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Leaf orientation may determine particulate matter retention efficiency in trees and shrubs species: a case study in Faisalabad city

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Abstract

Globally, air pollution has been a serious concern especially in case fine particles termed as particulate matter (PM). Vehicle emissions, industrial chimneys, open waste burning, dust from building sites, and unpaved roads are the primary sources of PM. Although vegetation has been found to be effective by filtering out PM from the atmosphere, however, PM removal efficiency varies from one specie to another. To fill this research gap, the study focused on compering the PM retention efficacy of five native broad-leaf tree species and five native shrub species commonly found in Faisalabad city, Pakistan. Leaves were collected at high traffic sites, Club Road, Civil Lines (31°42'N 73°08'E The location for the experiment was selected owing to the occurrence of selected tree and shrub species along a stretch of 3±0.5 km. The Findings have shown that among trees, Ficus benghalensis demonstrated the highest PM retention ability (5.61g/m²), whereas Lantana camara emerged as the most efficient shrub (6.27g/m²), significantly exceeding all other species analyzed. Morphological and architectural features such as leaf length, leaf width and petiole length (19.6 cm, 10.7 cm, 4.6 cm, respectively) and twig-petiole and petiole-blade angle (108°, 222.6°) were also found highest in Ficus benghalensis. Furthermore, leaf length and leaf width were found positive correlated with PM retention across tree species. Therefore, it can be concluded that increased PM retention efficiency in Ficus benghalensis was related to larger leaf size and horizontal leaf orientation.

1. Introduction

Survival of biological species is mainly linked with the air pollution in modern era. Therefore, reducing concentration of particulate matter has become a serious concern. In this regard, particulate matter (PM) refers to a complex mixture of solid and liquid particles with different sizes, shapes, and compositions. Globally, PM can originate from both natural and man-made sources (TPM. 2011). PM is predominantly categorized in two health relevant fractions which are being used to frame the air quality regulations and guidelines, PM2.5 and PM10. PM2.5 refers to mass-measured particles that pass through a sampling intake with a 50% cut-off efficiency at 2.5 µm and PM10, measures the mass of particles that pass through a sampler inlet with a 50% efficiency cut-off at 10 µm (Patel and Aggarwal. 2022). Worldwide, primary sources of particulate matter that contribute to air pollution in cities are traffic, combustion and agriculture, domestic fuel burning, natural dust and salt, and industrial activities. Resultantly, roadside air quality is quite bad and harmful to the health of exposed public (Zeeshan et al., 2024). It is commonly recognized that exposure to PM has both immediate and long-term health impacts, and raises the incidence of a variety of illnesses, including cancer, heart

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disease, and respiratory disorders (Beelen et al., 2014; Burnett et al., 2014; Shiraiwa et al., 2017; Moyebi et al. 2023). PM2.5 and PM10 were found correlated with death from cardiovascular, pulmonary, and cerebrovascular causes (Orellano et al., 2020). Dominici et al., (2019) reported that PM2.5 and O3 are linked to a higher risk of death during warm season, and this risk was noted at concentrations below the existing threshold levels. Prolonged exposure may cause chronic diseases or premature mortality. Therefore, it is crucial to regulate these airborne particles and lessen their concentration in densely populated urban areas.

According to the IQ Air 2024 report, Pakistan's yearly average concentration of $PM_{2.5}$ was recorded at 73.7μg/m³, nearly 15 times higher than the safe levels established by the World Health Organization (WHO). Evaluations of $PM_{2.5}$ and PM_{10} concentrations were conducted in fifteen to eighteen Pakistani cities. The review found that Lahore, Faisalabad, Karachi, Gujranwala, Multan, Vehari, Bahawalnagar, Okara, Pakpattan, Jehlum, Sargodha, Peshawar Quetta, Islamabad, Haripur, Mingora, and Mardan (Jalala) had the highest $PM_{2.5}$ concentrations. Particularly, Lahore, Faisalabad, Peshawar, Charsada, Karachi, Gujranwala, Multan, Rawalpindi, and Quetta had the highest PM_{10} concentrations (Aslam et al., 2020; Zeeshan et al., 2024; Subhanullah et al., 2025). Faisalabad, one of the most advanced cities of Pakistan, has lately become a major hotspot for urban air pollution (Rasheed et al., 2025). IQ Air (2024) also reported that $PM_{2.5}$ level in Faisalabad in 2024 is around 88.8μg/m³. The month of April has been reported as the cleanest month, in which $PM_{2.5}$ rating was 39.1 μg/m³, which is still very high. The $PM_{2.5}$ count increases to such levels because of increased wood burning fuel during the winter months and cold weather that causes thermal inversion, which further entrenches the pollution within the city (Zeeshan et al., 2024). The IQ report 2024 further revealed that the air quality significantly decreased during the cold months from December to January, reaching its lowest point in January with PM at 211.6 μg/m³, and December with PM at 175.8 μg/m³.

Studies have shown that carefully chosen trees and bushes can significantly reduce urban pollution, particularly the microscopic dangerous particles like $PM_{2.5}$ and PM_{10}. Studies conducted around the world have demonstrated that smartly arranging the proper species helps lower air pollution in urban areas. Urban vegetation is crucial for removing pollutants from the air; for this, designing configuration strategies for urban green spaces requires an understanding of the functional characteristics of plants that have a significant potential to hold fine particulate matter. Rasheed et al., (2025) discovered that urban trees such as *Ficus benghalensis, Syzygium cumini,* and *Terminalia arjuna* had the highest PM retention among ten local tree species in Faisalabad, Pakistan, making them perfect for air pollution mitigation, especially in urban areas. The study demonstrated how urban plantations may be effective to clean the air in cities by using species with appropriate leaf properties and placing them strategically, particularly when mixing trees and shrubs. However, in this study shrubs were not included, which are an integral part of urban green infrastructure. In addition to less space availability in urban areas, shrubs are a very good option for capturing particulate matter because of their huge surface area near the ground, where pollution levels are the highest. Building on the review of literature, the current study focused on species that may flourish in constrained urban environments and includes both trees and shrubs. Therefore, the study was designed to evaluate the efficiency of five local trees and five shrub species in retaining particulate matter in constrained urban areas. Furthermore, leaf morphological traits that are known to have a major impact on PM accumulation, such as leaf size, twig-petiole angle, petiole-blade angle and petiole size, were also taken into consideration under the current study, which were missing in the previous studies. For urban greening projects in heavily populated and dirty cities like Faisalabad, this study will provide a more realistic and scientifically supported framework for selecting tree and shrub species for future urban greening initiatives.

2. Materials and Methods

2.1. Site Selection and Foliage collection

Faisalabad has a semi-arid to humid subtropical climate with hot summers and chilly dry winters. Average annual temperature is approximately 26°C, while annual rainfall averages around 602 mm, much of which is received during the monsoon months (August-September). The study focused on five local broadleaf tree species (*Ficus benghalensis, Ficus virens, Syzygium cumini, Cassia fistula, Conocarpus erectus*) and five local shrub species (*Lantana camara, Hibiscus rosa-sinensis, Gardenia jasminoides, Jatropha integerrima, Tecoma stans*) that are commonly found in urban areas of Faisalabad city. The site selected in Faisalabad city was Club Road, Civil Lines (31°42'N 73°08'E) due to high traffic volumes, which is a prerequisite for studying species differences for particulate matter retention. Furthermore, at this location the selected tree and shrub species were present along a stretch of 3±0.5 km, enabling us to assume that the selected individual of tree and shrub species were subjected to similar environmental conditions. Branch samples were taken on 1st November 2024 between 11:00 am and 12:00 pm, about 33 days after the last rainfall event (September 28, 2024). Sampling was done on the road facing side of each plant ensuring the highest exposure to air pollution from traffic. The branches of trees and shrub plants were excised by individuals 3 ± 1 meters from the main road and at a consistent height, 3 meters for trees and 1.5 meters for shrubs, respectively. This sampling technique enabled us to compare PM retention across species and assume that all samples were exposed to a consistent environmental condition. Leaf sampling was taken from three individuals per species for both trees and shrubs. To prevent PM loss, branches were carefully excised, placed in paper bags appropriately labeled, and kept at -18°C till further analysis.

2.2. Quantification of Particulate Matter (PM) through Leaf Wash and Filtration

Meticulous technique of leaf washing and filtering was employed to determine how well various plants in the city can capture particulate matter PM (Rasheed et al., 2025). Since leaf size of all the tree and shrub species were different therefore, it was important to homogenize the leaf area of all tree and shrub species. To homogenize leaf surface area for all the tree and shrub species 1 m^2 quadrate was used, and leaves of each species were carefully placed inside the quadrate to fully cover the area inside the quadrate (more number leaves were placed for species with smaller leaves and vice versa). This technique allowed us to homogenize the leaf area of all the tree and shrub species to 1 m^2 (Rasheed et al., 2025). Subsequently, the leaves within 1 m^2 area were washed in two steps: first with light brushing with soft, non-scratching nylon bristles lab brush in 1500 ml of pure distilled water. To remove any remaining tiny particles, the same leaves were then placed in a second container with 1000 mL of distilled water and were brush washed gently. Lower (abaxial) and upper (adaxial) surfaces were cleaned during this procedure. Following washing, special filter paper (Whatman Grade 42, which captures minuscule particles as small as 2.5 micrometers) were pre-weighted and were used to filter the water containing the dust. To help push the water through the filter paper, a vacuum pump was used. The filter papers with dust load were dried and reweighted. Dust load accumulated by each tree and shrub species was calculated as the weight difference of filter paper before and after the filtration process.

Measurement of Morphological Characters

The morphological characters of selected tree and shrub species were also measured. All measurements took place between 10 am to 12 pm to homogenize the turgor pressure. Measurements were taken on ten mature leaves of each five tree and five shrub species. Only road facing leaves were selected for the measurement to homogenize the confounding environmental factors. For each species, following morphological traits were measured petiole length (mm), leaf length (mm), leaf width (mm), (Figure 1), angle between twig and leaf petiole, and angle between leaf petiole and leaf blade using a protector (Figure 1b). To relate these results, we selected the same trees and shrubs from which branch samples were taken to analyze the dust load.

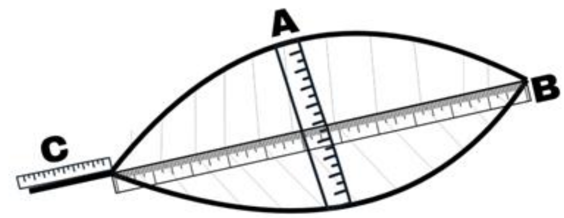

Figure 1a. Schematic diagram for measuring (a) leaf width, (b) leaf length, and (c) petiole length.

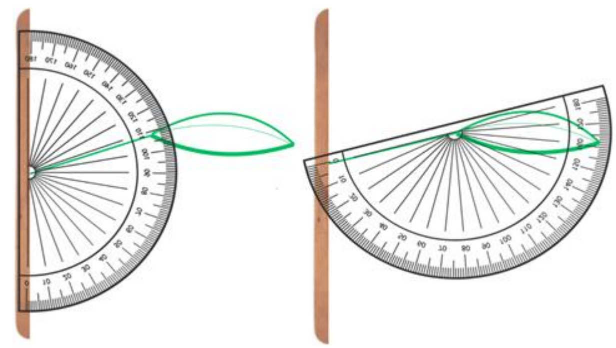

Figure 1b. Schematic diagram for measuring a) twig-petiole angle b) petiole-blade angle

2.3. Statistical Analysis

Prior to analysis, residual versus predicted plots were used to evaluate the data's homogeneity and normality. To assess the impacts of species (S-effect), data for the year 2024 was examined independently using a general linear model (GLM) for trees and shrub separately. Significant differences using Tukey's HSD multiple comparison test between means were investigated. The means were presented with their standard error (SE) with $p < 0.05$ as the significance level. STATISTICA (Version 12.5, Stat Soft, Maisons-Alfort, France) was used to conduct the statistical analyses.

3. Results

Leaf morphology and leaf orientation of various tree species

The leaf morphological characteristics varied significantly across the studied tree species ($P<0.001$; Table 1). *Ficus benghalensis* (Bargad) had the largest leaf with leaf length of 19.6 cm, a leaf width of 10.7 cm, a petiole length of 4.6 cm and the smallest leaf was of *Conocarpus erectus* (Conocarpous) which had a leaf length of 9.6 cm, a leaf width of 1.76 cm, a petiole length of 0.8 cm, Leaf architecture also varies significantly across the five tree species ($P<0.001$; Figure 2a,b) where *Ficus benghalensis* (Bargad) had a twig-petiole angle of 108°, and a petiole-blade angle of 222.6° and *Conocarpus erectus* (Conocarpous) had a twig-petiole angle of 95°, and a petiole-blade angle of 215.6°.

Particulate Matter Retention in Five Tree Species

The mean PM average retention varied significantly across the five tree species in the urban setting of Faisalabad, Pakistan. Bargard (*Ficus Benghalensis*) leaves exhibited the highest mean PM retention, averaging 5.61g/m², followed by Pilkhan (*Ficus virens*) 4.56g/m² and Jaman (*Syzygium cumini*) retained and 3.45g/m². Amaltas (*Cassia fistula*) demonstrated a retention capacity of 2.81g/m², whereas Conocarpus (*Conocarpous erectous*) had the lowest PM retention at 1.98g/m². It shows tree species belonging to genera Ficus retained the highest PM load. Species ranking was Bargad>Pilkhan>Jaman>Amaltas> Conocarpous. The PM retention across the tree species was found positively correlated to the leaf length and width (Figure 3a, b) where species with largest leaf, Bargard (*Ficus Benghalensis*), showed the highest PM retention and the species with smallest leaf, Conocarpus (*Conocarpous erectous*), showed the lowest PM retention.

Leaf morphology and leaf architecture of various shrub species

The leaf morphological characteristics varied significantly across the studied shrub species (Table 1). Lantana camara had the largest leaf with a leaf length of 7.3 cm, a leaf width of 4 cm, a petiole length of 2.6 cm and Tecoma stans had the smallest leaves with a leaf length of 12.2 cm, a leaf width of 3 cm, a petiole length of 7.5 cm. Leaf architecture also varies significantly across the five shrub species (Figure 2a,b) where *Lantana camara* had a twig-petiole angle of 122.6°, and a petiole-blade angle of 212.3° and *Tecoma stans* had a twig-petiole angle of 131.6° and a petiole blade angle of 202.3°.

Table 1. Means and SE of various morphological and particulate matter (PM) load of various species measured during the study. Small letters represent the Mult comparison test done using HSD Tukey's test.

Species type	Species	Leaf width (cm)	Leaf length (cm)	Stock length (cm)	PM load (g/m²)
Tree	*Cassia fistula*	5.5 ± 0.06 b	12.5 ± 0.12 c	0.73 ± 0.09 c	2.81 ± 0.02 d
	Conocarpus erectus	1.76 ± o.02 e	9.63 ± 0.09 d	0.87 ± 0.06 c	1.98 ± 0.06 e
	Syzygium cumini	4.1 ± 0.06 d	13.7 ± 0.02 b	1.07 ± 0.09 c	3.45 ± 0.03 c
	Ficus Bengalensis	10.8 ± 0.07 a	19.7 ± 0.17 a	4.6 ± 0.06 b	5.62 ± 0.02 a
	Ficus virens	4.9 ± 0.06 c	14.2 ± 0.15 b	5.43 ± 0.12 a	4.56 ± 0.03 b
Shrub	*Jatropha integrimma*	3.8 ± 0.06 b	11.0 ± 0.09 b	3.3 ± 0.06 b	2.7 ± 0.03 d
	Hibiscus rosa-sinensis	2.5 ± 0.06 d	6.5 ± 0.06 d	2.13 ± 0.09 d	4.36 ± 0.02 b
	Lantana camara	4 ± 0.06 b	7.33 ± 0.09 c	2.63 ± 0.09 c	6.27 ± 0.01 a
	Tecoma stans	3.3 ± 0.06 c	12.2 ± 0.12 a	7.53 ± 0.09 a	2.15 ± 0.08 e
	Gardenia jasminoidea	6.63 ± 0.09 a	12.4 ± 0.23 a	1.63 ± 0.09 e	3.49 ± 0.03 c

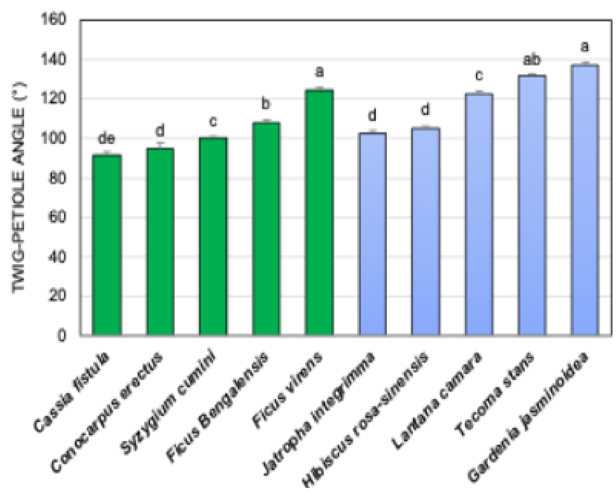

Figure 2a. Means and SE of twig-petiole angle in various tree (green bars) and shrub species (blue bars) measured during the study. Small letters represent the Mult comparison test done using Tukey's HSD test.

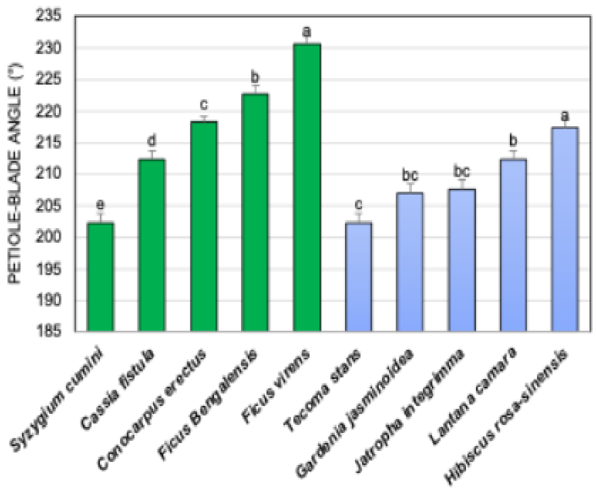

Figure 2b: Means and SE of petiole-blade angle in various tree (green bars) and shrub species (Blue bars) measured during the study. Small letters represent the Mult comparison test done using Tukey's HSD test

Particulate Matter Retention on Shrub Specie Leaf Surfaces

The mean PM average retention varied significantly across the five shrub species in the urban environment.

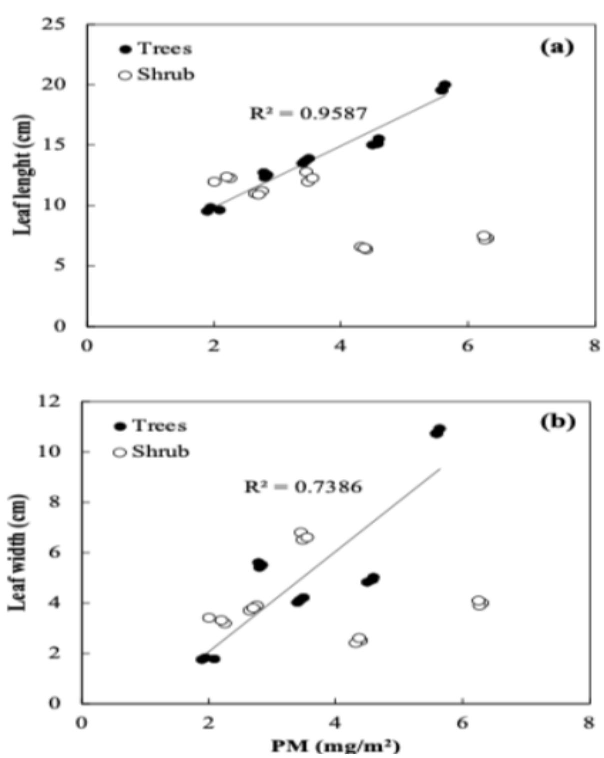

Figure 3. Correlation between particulate matter (PM) load and (a) leaf length and (b) Leaf width in tree (closed circles) and shrub species (open circles). R^2 values are the significant correlations found in tree species only.

Lantana's (*Lantana camara*) had the highest mean PM retention of 6.27g/m² indicated that it has the strongest ability to trap coarse particulate matter. Hibiscus (*Hibiscus rosa sinensis*) followed by Chandna (*Gardenia jasminoides*) show average PM retention of 4.36g/m² and 3.49g/m². Jatropha (*Jatropha Integrimma*) showed PM retention in the group 2.7 g/m2, but Yellow Bell (*Tacoma stans*) showed lowest retention with an average of 2.15g/m2. It was observed that the ability to retain particulate matter decreased in the following order: Lantana > Hibiscus > Chandna > Yellow Bell > Jatropha. The PM retention across the shrub species was not found correlated to the leaf size (Figure 3).

4. Discussion

The current study examined the ability of selected tree and shrub species to retain particulate matter (PM) in urban areas of a semi-arid region. Results showed that Ficus benghalensis exhibited the highest particulate matter retention among all the tree species. It was also noted that morphological characteristics such as leaf size, petiole length, and leaf angle significantly affect the particulate retention capacity. In this study, *Ficus benghalensis* had the largest leaf size, it also showed highest PM retention. In contrast, *Conocarpus erectus* had the lowest capacity for particulate matter retention and it had small leaves. In a comparable study, Jeanjean et al. (2016) examined the PM accumulation capacity of twenty-one tree species in Sambalpur, India, and found a positive correlation between high PM catching capacity and leaf area. Similar findings have been reported in earlier research showing that tree species with larger leaves retained more PM (Weeakkodey et al. 2020; Paull et al. 2020). It has also been documented that leaf-petiole angles also have a significant influence on the retention capacity of the plant species where horizontally oriented leaves showed higher PM retention capacities. For example, a notable drop in PM has been shown in *Cassia fistula* despite having large size but vertically hanging leaves which restricts the PM retention (Weeakkodey et al. 2020). Similarly, Chaudhary et.al., (2019), evidenced that plants with horizontally oriented leaves were better at retaining dust than plants with vertically suspended leaves, and stated that the dust particles on vertically oriented leaves tends to slide down. Since the particles are more likely to slide under less leaf surface friction and similar phenomena were reported during breeze event followed by a rain event. Petroff et al., (2009) reported that large and horizontally oriented leaves present higher projected area, increasing PM deposition velocity. In this study similar results had been found where *Ficus bengalensis* and *Syzygium cumini* showed the highest twig-petiole and a petiole-blade angle and largest leaf size that led to efficient PM accumulation. In the present study, petiole size emerged as an important morphological factor influencing leaf inclination, with results showing a negative relationship between petiole size and the degree of leaf inclination. This suggests that leaves with longer or thicker petioles tend to maintain a more horizontal orientation, possibly because thicker petioles provide greater mechanical support and resistance to gravitational bending. Thin petioles, on the other hand, may be more flexible and therefore more prone to drooping or increased inclination. These findings align with studies that highlight the role of petiole biomechanics in determining leaf orientation (Petroff et al., 2009). Leonard et.al., (2016) stated that broader leaves with rough surface areas are more capable of collecting dust particles than smooth surfaces and needle-shaped leaves. Moreover, C. erectus with smooth and small leaves resulted in the least accumulation of PM. It has been reported that because of horizontally oriented leaves, *Azadirachta indica* demonstrated a greater ability for dust collection than *Phyllanthus emblica*.

Among the shrub species *Lantana camara* exhibited the highest PM retention capacity due to its unique morphological traits, compared to the *Jatropha integerrima* with least PM retention. Similar results were demonstrated by Rai al. (2015), who found that the dust deposition *of Lantana camara* leaves was 1.01 mg/cm^2. These results were linked to modest height, rough surface with a slightly curled edge, and waxy covering. Sultana, (2016) has also shown that the epidermis of *Lantana camara* had projections known as stem hairs, or trichomes. These trichomes are unicellular, bigger in appearance, and had a group of huge, radially organized epidermal cells at the base, which indicates high roughness of leaf surface and one of the major reasons for high PM retention. Moreover, we found that leaves of *Lantana camara* had a very stable angle of orientation that might have contributed to the high PM retention capabilities. Cavanagh et al., (2009) explained that the deposition of particles on the leaf blade surface can be increased by diffusion (Brownian motion), turbulence, or gravity. In this study, *Hibiscous rosa sinensis* had smaller leaves and moderate angles orientation but still managed to be second place in PM retention capacity. According to Zahid et al., (2016) this species has small stalk length which makes it comparatively rigid and retains PM effectively. Similar results have been reported by Weerakkody et al., (2017) reporting that the species with complex morphology and more stiffness are the best in holding onto PM. Current study has found that *Gardenia jasminoids* have the largest leaf area in selected shrub species. These findings are aligned with the results of Xu et al., (2024) who found that narrow leaves store less PM than broader leaves. Furthermore, Bui et al., (2023) demonstrated that although *Gardenia jasminoides* leaves are smooth but deep grooves on their leaves help retain more PM. Furthermore, *Gardenia jasminoides* have small petiole and horizontally arranged leaves that makes it effective for PM retention. Based on the results it can be concluded that tree species that have broad, rigid and horizontally arranged leaves tend to retain more PM. Although Rasheed et al., (2025) also stated that *Ficus benghalensis* (tree species) retain the highest particulate matter, however, the current study adds to the information on why these species retain higher PM than other species.

5. Conclusion

This study offers an empirical and trait-oriented assessment of PM retention by selected urban tree and shrub species in Faisalabad, Pakistan. Among the tree species, *Ficus benghalensis* demonstrated the highest ability for PM retention, whereas in shrub species, *Lantana camara* emerged as the most efficient, significantly exceeding all other species analyzed. The analysis of traits demonstrates that morphological features such as leaf area, petiole length, and orientation play a crucial role in affecting particulate accumulation. Plants featuring large, horizontally oriented leaves provided greater aerodynamic conditions that improved PM deposition. However, further studies, including other species, are required for informed decision making in this regard.

6. Funding

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7. Acknowledgment

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8. Conflict of Interest

The authors declare no conflict of interest.

9. Authors' Contribution

Momin Danish and Afnan Zahid contributed equally to the conceptualization of the study, literature survey, data collection, and drafting of the original manuscript. Asif Iqbal assisted in critical data analysis, figure conceptualization, and manuscript revision. Fahad Rasheed supervised the study, provided intellectual input, critically reviewed the manuscript, and coordinated revisions. Muhammad Azeem Sabir contributed to study design, critical evaluation of the content, and final approval of the manuscript. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

10. SDGs Addressed

This study contributes to SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production) by addressing environmental pollution and promoting sustainable bioremediation strategies for soil and water.

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