



Biological Evaluation of Air Quality of an Urban Ecosystem through Air Pollution Tolerance and Performance Index

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Abstract

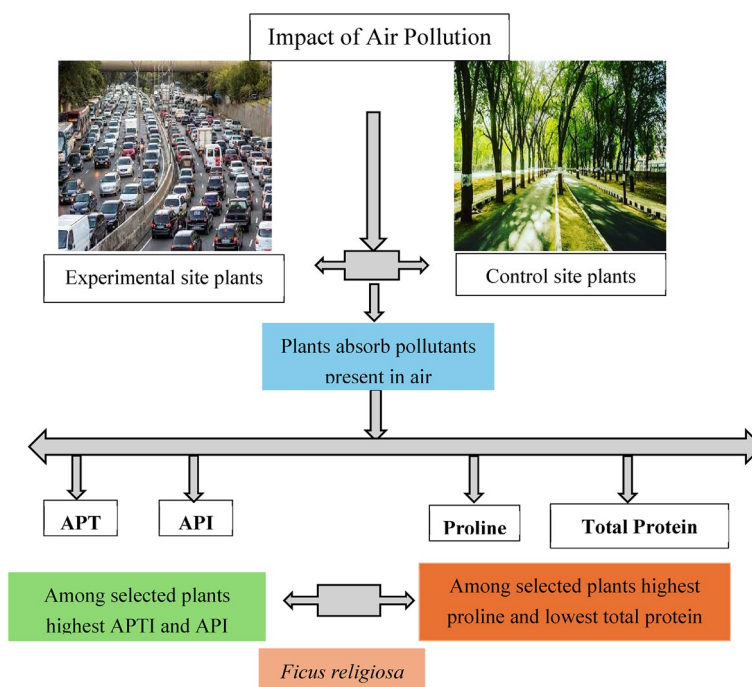
Purpose The rapid increase in urbanization leads to air pollution particularly in cosmopolitan city like Lahore (Pakistan) which poses a significant threat to human health. Air pollution has negative impacts on roadside vegetation and the environment. However, plants growing along roadsides have the ability to mitigate air pollution.

Methods For assessing the air quality of the urban ecosystem through road side plantation two indices Quantitative i.e. Air pollution Tolerance Index (APTI) and qualitative one i.e., Anticipated Performance Index (API) was used. Along with these Total protein content and proline amount was also assessed under high stress of particulate pollution.

Results Six different plant species were selected for the study: *Alstonia scholaris*, *Callistemon lanceolatus*, *Cassia fistula*, *Ficus religiosa*, *Mimusops elengi* and *Polyalthia longifolia*. Leaves of these selected plant species were collected from five distinct sites (four experimental and one control site). *Ficus religiosa* was found to be the best performer, while *Mimusops elengi* and *Callistemon lanceolatus* were resulted as good performers. The highest and lowest amounts of proline content were measured for *Ficus religiosa* and *Callistemon lanceolatus*, while protein content was found reduced at highly polluted sites.

Conclusions Screening of existing landscape of any cosmopolitan area with high APTI and API values will aid in green urban development by supporting conservation efforts aimed at protecting biodiversity and reducing the harmful impacts of air pollution on the environment and public health.

Graphical abstract



Keywords Air pollution tolerance index · Proline · Roadside vegetation · Total protein content

1 Introduction

In contemporary times, rapid industrialization, urbanization and unsustainable population growth significantly contribute to environmental degradation. Among the various issues resulting from these trends, air pollution stands out as particularly harmful, affecting both biotic and abiotic entities (Kumar et al. 2019). From 1999 to 2014, population and area expansion rates were 2.5% and 1.7%, respectively (Dixit et al. 2022). By 2030, 60% of the global population is expected to reside in metropolitan areas (Cetin and Sevik 2016). Air pollution is the fourth leading cause of death, causing 1.1 million fatalities and 21.8 million long-term disabilities (Sivarethinamohan et al. 2021). Vehicular emissions contribute to severe health issues, including lung cancer, reproductive disorders, immunological problems, asthma and cardiovascular diseases (Rai 2016). Urban air pollution is a significant concern, worsened by increasing traffic density, urban population and industrialization (Gholami et al. 2016). Particulates, toxic gases, heavy metals and polycyclic aromatic hydrocarbons are primary contributors to poor air quality and adversely affect human health (Dhamala et al. 2018). Chromium (Cr) concentrations are significantly higher in gridlock areas (Cetin et al. 2022) and heavy metals can affect entire ecosystems, including humans (Dixit et al. 2016).

Human activities often cause contaminants, with rises in air pollutants due to inadequate combustion, maintenance and insufficient climate policies (Roy et al. 2020). Poor fuel quality, high traffic density, old automobiles, poor roads and lack of proper inspection and maintenance strategies by government bodies all impact roadside air quality. Consequently, plants serve as significant sinks for air pollutants (Singh et al. 2019). Plants influence air pollution passively, especially those growing along roadsides, which are particularly vulnerable to pollution. Changes in the biochemical and physiological attributes of plants under air pollution lead to modifications in leaf characteristics, such as specific leaf areas, leaf extract pH, chlorophyll content and relative leaf water content (Bui et al. 2021). However, these alterations vary between plant species, with different plants responding differently to air pollution at various exposure sites (Bharti et al. 2018).

Some plants exhibit sophisticated responses to air pollution, while others are more susceptible. Controlling air contamination from factories and vehicles is a major concern, using plants as bioindicators is crucial. Plants must be carefully identified and categorized based on their sensitivity and resistance to serve as bioindicators

and pollution mitigators (Noor et al. 2015). Climatological considerations are essential when planning urban development to ensure areas are suitable for human well-being (Cetin 2015). Establishing habitation projects in less bio-comfortable locations is not ideal for energy conservation, mental health and people's overall health (Kilicoglu et al. 2020). Rapid urban growth in technically advanced areas through unnatural expansion can negatively impact emotional well-being (Cetin and Sevik 2016).

Land use and land cover changes are serious ecological issues, altering the form and dynamics of ecological systems (Aksoy et al. 2022). Plants, the major constituents of greenbelts, act as basins and filters to reduce environmental pollutants through assimilation, biosorption, purification, accumulation or biotransformation without significant leaf damage or growth reduction, thus improving air quality by providing oxygen (Kapoor and Chittora 2016). Greenways are a natural method of reducing air pollution by capturing dust particles and absorbing toxic gases (Han et al. 2021). Trees significantly enhance urban air quality by absorbing hydrocarbons and airborne particulates. Since plants are more vulnerable to toxic air pollutants compared to animals and humans, they are critical for maintaining environmental balance (Swami and Chouhan 2015).

The Air Pollution Tolerance Index (APTI) is calculated using the leaf extract pH, chlorophyll content, water content and ascorbic acid levels in different tree species (Ogunkunle et al. 2015; Yadav and Pandey 2020; Shrestha et al. 2021). This index helps assess a plant's tolerance to air pollutants. High APTI values indicate a plant's resistance to air pollutants, while low values suggest the plant can be used as a biological indicator of air pollution (Uka et al. 2017). The APTI varies among plant species. Tolerant plant species are used for urban vegetation and green belt formation in cities, while sensitive plants serve as indicator species in polluted environments (Ogunkunle et al. 2015). Understanding plant resistance to pollution is essential when selecting plants to efficiently reduce air pollution (Bui et al. 2021).

Under abiotic stress, proline accumulates in plant tissues, acting as an osmoprotectant. Proline serves several functions: nutrient storage for growth, protein and membrane preservation, free radical scavenging, and supporting the antioxidant system (Singh et al. 2015). This study aims to measure the protein content, proline content, and APTI values of six plant species at polluted sites in Lahore.

2 Methods

2.1 Study Location

Lahore, the capital of Punjab province, is the second largest city in Pakistan. It is known as the "City of Gardens" and is regarded as a major center for education, culture, politics, business, transportation, and entertainment. It occupies a 1772 km² area and is situated between 74 °20 '37 "E and 31 °32 '59 "N latitude and longitude, correspondingly. It represents characteristics of tropical climate with semi-arid region. The region is formed from alluvial plain of the River Ravi, in the upper part of the Indus Basin. Significant change in temperatures is also noticed from the last decade in which the average temperature of the city has been increased to 150 °C which increased the frequency of the heavy rain spells over the years but reduces (from 900 to 603 mm) the overall annual mean precipitation in the city (Illyas and Nissar 2022). Moreover, as far as wind direction is concerned, it was found to be NW (North West) in direction major parts of the year and it was recorded lowest in January i.e. 1.4 knots and highest in May and June i.e. 10.1 knots (EPA Punjab 2023). As per as, the ambient air quality of Lahore city is concerned. The average concentration of various air pollutants over past two years were compared with Punjab Environmental Quality Standards. Average value of PM_{2.5} was (115.49 µg/m³), higher than PEQS (15 µg/m³). The average concentration of PM₁₀ was observed as (207.54 µg/m³) which was higher than PEQS (120 µg/m³). The average level of NO₂ was (43.44 µg/m³) that was higher than PEQS (40 µg/m³). While, the average concentration of SO₂ was (21.38 µg/m³) which was lower than PEQS (80 µg/m³) as shown in Table 1.

2.2 Plant Species and Sampling

The most commonly occurring plant species, including *Alstonia scholaris*, *Cassia fistula*, *Callistemon lanceolatus*, *Ficus religiosa*, *Mimusops elengi* and *Polyalthia longifolia* were selected for this study. The names, shape of leaf, life form, and life cycle of these plants are listed in Table 2.

The selected plant samples were collected from four different polluted roads (Mall road, Shadman road, Jail road, Ferozpur road) and for comparison, the control plant samples were collected for each selected plant from Botanic Garden, GC University Lahore (Less polluted Site) as shown in Fig. 1. These roads were selected on the basis of the heavy traffic load and dominance of the plant diversity on the sampling sites. Moreover, these roads are the main link roads with all the other roads and always have intense traffic density throughout the day.

Mature leaves were gathered from control site and our selected roads during the period of 2022 – 2023. Three replicates of each plant species were collected. In order to keep them fresh, leaves were stored in zip-lock bags. The ice box was used to preserve the freshness of the leaves within these bags. Samples were investigated for numerous biochemical parameters including pH, total chlorophyll content, ascorbic acid content, relative water content, protein and total protein content.

2.3 Biochemical Parameter Measurement

2.3.1 pH

The protocol proposed by Das and Parsad (2010) was used to determine the pH of leave samples. Fresh leaf sample 1 g was crushed in 50 mL of distilled water and leaf extract was taken through Whatman filter paper no. 42. The pH was measured by the Hanna pH meter (Model No. HI 2210).

2.3.2 Total Chlorophyll Content

For total chlorophyll content measurement, 20 mL of 80% acetone was used to the crushed 2 g fresh leaves by using pestle and mortar. Through filtration, leaf extract was acquired in a conical flask with the help of filter paper and a funnel. By using a spectrophotometer, the absorbance value of this extract was measured for each sample at 663 nm and 645 nm. Total chlorophyll content was calculated by the formula suggested by Singh et al. (1991a):

$$\begin{aligned} \text{Total chlorophyll content (mg g}^{-1}\text{)} \\ = (20.2 \times A_{645} \div 8.02 \times A_{663}) \times V/1000 \times W \end{aligned} \quad (1)$$

Where A₆₆₃ = Absorbance value at 663 nm,

A₆₄₅ = Absorbance value at 645 nm,

V = Total leaf extract volume,

W = Leafweight

2.3.3 Asorbic Acid Content

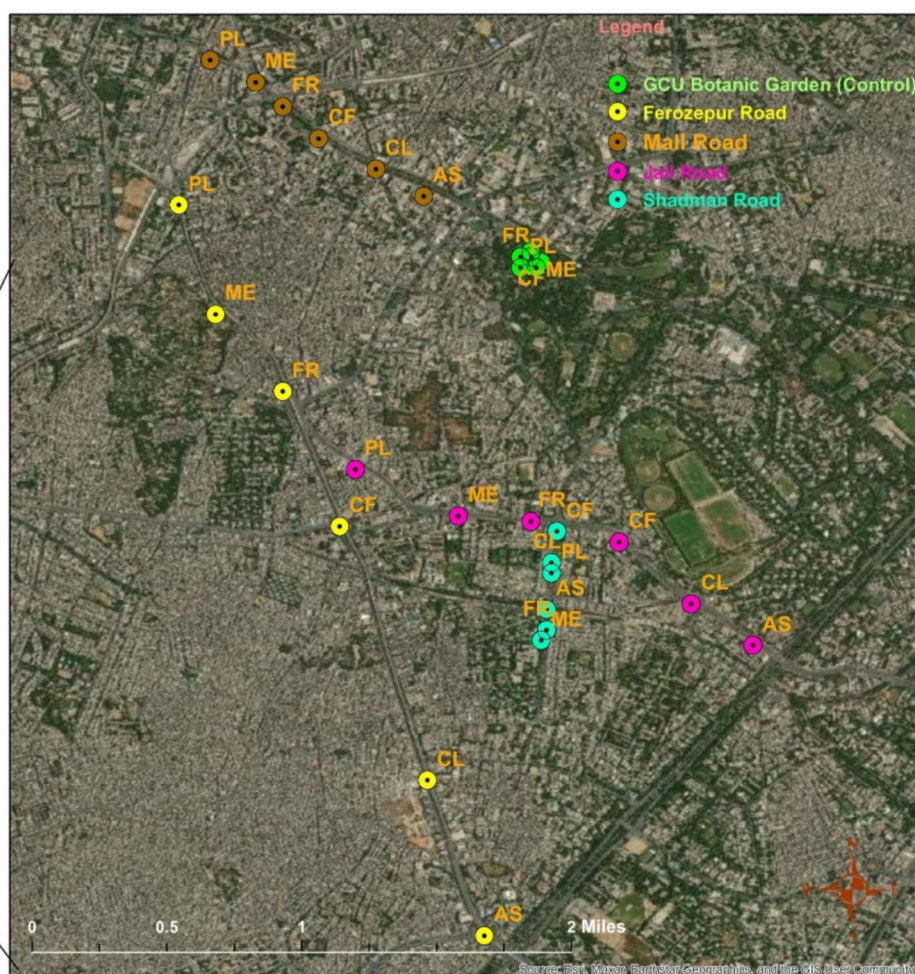
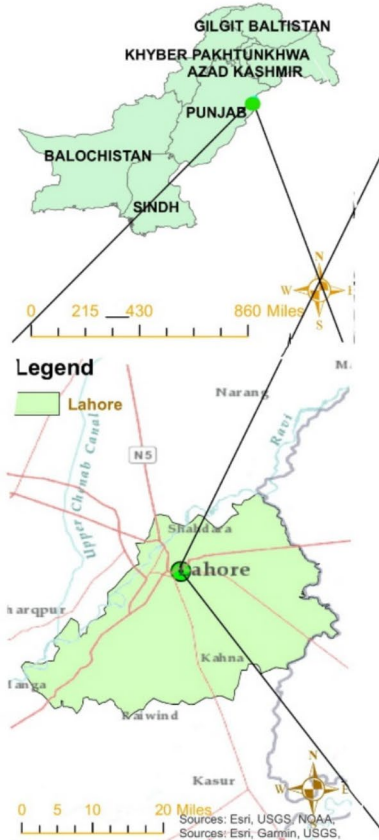
Two grams of fresh leaves were homogenized in 20 mL extraction solution (oxalic acid and EDTA) and the extract was filtered in a conical flask by using Whatman no. 1 filter paper. In an Eppendorf tube, 1.5 mL leaf extract was taken and centrifuged for 15 min at 6000 rpm. One mL supernatant was poured into a test tube and 5 mL 2,6-dichlorophenol indophenol (DCPIP) was added and pink color was observed. The optical density of the solution was measured at 520 nm by using the spectrophotometer. To decolorize solution, 1 drop of 1% ascorbic acid was added in it and

Table 1 Ambient air pollutant concentration in Lahore City

Pollutants	Concentrations ($\mu\text{g}/\text{m}^3$)		Average values ($\mu\text{g}/\text{m}^3$)	Punjab environmental quality standards (PEQS) ($\mu\text{g}/\text{m}^3$)
	(Nawaz et al. 2022)	(Malhi et al. 2023)		
PM _{2.5}	175	55.99	115.49	15
PM ₁₀	310	105.08	207.54	120
NO ₂	20.84	66.04	43.44	40
SO ₂	19.21	23.56	21.38	80

Table 2 Description of plants in this study

No	Scientific name	Shape of leaf	Life form	Life cycle
1	<i>Alstonia scholaris</i>	Oblong shaped	Tree	Perennial
2	<i>Cassia fistula</i>	Ovate shaped	Tree	Perennial
3	<i>Callistemon lanceolatus</i>	Lance-shaped	Small tree	Perennial
4	<i>Ficus religiosa</i>	Cordate	Tree	Semi-perennial
5	<i>Mimusops elengi</i>	Oblong shaped	Tree	Perennial
6	<i>Polyalthia longifolia</i>	Lance-shaped	Tree	Perennial

Legend**Fig. 1** Sampling sites (GPS coordinates) selected in this study

again measured the absorbance of this bleached solution at 520 nm. For the preparation of the blank, in the test tube, 5 mL of DCPIP, 1 mL of extracting solution, and one drop of ascorbic acid was added. Ascorbic acid content was assessed by the following the equation of Roy et al. (2020):

$$\text{Ascorbic acid content (ng g}^{-1}\text{)} = \frac{[E_b - (E_s - E_t) V]}{W \times V_s \times 1000} \quad (2)$$

where E_b = Absorbance of blank, E_s = Absorbance of pink solution, E_t = Absorbance of blanched solution, W = Weight of fresh leaves, V = Mixture volume, V_s = Supernatant volume.

2.3.4 Relative Water Content

Took 2 g fresh leaves and dipped in 200 mL distilled water overnight. The next day, dry dipped leaves by using blotted paper and obtained saturated weight by weighing the turgid leaves. After this, keep leaves in the oven at 70 °C for 24 h and weigh them again to estimate dried weight. Relative water content (RWC) of plant leaves was evaluated by the following equation (Hajizadeh et al. 2019):

$$\text{RWC (\%)} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100 \quad (3)$$

where FW = fresh leaves weight, DW = dried leaves weight, TW = turgid leaves weight.

2.3.5 Air Pollution Tolerance Index (APTI)

The following parameters were determined to calculate the APTI value of different plant species by the equation proposed by Kashyap et al. (2018):

$$\text{APTI} = \frac{[A(T + P) + R]}{10} \quad (4)$$

where A = the ascorbic acid content, T = total chlorophyll content, P = the pH of leaf extract, R = relative water content.

2.4 Anticipated Performance Index (API)

Anticipated Performance Index (API) characterizes the plant species against the various pollution levels according to their respective potential. It includes tolerance level (APTI), biological and socioeconomic and laminar attributes of the plants. APTI defines the pollution tolerance of the species whereas biological and socioeconomic attributes include plant habit, canopy structure and type of plants. Moreover, laminar attributes have size, texture, hardness and economic values. For each of the above mentioned characteristics

respective plus (+) and minus (−) was allotted depending upon the features of the sample plants to calculate the API assessment category as shown in Table 3. For this purpose, API score was calculated by the following formula to distinguish the plants in to different assessment categories (Prajapati and Tripathi 2008).

$$\text{API} = \frac{\text{Total plus acquired by the plant species}}{\text{The highest plus of plant species}} \times 100 \quad (5)$$

2.5 Proline Content

A 500 mg leaf sample was mixed with 5 mL of 3% aqueous sulfosalicylic acid and the homogenate was filtered. A 2 mL portion of the extract was combined with 2 mL each of acid ninhydrin reagent and glacial acetic acid in a test tube. The mixture was incubated in a water bath at 100 °C for 1 h. To terminate the reaction, the test tubes were placed in an ice bath. Then, 4 mL of toluene was added to each test tube and shaken vigorously for 10–20 s. Two distinct color layers formed in the test tube. The absorbance was noted at 520 nm using a spectrophotometer. The concentration of proline was estimated using a standard curve (Ruscitti et al. 2011).

2.6 Total Protein Content

A 500 mg leaf sample was weighed and mixed with 10 mL of 20% trichloroacetic acid. The mixture was centrifuged at 6000 rpm for 15 min, and the supernatant was discarded. Then, 5 mL of 0.1 N NaOH was added and centrifuged for 5 min. The volume of the supernatant was increased to 10 mL with 0.1 N NaOH. In a test tube, 1 mL of the extract was combined with 5 mL of reagent C. The solution was kept in darkness for 10 min. After this, 0.5 mL of folin-phenol reagent was added, and the mixture was placed in complete darkness for 30 min. Using a UV-spectrophotometer, the absorbance of the sample was noted at 660 nm. The protein concentration was determined using a standard curve (Bradford 1976).

3 Results and Discussion

3.1 pH

According to Karmakar and Padhy (2019), the pH of leaf extracts serves as an indicator of stress and is significantly correlated with the physiological functioning of leaves.

Acidic air pollutants can lower the pH of leaf extracts (Joshi and Swami 2009). It has been reported that when bitter chemicals such as SO₂ and NO₂ are present in the atmosphere, the pH of leaf extracts decreases. Photosynthetic efficiency, stomatal activity, enzymatic activity, and cell expansion have all shown a strong correlation with plant pH (Mukhopadhyay et al. 2021). A decrease in the pH of the sap vacuole, which indicates greater vulnerability to air pollution, disrupts gas exchange, and lowers photosynthetic efficiency (Malav et al. 2022). By accelerating the formation of ascorbic acid from hexose sugar, an elevated pH indicates increased resistance (Mandal and Dhal 2022). Some investigators (Ghafari et al. 2021; Liu et al. 2021) have found that plant leaves with higher pH values are more resilient to air pollution.

According to the results, the pH of leaf extracts in highly polluted sites ranged from (6.08 ± 0.13) to (7.24 ± 0.17) , whereas in control site (less polluted), it ranged from (6.99 ± 0.01) to (8.05 ± 0.09) , as shown in Table 4. *Ficus religiosa* and *Alstonia scholaris* had the highest leaf extract pH values in both highly and control site (less polluted), while *Mimosa elengi* had the lowest pH values in both sites. According to Bora and Joshi (2014), low-pH plant species act as bioindicators of acidic pollution. Leaf extracts with a basic or neutral pH are considered resistant, while those with an acidic pH are considered more sensitive (Singh and Verma 2007). This indicates that *Ficus religiosa* and *Alstonia scholaris* were the most resistant plants, and *Mimosa elengi* was the most sensitive species with regard to sharp air pollutants in both sites.

3.2 Total Chlorophyll Content

The photosynthetic pigment "chlorophyll" acts as a photoreceptor and an indicator of productivity. The quantity of chlorophyll in a plant is influenced by various factors, including plant species, environmental conditions, and stress caused by air pollution (Malav et al. 2022). Air pollution and dust

accumulation on the surface of leaves are two factors that can decrease total chlorophyll content (Iqbal et al. 2015). Chlorophyll is a crucial physiological factor that determines photosynthetic activity and biomass growth. Pollutants like carbon dioxide and nitrogen oxide can reduce chlorophyll levels in the atmosphere (Joshi and Swami 2009).

Several factors contribute to the decline in chlorophyll quantity and photosynthesis rates in plants, including the generation of metabolic chlorophyllase, the production of reactive oxygen species (ROS), the formation of pheophytin (with the formation of H₂SO₄), and the closure of stomatal pores (Shakeel et al. 2022; Mukhopadhyay et al. 2021). Elevated levels of air pollution negatively impact chlorophyll, ascorbic acid (AA) levels and carotenoids in plant cells (Rai 2019). The levels of chlorophyll indicate a plant's tolerance or sensitivity to environmental stress. The maximum level of chlorophyll content was recorded in *Callistemon lanceolatus* (1.71 ± 0.17), and the minimum level was noted in *Ficus religiosa* (1.33 ± 0.24), as shown in Table 4.

3.3 Ascorbic Acid Content

The chloroplast contains ascorbic acid (AA), also known as vitamin C, which is a potent non-enzymatic antioxidant (Mandal and Dhal 2022). AA plays a crucial role in photosynthesis, cell division, detoxification, and cell wall synthesis, and is located in the chloroplasts of plants (Ogunkunle et al. 2015). It also protects the plasma membrane and regulates numerous metabolic and biosynthetic pathways (Banerjee et al. 2022). Elevated levels of pollutants can increase AA content at polluted sites, likely due to its role in absorbing reactive oxygen species (ROS) (Mukhopadhyay et al. 2021). A higher concentration of ascorbic acid helps plants tolerate and survive under stressful ecological conditions such as drought, salinity and extreme temperatures by protecting pigments and nucleic acids (Shakeel et al. 2022; Mandal and Dhal 2022). This study was found the maximum ascorbic acid content in *Ficus religiosa* (1.46 ± 0.08) and the minimum in *Callistemon lanceolatus* (1.29 ± 0.13).

3.4 Relative Water Content

Water is an essential component for all life on earth. Relative water content (RWC) is crucial for maintaining the plant's cell wall permeability and turgor pressure, demonstrating the balance between water intake and release (Banerjee et al. 2022). RWC significantly affects plant respiration, growth, transpiration and metabolic processes such as cell permeability, photosynthetic activity and other enzymatic responses (Rai and Panda 2014). Under stress conditions, water helps plants maintain their physiological balance (Jabeen 2019). Normal development and metabolic processes of plants

Table 3 API (Anticipated Performance Index) Categories with variable scores of plant species

Grade	Score (%)	Assessment category
7	91 – 100	Best
6	81 – 90	Excellent
5	71 – 80	Very good
4	61 – 70	Good
3	51 – 60	Moderate
2	41 – 50	Poor
1	31 – 40	Very poor
0	≤ 30	Not recommended

Table 4 Biochemical parameters and APTI of selected plant species

Plants	pH		TCC (mg g ⁻¹)		AAC (ng g ⁻¹)		RWC (%)		APTI	
	Cont	Mean	Cont	Mean	Cont	Mean	Cont	Mean	Cont	Mean
<i>Alstonia scholaris</i>	8.01 ± 0.11	7.17 ± 0.14	2.87 ± 0.43	1.68 ± 0.21	1.22 ± 0.09	1.35 ± 0.15	71.3 ± 1.42	45.7 ± 2.33	7.13 ± 0.25	4.58 ± 0.15
<i>Callistemon lanceolatus</i>	7.83 ± 0.04	6.11 ± 0.19	2.28 ± 0.13	1.71 ± 0.17	1.01 ± 0.01	1.29 ± 0.13	61.3 ± 0.51	29.1 ± 1.44	6.13 ± 0.12	2.91 ± 1.0
<i>Cassia fistula</i>	7.58 ± 0.12	6.79 ± 0.13	2.76 ± 0.24	1.53 ± 0.08	1.19 ± 0.01	1.44 ± 0.04	70.5 ± 0.92	57.3 ± 2.70	7.05 ± 0.21	5.73 ± 0.23
<i>Ficus religiosa</i>	8.05 ± 0.09	7.24 ± 0.17	2.36 ± 0.20	1.33 ± 0.24	1.26 ± 0.11	1.46 ± 0.08	74.4 ± 1.52	59.4 ± 2.43	7.44 ± 0.27	5.94 ± 0.28
<i>Mimusops elengi</i>	7.48 ± 0.18	6.08 ± 0.05	2.62 ± 0.10	1.70 ± 0.18	1.24 ± 0.05	1.32 ± 0.07	61.3 ± 0.65	39.6 ± 0.98	6.14 ± 0.10	3.96 ± 0.43
<i>Polyalthia longifolia</i>	6.99 ± 0.01	6.51 ± 0.06	2.48 ± 0.03	1.54 ± 0.07	1.29 ± 0.06	1.41 ± 0.18	71.4 ± 0.97	51.3 ± 2.12	7.14 ± 0.08	5.13 ± 0.57

Cont. = Control sample

depend on RWC. According to Lohe et al. (2015) and Tsega and Prasad (2014), higher RWC in plants indicates the ability to sustain biological processes, endure environmental challenges and maintain physiological equilibrium under stresses like air pollution and drought.

Exposure to air pollution can lower the relative water content due to various pollutants (Lohe et al. 2015). The decrease in transpiration caused by stomatal closing due to the accumulation of dust on leaves and the water content of the soil at contaminated sites contributes to this reduction (Shakeel et al. 2022). Increased cell permeability can lead to significant water and mineral loss from plant cells, potentially hastening leaf senescence as air pollution levels rise (Ogunkunle et al. 2015).

The present research outcomes verified that all plant species had lower relative water contents in highly polluted sites compared to control (less polluted). The highest relative water content was recorded in *Ficus religiosa* (74.4 ± 1.52) at control (less polluted) and (59.4 ± 2.43) in highly polluted sites, as shown in Table 4. Relative water content is lower in highly polluted environments due to the high transpiration rate of some plant species, which could explain the low relative water content in *Callistemon lanceolatus* as shown in Table 4.

3.5 APTI

The APTI explains a plant's intrinsic capacity to endure air pollution (Nadgórska-Socha et al. 2017). The APTI index varies between plant types. Tolerant plant species are used for urban vegetation and the formation of green belts in cities, while sensitive plants can serve as indicator species in polluted environments (Ogunkunle et al. 2015). Therefore, understanding plant resistance to pollution is essential when choosing plants to effectively reduce air pollution (Bui et al. 2021).

APTI values of certain plants are presented in Table 4. At control (less polluted) location, APTI values range from (6.13 to 7.44), while at highly polluted sites, they range from (2.91 to 5.94). Plant types with lower APTI values are sensitive to air pollutants (Kour and Raina 2014). The highest APTI value (5.94 ± 0.28) was observed in *Ficus religiosa*, followed by *Cassia fistula* (5.73 ± 0.23), *Polyalthia longifolia* (5.13 ± 0.57) and *Alstonia scholaris* (4.58 ± 0.15). The lowest APTI value (3.96 ± 0.43) was found in *Mimusops elengi*, with *Callistemon lanceolatus* having the lowest at (2.91 ± 1.0). The selected six species of roadside trees can be ranked based on mean APTI values as follows: *Ficus religiosa* > *Polyalthia longifolia* > *Alstonia scholaris* > *Cassia fistula* > *Mimusops elengi* > *Callistemon lanceolatus*.

Figure 2 illustrates the correlation between APTI and pH, ascorbic acid content, total chlorophyll content and relative water content. The correlations between APTI and

pH ($r=0.548$) and total chlorophyll content ($r=0.723$) were not very strong. However, a strong positive correlation was found between APTI and ascorbic acid levels in leaves ($r=0.927$) and relative water content ($r=1$), highlighting the role of ascorbic acid in the development of tolerance to air pollution.

3.6 Anticipated Performance Index

Out of the six tree species, *Ficus religiosa* has achieved a 90% API score with an API grade of 6, qualifying it for the excellent performer category. Its dense canopy cover makes it highly recommended for plantation. *Alstonia scholaris*, *Polyalthia longifolia*, and *Cassia fistula* have each obtained an 80% API score with an API grade of 5, qualifying them for the very good performer category. These species are also recommended for plantation and are well known for their economic value. The remaining two tree species, *Mimusops elengi* and *Callistemon lanceolatus*, have a 70% API score along with an API grade of 4, classifying them as good performers, as shown in Table 5.

According to the API investigation, *Ficus religiosa* was found to be the perfect plant species to reduce pollution in severely stressed environments. Due to their dense tree canopies and ability to lower air pollutants, certain plant species have been found to be incredibly efficient at maintaining their physiological and biochemical processes in heavily polluted environments. As a result, these species have been recommended for the development of green spaces in cities (Tsegay and Devi-Prasad 2014).

Recommending these plant species for the development of eco-friendly green belts in an urban ecosystem not only contributes to maintaining the ecosystem's structure but also helps sustain its functions. As the city of Lahore is a major cosmopolitan city facing severe air pollution pressures, better landscape strategies are needed. Authorities should plan plantations with high tolerance potential against air pollution and excellent carbon sequestration capabilities. This would help mitigate CO₂ levels, and such plant diversity pockets would act as carbon sinks.

3.7 Prolein Content

In response to environmental stress, proline, an amino acid, has been shown to accumulate (Ozturk and Demir 2002; Khedhar and Gadge 2014). The current study results indicated that the response of proline content was pointedly higher at the polluted site (9.86 ± 1.64) compared to the control (less polluted) (0.38 ± 0.04).

Similar results were reported by (Seyyednejad et al. 2009b; Seyyednejad and Koochac 2011; Agbaire 2016; Khedhar and Gadge 2014). According to Gupta et al. (2016), proline content is a stress marker for plants and is crucial to their defence mechanisms, particularly when it comes to oxidative damage. The accumulation of proline amino acid under stressful conditions, including air pollution, may be utilised to choose species because tolerant species have been shown to have higher proline content (Agbaire 2016). Under stressful conditions, proline accumulates due to the regulation of two pathways: increased proline synthesis enzyme levels and decreased proline degradation activity (Peng and Vermal 1996). Proline protects various plant proteins and membranes and regulates cell pH and osmosis. It has been observed that proline levels differ between species and among different plant parts (Nathalie and Christian 2008). The highest proline content was measured for *Ficus religiosa* with a value of 9.86, followed by *Alstonia scholaris* with 9.36. The lowest proline content was noted in *Callistemon lanceolatus* with 0.38 at control (less polluted). All leaf samples of plant species showed the lowest proline content at less polluted sites compared to other sites, as shown in Table 6.

3.8 Total Protein Content

The total protein content was lowest in *Ficus religiosa* with (16.60) at polluted site. All plant species accumulated higher total protein content at the control (less polluted) than at other sites, as shown in Table 7. The total protein content at the control (less polluted) was (91.83), while it was lower at all other sites. Decrease in total protein content in six plant species at all polluted sites were sufficient indication of automobile pollution toxicity. Similar results were reported by Srivastava et al. (2011), Khalid et al. (2019), Tripathi and Gautam, (2007) and Tiwari et al. (2006) While, present study results were inconsistent with findings of Sanaeirad et al. (2017). The primary reason for the reduction of total protein in plants was the presence of NO₂ and SO₂. Protein denaturation also caused a decline in protein levels in plants. Another probable reason is the formation of amino acids by the breakdown of polypeptides to endure stress due to pollution.

The results of this investigation have significant consequences for urban planning and environmental management. Urban green infrastructure can deliberately include the identified air pollution-tolerant plant species, especially *Conocarpus erectus*, *Ficus religiosa* and *Ficus benjamina* to reduce air pollution. Using these findings, urban planners

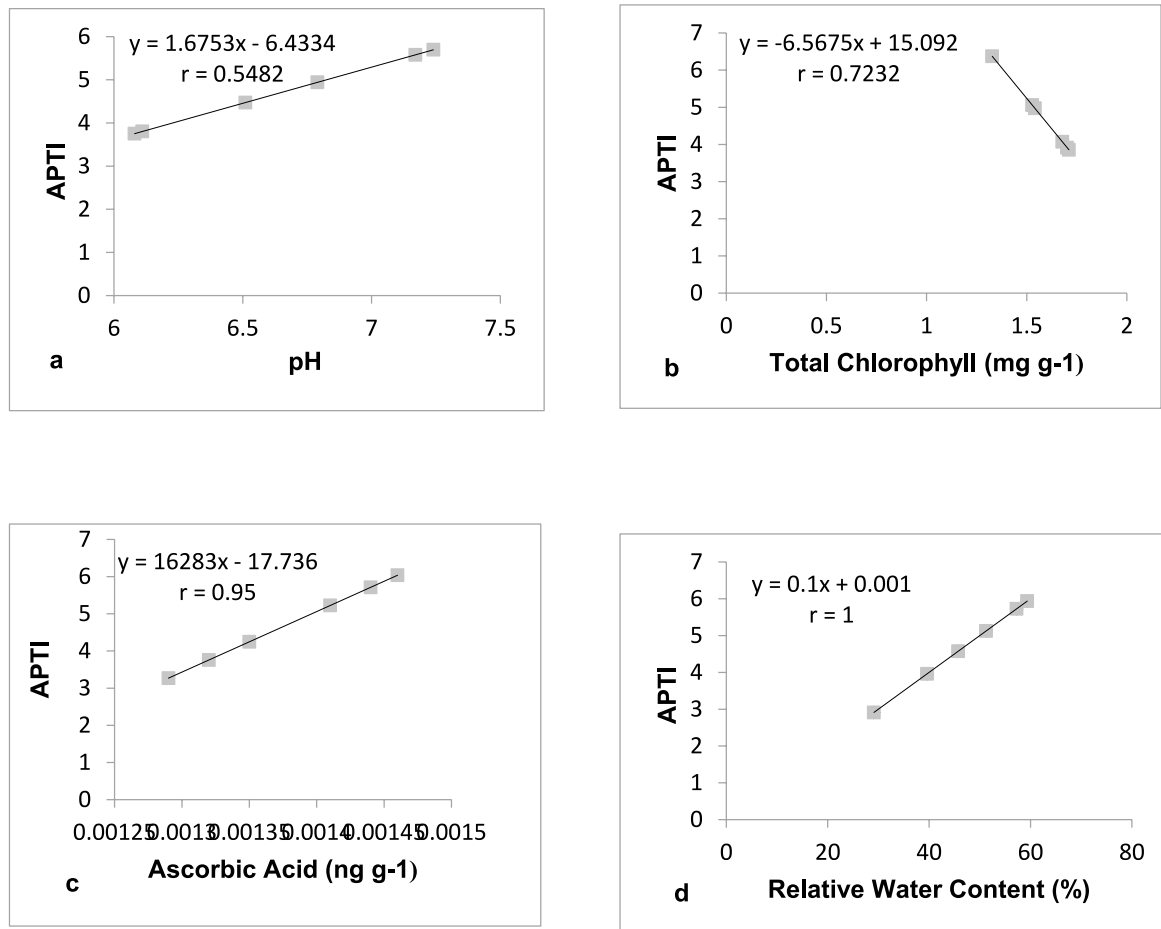


Fig. 2 Correlation between APTI and **a** pH, **b** Total chlorophyll, **c** Ascorbic acid, **d** Relative water content

and policymakers can prioritize species with high Air Pollution Tolerance Index (APTI) values when forming green corridors, parks and urban forestry projects. Additionally, you can improve space and enhance air quality by adding tolerant species to gardens and green walls. In the end, these suggestions increase public health and urban live ability by enlightening urban greening policies, air quality monitoring and public awareness initiatives.

4 Conclusions

The problem of air pollution in Lahore is exacerbated by the city's high traffic density. For planting resistant species along Lahore's busiest roads, this study offers policy recommendations to environmental protection organizations. *Ficus religiosa* has been identified as the most resistant species to air pollution. *Cassia fistula* and *Polyalthia longifolia*

are additional options in the resistant group. APTI is a significant parameter for selecting plants to be planted along busy roads to mitigate air pollution. The capacity of certain plant species to tolerate air pollutants can help to reduce the negative effects of such exposure. *Ficus religiosa* and *Cassia fistula* are the most resilient to air pollution, according to their high APTI values.

Generally, high APTI values may be used as bio-accumulators, while low APTI values could serve as bio-indicators of air pollution. Our study shows that selecting the right tree species for the growth of urban green belts can greatly benefit from evaluating the expected performance of plants. It is advised to use plants with high APTI and API values when creating green belts in such locations. To manage air pollution in these urban areas over a long period, these plants can be incorporated into an urban forestry plan. According to this research, plants with a high APTI value tend to have high proline content and the lowest total protein content.

Table 5 API estimation of plant species based on their APTI values, biological and socioeconomic characters

Plants	APTI value	Plant height	Canopy structure	Type of plant	Size	Texture	Hardness	Economic value	Total plus	Score (%)	API grade
<i>Alstonia scholaris</i>	—	+	+	+	+	—	—	+	8	80	5
<i>Callistemon lanceolatus</i>	—	+	+	+	—	+	+	+	7	70	4
<i>Cassia fistula</i>	—	+	+	+	+	—	+	—	8	80	5
<i>Ficus religiosa</i>	—	+	+	+	+	—	—	+	9	90	6
<i>Mimosops elengi</i>	—	+	+	+	+	+	+	+	7	70	4
<i>Polyalthia longifolia</i>	—	+	+	+	+	+	+	+	8	80	5

Table 6 Prolein content of various plant species

Plant species	Prolein content	
	Experimental samples	Control samples
<i>Alstonia scholaris</i>	9.36 ± 1.62	0.45 ± 0.03
<i>Callistemon lanceolatus</i>	7.31 ± 1.47	0.38 ± 0.04
<i>Cassia fistula</i>	9.08 ± 1.46	0.50 ± 0.05
<i>Ficus religiosa</i>	9.86 ± 1.64	0.41 ± 0.01
<i>Mimosops elengi</i>	8.46 ± 0.87	0.53 ± 0.06
<i>Polyalthia longifolia</i>	8.61 ± 0.56	0.55 ± 0.08

Table 7 Total protein content of various plant species

Plant species	Total protein content	
	Experimental samples	Control samples
<i>Alstonia scholaris</i>	31.42 ± 7.58	75.16 ± 3.33
<i>Callistemon lanceolatus</i>	42.45 ± 4.63	72.66 ± 4.20
<i>Cassia fistula</i>	40.03 ± 11.2	91.83 ± 12.5
<i>Ficus religiosa</i>	16.60 ± 4.71	79.33 ± 5.90
<i>Mimosops elengi</i>	48.38 ± 7.50	63.55 ± 6.15
<i>Polyalthia longifolia</i>	31.47 ± 3.93	86.01 ± 7.42

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no conflict of interests.

Ethical approval The experiment requires no ethical approvals.

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