Air Pollution Tolerance Index of Road Avenue Trees in Urban Ecosystem of Lahore City (Punjab), Pakistan

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Abstract

Lahore is one of the most polluted cities in the world and the second most populated city of Pakistan. Now a days, it is facing tremendous increase in population, rapid urbanization, unplanned industrialization and ever-increasing number of vehicles on its roads. All these phenomena are cumulatively affecting not only the human health drastically but also the quality and quantity of the plants. There is limited number of air quality monitoring stations in this city, so the road side plants which are naturally biomonitors of air pollution, are investigated for their tolerance and sensitivity towards air pollutants. For the present study, 11 dominant tree species in landscape of Lahore city were selected to determine the Air Pollution Tolerance Index (APTI). APTI was calculated by measuring the parameters i.e., chlorophyll content (mg/g), ascorbic acid content (mg/g), relative water content (%) and pH. Air Pollution Tolerance Index (APTI) in descending orderof *Mangifera indica* L. (9.95 ± 0.55), *Alstonia scholaris* L. (9.65 ± 0.25), *Dalbergia sissoo* Roxb. (9.054 ± 0.35), *Syzygium cumini* (L.) Skeels (8.80 ± 0.60), *Salix tetrasperma* Roxb. (8.40 ± 1.20), *Callistemon lanceolatus* DC (8.30 ± 0.90), *Terminalia arjuna* Roxb. Ex Dc.) Wt. & Arn. (8.05 ± 1.22), *Heterophragma adenophyllum* Seem. Ex Benth & Hook.f. (7.10 ± 0.50), *Bauhinia variegata* L. (6.75 ± 1.15), *Salix babylonica* L. (6.75 ± 0.55) and *Cassia fistula* L. (5.90 ± 1.70), respectively showing their sensitivity towards air pollutants.

Keywords: Air Pollution Tolerance Index (APTI), Phytoremediation, Urban greenery

INTRODUCTION

Lahore is one of the most populous cities in the world and it is the second-largest in terms of its population in Pakistan. The rapid increase in infrastructure and urbanization in metropolitan cities contributed in the increase of road transport. Traffic vehicles contribute majorly pollutants which are extremely hazardous in terms of their effect on air quality and the human health. The growth of population is due to the infrastructural development in Lahore and lack of basic resources in nearby cities and towns so in this regard people move towards this city for their daily needs which directly contribute to ever increasing levels of pollution. This tremendous rise in population and their horizontal settlement in the city ruined the esthetically rich landscape diversity of the metropolis ecosystem. Transportation and industrialization are the two main anthropogenic contributing factors of air pollution which have been sources of NOx, COx, NMVOCs, SOx, and $PM_{2.5}$ (FAO, 2020; Leffel et al., 2022). For example, vehicular exhaust from gasoline and diesel-powered vehicles contribute inhalable particle organic carbon, elemental carbon and aerosol mass, making traffic pollution a major contributor to urban pollution of the city (Zhang et al., 2008). Lahore, being a metropolitan city of Pakistan, is facing unplanned urbanization, industrialization, and heavy traffic load, therefore the levels of toxic air pollutants is increasing like lead, zinc and cadmium at concentrations of 4.4, 12 and 0.077 $\mu g\ m^{-3}$ respectively (Hasnain et al., 2024; Von et al., 2010; Sughis et al., 2012; Aslam et al., 2022).

Particulate matter (PM_{10} and $PM_{2.5}$), sulphur dioxide (SO_2), nitrogen dioxides (NO_2), carbon monoxide (CO) and ozone (O_3) are the most hazardous air contaminants. Long-term exposure to these pollutants can cause a variety of health issues, such as respiratory conditions, cardiovascular disease, premature death and eye irritation (Rajak & Chattopadhyay, 2020; Zhang et al., 2020). The built-up area has increased by 57%, green cover has decreased by 21%, open land has decreased by 42% and water bodies have decreased by 58% in Lahore (Shah et al., 2021). The main causes of the city's air pollution include emissions from vehicles, industrial sources and smoking. Lahore is rapidly growing metropolis city with a significant population, featuring a network of forty-two major and busy roads throughout its expanse (Shah et al., 2020).

Plants capture the pollutants by three ways; assimilation, surface deposition and particles falling on the leeward facet. Pollutants such as fluoride (HF), sulfur dioxide (SO_2) and heavy metals adversely affect photosynthetic rate, seed germination and florescence. Plants adopt themselves according to the surrounding polluted environment by having biochemical changes such as in pH, relative water content, chlorophyll content and leaf ascorbic acid content. The evaluation of biochemical and physiological changes in response to the pollutants, the tolerance and sensitivity of plant species is determined which is helpful for Green belt and biomonitoring (Nadgórska-Socha et al., 2017; Bharti et al., 2018).

The role of roadside plantation and its management in capturing atmospheric carbon and reducing effects of climate change due to increasing greenhouse gas emissions was monitored in metropolitan cities (Rao et al., 2004; Nemec et al., 2022). Due to deposition of dust particles, plants revealed symptoms like chlorosis, necrosis and epinasty. Metabolic changes i.e., increased ascorbic acid content and decreased chlorophyll content take place after absorption of pollutants like hydrogen fluoride, sulfur dioxide and heavy metals. Major parameters which are investigated to find the sensitivity and tolerance of plant species toward air pollution are pH, chlorophyll content, relative water content and ascorbic acid content (Mahrukh et al., 2023; Bashir et al., 2021;Nadgórska-Socha et al., 2017; Madan & Chauhan, 2015).

Recently, different workers contributed to air pollution biomonitoring and its application for future environmental challenges regarding air pollution in urbanized cities. High APTI and API in *Ficus benghalensis, Polyalthia longifolia and Saraca asoka* value was found in three diverse areas of West Bengal, India for mitigation of air pollution (Karmakar et al., 2021). The biochemical and physiological parameters of different plant species were studied at two busiest roads, FS (Faisalabad Sargodha Road) and M2 (Motorway 2) in Punjab, Pakistan. It was investigated that *Datura alba* was helpful for biomonitoring while *Ricinus communis* for phytoremediation (Khalid et al., 2019). Along with these, *Ficus religiosa, Ficus benghalensis and Mangifera indica* were recommended as high air pollution tolerant in Kolar industrial city of India (Roy et al., 2020). *Vinca rosea* and *Beta spectabilis* were tolerant while *Ocimum sanctum* was sensitive towards air pollution on the basis of APTI value in Bengaluru (Manjunath & Reddy, 2019). Particulate matter that was present on exposed surface of leaf in the form of dust or deposited in waxy cuticle layers of leaf showed positive correlation with APTI values, so the tolerant plant species having high APTI values reduced particulate matter that is the main contributing factor toward air pollution (Bui et al., 2021).

Because of tremendous rise in air pollution in Lahore, APTI is a valid approach to investigate the susceptibility and tolerance of different plant species to various pollutants (Bharti etal., 2018; Bui et al., 2021). By considering the drastic impacts of air pollution on plants and lack of data regarding classification and potential of plants based on air pollution tolerance levels, the present research work was planned to carry out on dominant tree species of an urban ecosystem (Lahore City). These dominant trees are bioindicators on various roadsides of Lahore city. This can help the planners and policy makers not only to formulate the air pollution tolerant species in urbanized cities but also to determine the tolerance abilities of the plants regarding defense mechanism against air pollution.

MATERIALS AND METHODS

Study area and Sampling Sites

Lahore city is located (31°15′ to 31°45′ N and 74°01′ to 74°39′ E) in the province of Punjab, Pakistan, in a semi-arid region. In the current study, Canal Bank Road, Lahore, was selected as sampling site due to its rich diversity of trees and heavy flux of the traffic density and population density around this road. The Canal Road, having two sets of highways opposite lanes, is separated by canal and it is rich in plant diversity along left side, right side, left adjacent side and right adjacent side along the entire length (29 km) of the Road. It was selected as the polluted site and GC University; Lahore campus and its Botanical Garden were selected as control sites (Figure 1).

Plantation survey was carried out and list of plants (Floristic Composition) was prepared to select the most dominant tree species among them for determining their Air Pollution Tolerance Index (APTI) values at three different sites of the road. The selected tree species based on dominance were *Alstonia scholaris* (L.) R.Br., *Bauhinia variegata* L., *Cassia fistula* L., *Callistemon lanceolatus* DC., *Dalbergia sissoo* Roxb., *Heterophragma adenophyllum* Seem. Ex Benth & Hook.f., *Mangifera indica* L., *Salix babylonica* L., *Salix tetrasperma* Roxb., *Syzygium cumini* (L.)

Skeels and *Terminalia arjuna* (Roxb. Ex Dc.) Wt. & Arn. Three samples for each tree species were collected from both polluted and control sites to determine pH, total leaf chlorophyll content, ascorbic acid content and relative water content.

Methodology

Leaf extracts was taken for pH determination with digital pH meter (HI pH-2210) after following (Das & Prasad, 2010). While determination of total chlorophyll content was based on estimation of Chlorophyll a & b which was calculated by the method described by (Singh et al., 1991).

Fresh Wt. Chlorophyll a (mg/g) = (Abs.663 × 0.0127 + Abs.645 × 0.00269) ×10 × 50
Fresh Wt. Chlorophyll b (mg/g) = (Abs.645 × 0.0229 + Abs.663 × 0.00468) ×10 × 50

Total chlorophyll (mg/g) = (Abs.663 × 0.0202 + Abs.645 × 0.00802) × 10 × 50

Where, Abs.663= Absorbance at 663 nm, Abs.645= Absorbance at 645 nm
Ascorbic acid (AA) content (mg/g) of leaf samples was estimated by following method given bellow (Keller & Schwager, 1977).
AA (Ascorbic acid content) (mg/g) = [Eo – (Es – Et) ×V] / W ×V1 × 1000

%RWC (% Relative Water Content) of leaf samples was determined by using method which given bellow (Sivakumaran & Hall, 1978).

%RWC = Initial weight - Dry weight ×100/Saturated weight –dry weight

APTI (Air Pollution Tolerance Index) was calculated by using formula given bellow (Singh & Rao, 1983).

(APTI) = [A (T+P) + R]/10

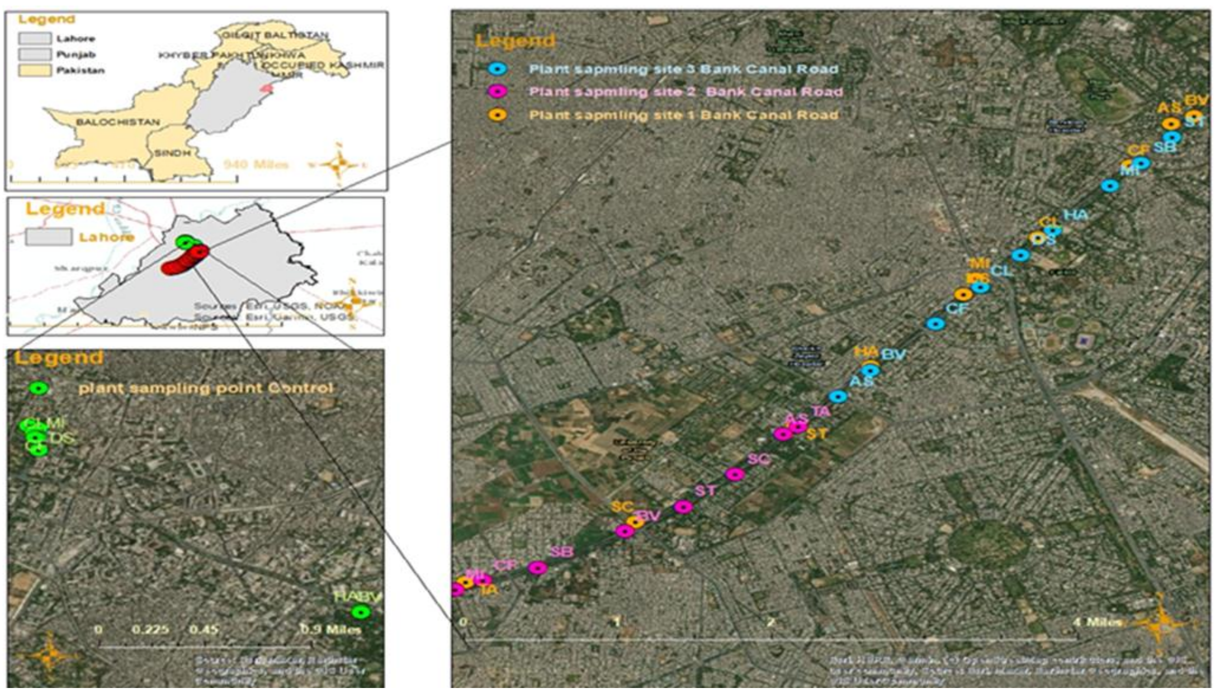

Figure 1. Study area map of control and polluted sites represented different sampling points

RESULTS

pH of plant

The pH of leaf samples concluded from the results ranged between 5.97 to 7.77 in all control tree samples and 6.54 to 7.50 in experimental samples (Table 1). Low pH (acidic) values were shown by *Alstonia scholaris*, *Bauhinia variegata*, *Cassia fistula*, *Callistemon lanceolatus, Heterophragma adenophyllum*, *Mangifera indica*, *Salix babylonica, Syzygium cumini* and *Terminalia arjuna* except in *S. tetrasperma* and *Dalbergia sissoo* and for both control and experimental samples (Figure 2).

Chlorophyll Content of leaf

The chlorophyll content (mg/g) in leaf samples of polluted site was found less as compared to the control samples as shown comparatively in Figure 3. It was 1.19 in case of *A. scholaris*, 1.15 in *B. variegata*, 1.70 in *C. fistula*, 1.13, 1.03, 1.15, 1.34, 1.14, 1.19, 1.37 and 1.00 in *C. lanceolatus*, *D. sissoo, H. adenophyllum*, *M. indica*, *S. babylonica*, *S. tetrasperma, Syzygium cumini* and *Terminalia arjuna* (Table 1). Chlorophyll content values were found higher in concentration in control samples ranged from 2.09-1.08 in all eleven tree samples. The sensitivity of these trees against air pollution flux is comparatively indicated in Figure 3.

Ascorbic acid content (mg/g) of plant

The results showed highest ascorbic acid content of 2.26 mg/g for *Cassia fistula* and lowest value of 1.23 mg/g for *Terminalia arjuna* at polluted site as give (Table 1).

A. scholaris, *B. variegata, C. lanceolatus, D. sissoo, H. adenophyllum*, *M. indica*, *S. babylonica*, *S. tetrasperma* and *Syzygium cumini* had high ascorbic acid content in polluted site samples i.e., 2.20, 1.96, 1.40, 1.38, 1.67,1.36, 1.34, 1.59 and 1.36 respectively, whereas control site samples had 1.77, 1.66,1.90, 1.31, 1.74, 1.41, 1.08, 1.21, 1.40 1.08 and 1.10 ascorbic acid content in all tree samples respectively (Table 1). The comparative values of the control and polluted site samples are given in Figure (4).

Relative water content of plant

% RWC was found less in control samples as compared to the experimental samples as the plant cells under any stress showed resistance against rapid water loss from the cells and retain their water content as they can. It was evidently observed in these results shown in Table 1 and comparison of both the samples are given in Figure (5). The %RWC values ranged from 85.20 to 26.2 in control samples and 93.40 to 57.20 in experimental samples. Both the samples of polluted and less polluted sites showed wide range of their ecological amplitude which indicated greater resistance ability of the plants against increased atmospheric pollution levels in Lahore.

Air pollution tolerance index of plant

Comparatively highest APTI value was observed in *Mangifera indica* i.e. 9.95 followed by 9.65 in *A. scholaris*, 9.05 by *D. sissoo*, 8.80 in *S. cumini*, 8.40 in *S. tetrasperma*, 8.30 in *C. lanceolatus*, 8.05 in *T. arjuna*, 7.10 in *H. adenophyllum*, 6.75 in *B. variegata* and *S. babylonica* each and 5.90 in C. fistula (Table 1). High APTI values of plants indicate their resistance towards the pollution and sensitivity in case of low APTI values [(Singh et al., 1991)].

Correlation of APTI with four physicochemical parameters

Figure 6. Illustrates the correlation of APTI with four physicochemical parameters i.e., ascorbic acid, chlorophyll, relative water content and pH. In figure 6(a), slightly positive correlation of APTI with pH values was found having R^2 value of 0.0196 and highly positively correlation with relative water content with R^2 value 0.7364 in figure (d) which indicates the plants strong defense mechanism to combat air pollution. Figure 6 (c and d) represents a little positive correlation of APTI with ascorbic acid content and chlorophyll content with R^2 values of 0.1093 and 0.0774 respectively, indicating their significance in maintaining the resilience of plants. This statistical analysis shows the participation of all four physicochemical parameters in building up the defense mechanism of plants against air pollutants. Moreover, comparative analyses of all these parameters were performed with respect to both experimental and control as shown in Figures 2-5.

Tabe 1. Comparative analysis of API values of urban landscape trees of Lahore

S. No.	Tree Species	Total Leaf pH		Total Chlorophyll Content (mg/g)		Ascorbic Acid Content (mg/g)		% Relative Water Content		APTI
		Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	
1.	*Alstonia scholaris* L.	6.49 ±0.1	6.62 ±0.04	1.38 ±0.02	1.19 ±0.01	1.77 ±0.01	2.20 ±0.10	53.7 ±0.01	81.50 ±0.03	9.65 ±0.25
2.	*Bauhinia variegata* L.	7.59 ±0.01	6.54 ±0.70	1.46 ±0.25	1.15 ±0.04	1.66 ±0.02	1.96 ±0.10	41.5 ±0.03	62.60±1.20	6.75 ±1.15
3.	*Cassia fistula* L.	6.45 ±0.01	6.54 ±0.70	1.92 ±0.60	1.70 ±0.04	1.90 ±0.02	2.26 ±0.10	26.2 ±0.03	57.20 ±3.34	5.90 ±1.70
4.	*Callistemon lanceolatus* DC	6.6 ±0.01	6.71 ±0.26	1.19 ±0.10	1.13 ±0.02	1.31 ±0.01	1.40 ±0.10	63.8 ±0.03	80.80 ±1.37	8.30 ±0.90
5.	*Dalbergia sissoo* Roxb.	7.74 ±0.01	7.50 ±0.82	1.14 ±0.04	1.03 ±0.02	1.74 ±0.10	1.38 ±0.02	78.70 ±0.03	79.10 ±0.69	9.054±0.35
6.	*Heterophragma adenophyllum* Seem. Ex Benth & Hook.f.	6.83 ±0.01	6.76 ±0.19	1.28 ±0.15	1.15 ±0.02	1.41 ±0.01	1.67 ±0.11	51.70 ±0.03	63.00±0.51	7.10 ±0.50
7.	*Mangifera indica* L	6.34 ±0.01	6.58 ±0.36	2.09 ±0.43	1.34 ±0.04	1.08 ±0.01	1.36 ±0.16	85.20±0.05	93.40 ±0.22	9.95 ±0.55
8.	*Salix babylonica* L.	6.38 ±0.01	6.91 ±0.63	1.35 ±0.06	1.14 ±0.04	1.21 ±0.01	1.34 ±0.26	42.10±0.05	62.90 ±1.00	6.75 ±0.55
9.	*Salix tetrasperma Roxb.*	6.66 ±0.08	7.05 ±0.48	1.66 ±0.07	1.19 ±0.05	1.40 ±0.01	1.59 ±0.15	60.40 ±0.10	69.10 ±1.00	8.40 ±1.20
10	*Syzygium cumini* (L.) Skeels	5.97 ±0.04	6.79 ±0.18	2.08 ±0.54	1.37 ±0.04	1.08 ±0.02	1.36 ±0.13	73.10 ±0.12	83.20 ±0.55	8.80 ±0.60
11.	*Terminalia arjuna* Roxb. Ex Dc.) Wt. &Arn.	7.77 ±0.02	6.51 ±0.70	1.08 ±0.01	1.00 ±0.01	1.10 ±0.02	1.23 ±0.01	65.70 ±0.02	75.40 ±0.17	8.05 ±1.22

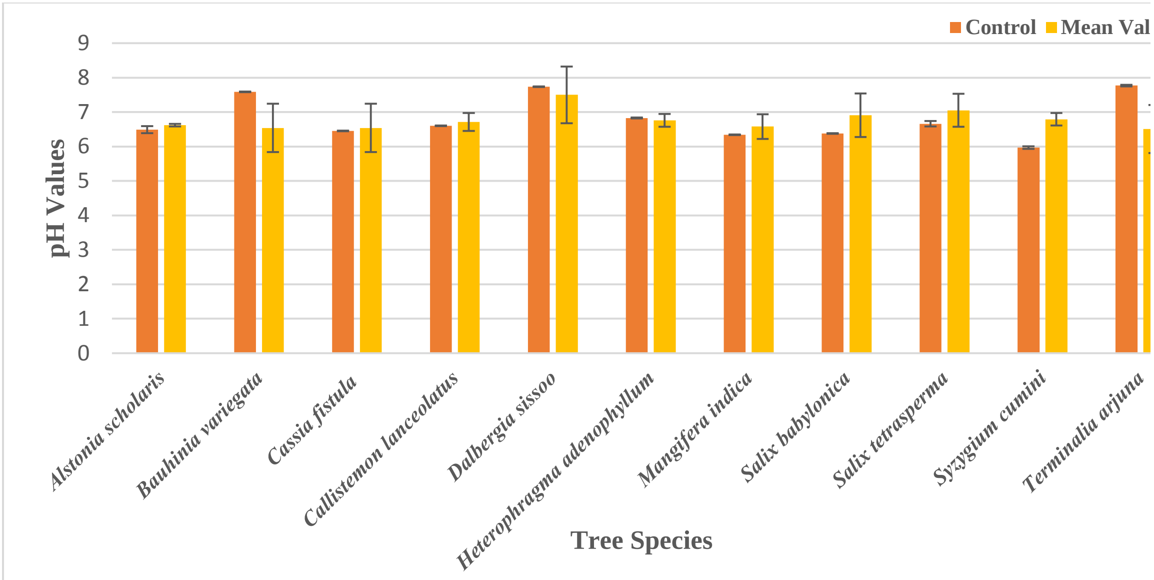

Figure 2. Comparative values of pH in leaf samples of different tree species

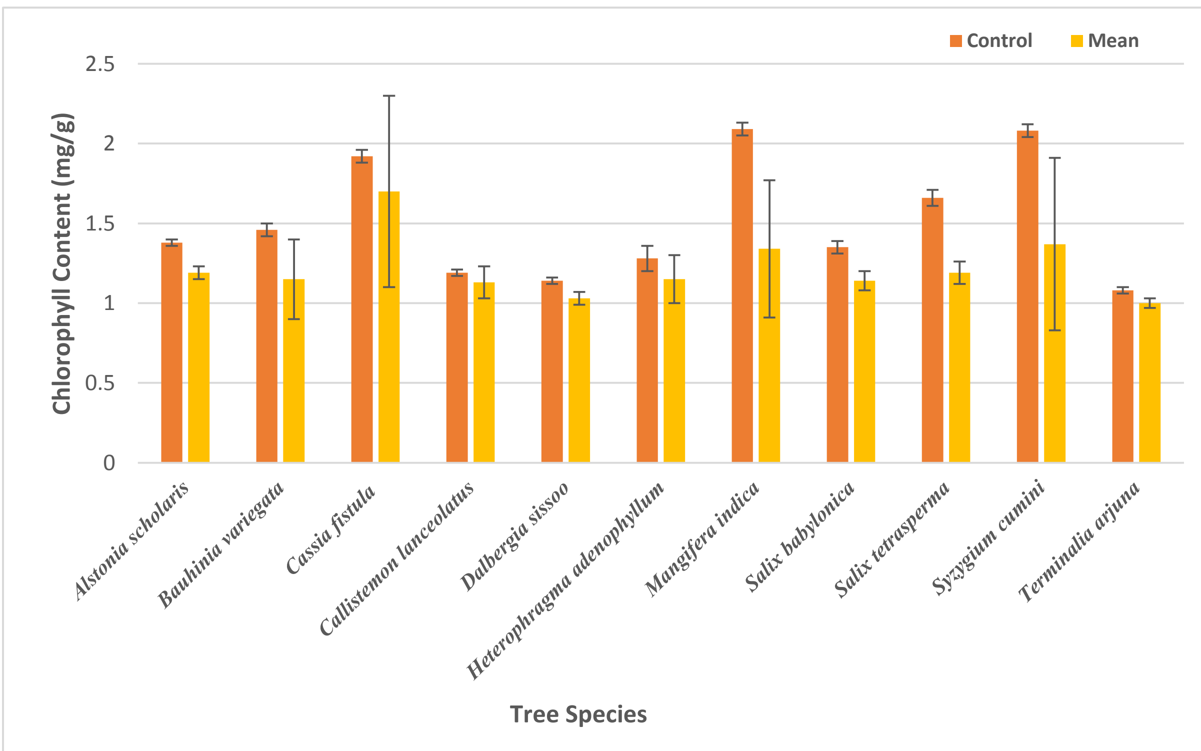

Figure 3. Comparative values of Chlorophyll Content (mg/g) of different tree species.

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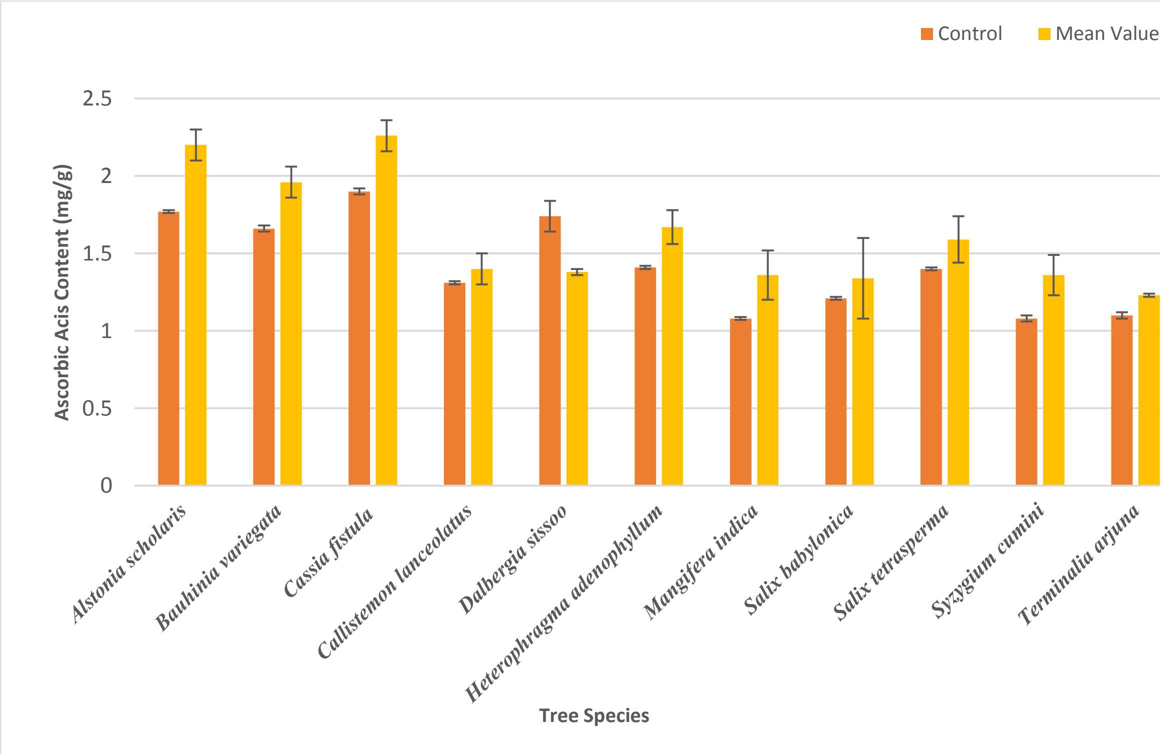

Figure 4. Comparative analysis of Ascorbic Acid content (mg/g) of different tree species

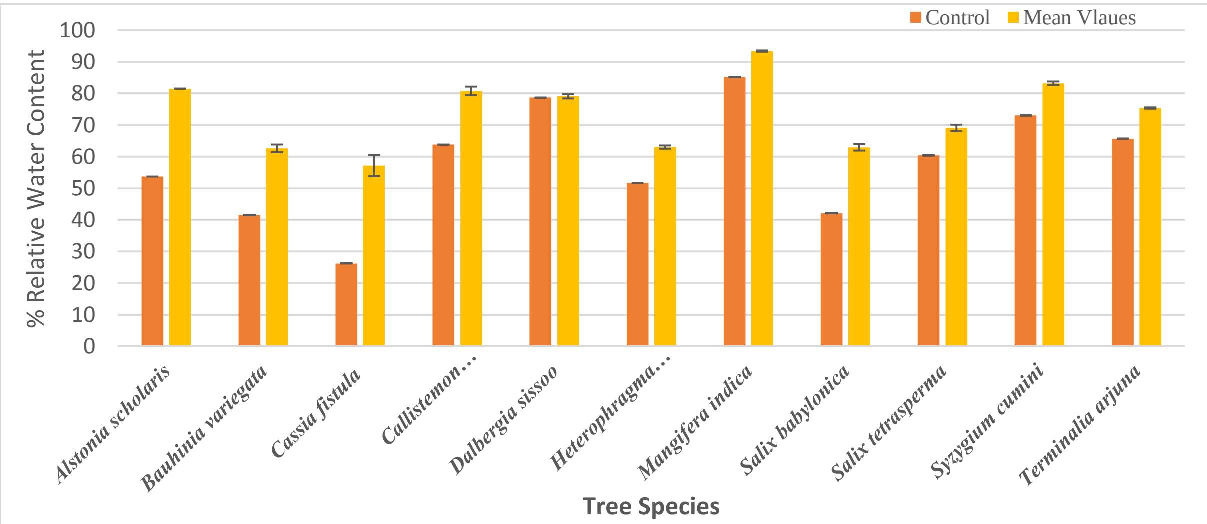

Figure 5. Comparative analysis of % Relative Water Content (RWC) of different tree species

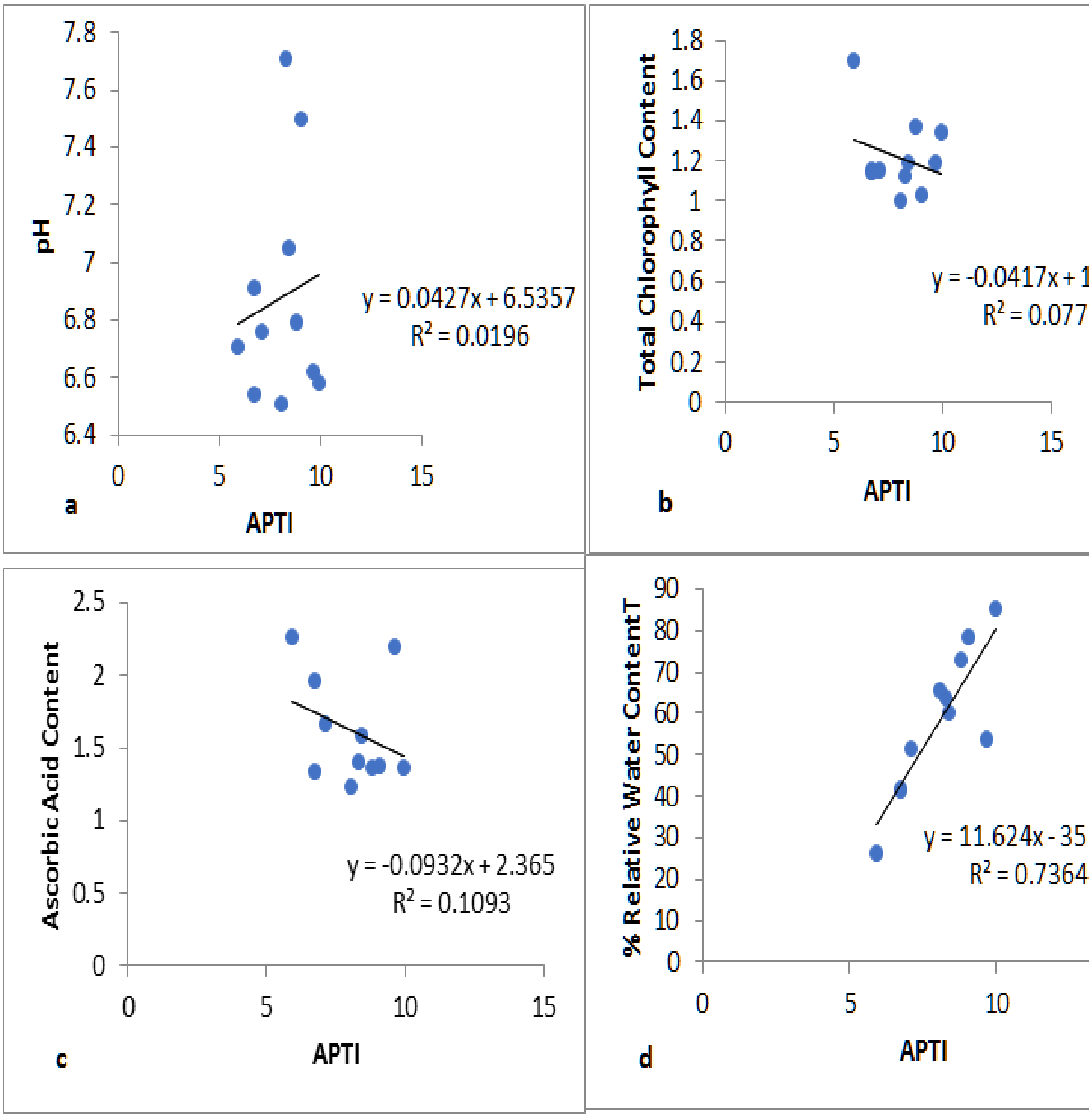

Figure 6(a-d). Regression analysis of four physiochemical parameters with A

DISCUSSION

For determination of tolerant plant species to be used for the development of green belts in heavily populated and polluted cities like Lahore, Canal Bank Road was selected. Four biochemical parameters were assessed to evaluate APTI and classify tree species as sensitive (< 12), intermediate (13–20) and tolerant (> 20) based on their APTI score after Aji et al., 2015.

Acidic pH was presented by *Cassia fistula, Mangifera indica, Syzygium cumini, Heterophragma adenophyllum, Alstonia scholaris* and *Callistemon lanceolatus* for both control and experimental samples. It was demonstrated that plants with acidic pH are susceptible to air pollution. *Salix tetrasperma, Salix babylonica* and *Dalbergia sissoo* with basic pH were considered pollution tolerant in recent study (Liu & Ding, 2008). It was investigated that basic pH of leaf helps in the conversion of hexose sugar into ascorbic acid and also in the absorption of sulfur dioxide and nitrogen oxides from atmosphere (Escobedo et al., 2008; Das et al., 2018; Uka et al., 2019; Zou, 2007).

Chlorophyll content controls photosynthetic activities, plant growth and biomass development. It decreases under stress condition, degradation of chlorophyll depend upon the type of pollutant i.e. SO_2 injure chloroplast membrane and cause chlorophyll destruction [(Hamal & Chettri, 2017)]. Whereas, high chlorophyll content values were recorded for *Bauhinia variegata, Terminalia arjuna, Callistemon lanceolatus, Dalbergia sissoo, Heterophragma adenophyllum* and *Salix babylonica* in test samples. High chlorophyll content in experimental leaf samples is an indication of their resistance towards pollution (Singh & Verma, 2007). It was reported that leaf chlorophyll content is mainly dependent upon the accumulation of ascorbic acid in chloroplast (Liu & Ding, 2008). Highest value was recorded in *Cassia fistula* i.e., 1.62 mg/g and lowest value in *Terminalia arjuna* i.e., 1.08 mg/g at polluted site. High level of pollutants degrades chlorophyll in cell to phaeophytin by replacing magnesium ions with H-atoms (Rao & LeBlanc, 1966). Air pollution causes a decrease in chlorophyll and carotenoids pigments during absorption of air pollutants, which ceased plant yield and photosynthetic activity (Madan & Chauhan, 2015). High ascorbic acid content in experimental samples depicts tolerance towards pollution and plants with low values of ascorbic acid are considered as sensitive plants (Chandawat et al., 2011; Meerabai et al., 2012). In this study low ascorbic acid content was observed in *Dalbergia sissoo*, *Heterophragma adenophyllum*, and *Salix babylonica*.

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The reducing ability of ascorbic acid enables it to play role in physiological processes of plants and in carbon fixation (Pasqualini et al., 2001). It also acts as a defense mechanism against other pollutants like SO_2 because it leads to formation of reactive oxygen and hydrogen peroxide in cells. The enzymes involved in CO_2 fixation and chlorophyll activation might be inhibited by these pollutants (Kumar & Nandini, 2013). The reducing power of ascorbic acid depends on its amount that is present in the cell. So, it is placed in the formula of ascorbic acid as multiplication factor (Swami & Chauhan, 2015). The airborne pollutants in leaf enhance the formation of reactive oxygen species (ROS) by the process of photo-oxidation. Ascorbic acid rapidly degrades ROS and control overexpression of gene linked to stress response, so it increases tolerance level of plants under polluted conditions (Pathak et al., 2019). The role of ascorbic acid in plant cell is of detoxification, cell expansion control and cell division as well, being an antioxidant molecule (Mehmood et al 2024; Sahu et al., 2020; Rini et al., 2008). Production of reactive oxygen species during stress conditions like cold or drought is controlled by ascorbic acid as it prevents plants from oxidative injury, caused by aerobic metabolism of plant cells.

Relative water content resists abiotic stress, responsible for plant growth, transpiration, respiration and physiological balance. Relative water content linked to the permeability of protoplast. High relative water content in plant increase resistance and make plant more tolerant to resist stress caused by air pollution (Karmakar et al., 2021). Relative water content that is present in any particular plant species maintains its physiological balance; especially when the level of pollutants is high plants do not allow water to transpire. The plants species that showed high relative water content at less polluted site were *Heterophragma adenophyllum* and *Salix babylonica* with 63% and 62.9% RWC respectively as compared to the polluted site with 51.7% and 42.1 % RWC respectively. Pollutants affected the transpiration rate in leaves by reducing leaf water content (Lohe et al., 2015).

Plants with APTI $\leq$ 16 are considered as sensitive plants (Aji et al., 2015). All the plants were sensitive towards air pollution as per our findings. *Mangifera indica* also had greater relative water content and *Salix babylonica* had lowest RWC among other species; thereby indicating their relationship with air pollution tolerance at polluted regions respectively. *Dalbergia sissoo, Heterophragma adenophyllum* and *Salix babylonica* had low APTI values at polluted site than at the control site. It showed their relative sensitivity towards increasing pollution as compared to *Alstonia scholaris, Bauhinia variegata, Cassia fistula, Callistemon lanceolatus, Mangifera indica, Salix tetrasperma, Syzygium cumini* and *Terminalia arjuna* having high APTI values at polluted site.

CONCLUSION

One of the busiest roads of Lahore is canal bank road with continuous flow of traffic which is affecting a variety of plant species and human health. Plants have continued exposure to air pollutants which leads to changes in the leaf pH, relative water content, chlorophyll content and ascorbic acid content. So, there is need to grow more plants with maximum canopy cover, providing resistance towards air pollution and are able to mitigate pollution by biological methods. Plants with maximum pollution tolerance and dust scavenging capability should be part of the urban planning to control the increasing pollution in urban areas. In this way plant that acts as a sink for those pollutants can be selected to combat air pollution. Air pollution tolerance index (APTI) of some selected species was assessed by measuring these parameters. All the plants were sensitive to air pollution according to the result of present study. Among all *Mangifera indica, Alstonia scholaris, Dalbergia sissoo* and *Syzygium cumini* show better results toward air pollution tolerance, hence these plants should be planted for urban green belt to cope alarming air pollution issue in Lahore, which is the most polluted city in the world as per Air Quality Index (AQI).

ACKNOWLEDGEMENTS
The authors are thankful to the department of Botany, Government College University Lahore, for providing necessary facilities during this research work.

AUTHOR CONTRIBUTIONS
All the authors contributed significantly in preparation of this manuscript.

DECLARATION
The manuscript under consideration contains solely their original work that is not under consideration for publishing in any other journal in any form.

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Submission: March 20, 2025, Revised: May 10, 2025

Accepted: May 30, 2025

Published Online: July 22, 2025