *S. babylonica* and *F. chinensis* among broad-leaved trees. *G. biloba* and *Populus* had the lowest such capacity.

This was because the foliar structure of different tree species was different. Studies found that tree species with more pores and villi and significant roughness were more conducive to lagging particles, while tree species with smooth leaves were not conducive to lagging particles adhering to their surface [16,17]. Many studies [18,19] pointed out that the leaves of coniferous trees were rougher, and the leaves of broad-leaved trees were smoother than those of coniferous trees. Therefore, the capacity of coniferous trees to hold particulate matter was higher than that of broad-leaved trees, which was consistent with the results of this study.

This study showed that the PM$_{10}$ dust-retention capacity per unit leaf area of each tree species in different months was in the order of October > September > May > July > June > April > August, and that of PM$_{2.5}$ was in the order of October > September > June > July > May > August > April. It was seen that the particulate matter dust-retention capacity of different tree species was the highest in October and September and the lowest in August and April. The dust-retention capacity of leaves significantly changed with weather conditions, such as rainfall, wind, and sand dust. The amount of dust washed away by the same rainfall was also different due to the differences in leaf surface structure. This indicated that the dust-retention process of plant leaves was a complex and dynamic process, which was not linearly related to the passage of time, but also involved dust retention and dust shedding at the same time [20]. Wang et al. [21] observed the dust...
retention on the leaf surfaces of some coniferous tree species in Beijing and found that many particles were hidden in the grooves between the dense ridges on the leaf surfaces of *P. orientalis* and *S. chinensis*, and the particles were firmly attached and not easy to be washed away by moderate-intensity (14.5 mm) rainfall. This was related to the growth status of trees at different times, weather conditions, and mass concentration of particulate matter outside. In this study, April was the period when the trees taken for this study had just started growing leaves. Most of the trees at that time had tender leaves, and both coniferous and broad-leaved trees had a low capacity to hold particulate matter. August had the rainy season, with the highest rainfall of 43.67 mm. Under the scouring effect of rainfall, a large number of overdue particles on the leaves of trees were washed out. Hence, the particulate matter dust-retention capacity of different tree species in August was the lowest. In October and September, trees grew for a long time and belonged to the late stage of growth. With the prolongation of growth time, the quantity of particulate matter on leaves increased. Moreover, September and October belonged to the autumn season. The mass concentration of PM$_{2.5}$ in autumn was 20.80 µg·m$^{-3}$, and the mass concentration of PM$_{2.5}$ in summer was 18.13 µg·m$^{-3}$. The mass concentration of PM$_{2.5}$ in autumn was 1.11 times that in summer. In autumn, more particulate matter sources fell on the surface of trees and leaves. Therefore, the particulate matter dust-retention capacity of different tree species was the highest in October and September.

### 4.2. Relationship between Particulate Matter Dust-Retention Capacity and Leaf Morphological Characteristics of Different Tree Species

Under the influence of rain, wind, sand, and dust, foliar dust retention changed frequently, and the degree of variation varied with species. Luo et al. [22] studied the PM$_{2.5}$ dust-retention capacity in six landscape tree species in Shenyang, including *P. tabulaeformis*, *P. orientalis*, *P. bungeana*, *P. alba berolinebsis*, *S. babylonica*, and *A. momo*. They found that the PM$_{2.5}$ clearance rate under rainfall conditions was 37.69% in broad-leaved trees and 27.76% in coniferous trees. This was because the concave and convex structures of *P. tabulaeformis* and *P. orientalis* were advantageous to the particulate matter. The secretion of viscous oil to form small particles accumulated in the mesh structure of the particle group; in the wind, rain, sand, and dust, weather events occur, so the dust-retention capacity of foliar dust will not change obviously, and the dust-retention capacity of foliar dust has little influence from the external environment change. On the contrary, some particles of small size in the air can easily enter a large number of depressions on the leaf surfaces of coniferous trees. Once trapped, they are not easily blown away by the wind or taken away by rainfall, and hence they accumulate on the leaf surface for a long time. However, the contact area between leaves and particles is small due to the relatively smooth micromorphological structure and hydrophobic nature of the leaf surface of broad-leaved trees, such as *S. babylonica*, *A. momo*, and *Populus*, which leads to the low affinity between particles and leaf surface and makes it difficult for particles to deposit on the leaf surface [23]. Hence, the particles fall down in large quantities when rainfall occurs. This is consistent with the results of this study, as the particulate matter dust-retention capacity of the leaves of *P. tabulaeformis* and *P. bungeana* was high, while that of *S. babylonica*, *Populus*, and *Ginkgo biloba* was low. These results indicated that the leaf micromorphological structure of coniferous trees was more conducive to lagging particulate matter than that of broad-leaved trees.

This study showed that the PM$_{2.5}$ and PM$_{10}$ dust-retention capacity of the unit leaf area per hectare of forest land of coniferous trees was greater than that of broad-leaved trees. The leaves of *P. tabulaeformis* and *P. bungeana* were larger than those of different tree species. The leaves of *Populus* and *G. biloba* were the smallest, and the leaves of *S. babylonica*, *F. chinensis*, and *A. momo* were of average size. In April and October, the stomata distribution of *P. tabulaeformis* and *P. asperata* was widespread, and the leaf surface was smooth, with a large number of grooves and bumps. The leaf surface porosity of *S. babylonica* and *G. biloba* was less than that of *P. tabulaeformis* and *P. asperata*. The leaf surface of *G. biloba* was very smooth, and the stomata distribution was not clearly visible. The longer the leaf villi of a
plant, the easier it was to absorb particulate matter; additionally, the adsorption effect on particulate matter increased. These changes accelerated plant metabolism to adapt to the environment [24]. A larger amount of particulate matter was found on the leaf surface of each tree in October than in April, but the amount of particulate matter on the leaf surface of *P. tabulaeformis* and *P. asperata* was significantly higher than that of *S. babylonica* and *G. biloba*. The leaves of coniferous trees were rougher, while the leaves of broad-leaved trees were smoother. The results of this study were also consistent with the results of Lu et al. [11]. Chen et al. [25] believed that leaf surfaces with significant roughness, dense micromorphology and structure, and large difference in depth would increase the contact area between them and particles, resulting in a higher adsorption capacity of leaves to particles. The roughness of *P. tabulaeformis* leaves (144.35 ± 25.63 nm) was more than that of *G. biloba* (35.68 ± 8.54 nm). The leaf roughness of *P. tabulaeformis* was 4.05 times that of *G. biloba*. In this study, the PM$_{10}$ dust-retention capacity per hectare of *P. tabulaeformis* forest was 2.76 times that of *G. biloba*. In addition, the PM$_{2.5}$ dust-retention capacity per hectare of *P. tabulaeformis* forest was 3.24 times that of *G. biloba*, which proved the relationship between leaf roughness and dust-retention capacity.

5. Conclusions

The PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per unit leaf area of different tree species ranged from 1.31 ± 0.68 to 2.64 ± 1.29 µg·cm$^{-2}$ and 0.28 ± 0.13 to 0.99 ± 0.34 µg·cm$^{-2}$. The PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per unit leaf area of coniferous trees was higher than that of broad-leaved trees. The PM$_{10}$ dust-retention capacity per unit leaf area was the highest in October and the lowest in August. The PM$_{2.5}$ dust-retention capacity per unit leaf area was maximum in October (0.99 ± 0.34 µg·cm$^{-2}$) and minimum in April (0.28 ± 0.13 µg·cm$^{-2}$). The PM$_{10}$ and PM$_{2.5}$ dust-retention capacity per hectare of different tree species showed that the variation law of conifers was greater than that of broad-leaved trees. It was the highest for *P. tabulaeformis*, followed by *P. bungeana*. Among the broad-leaved tree species, the PM$_{10}$ and PM$_{2.5}$ dust-retention capacity was the highest in *A. momo* and *F. chinensis* and the lowest in *Populus* and *G. biloba*. The leaves of conifers were rough, and the leaves of broad-leaved trees were smooth. The leaves of *P. tabulaeformis* and *P. asperata* had a large stomata distribution, and the leaf surface was not smooth, with a large number of grooves and bumps. When the PM$_{2.5}$ dust-retention capacity per unit leaf area was high, the corresponding roughness was also significant, and a good logarithmic relationship existed between the roughness and the PM$_{2.5}$ dust-retention capacity per unit leaf area. Hence, coniferous trees should be considered for landscaping. *S. babylonica*, *F. chinensis*, and *A. momo* can also be considered among the broad-leaved tree species for landscaping purposes.

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