Physiochemical screening of road avenue plants in better landscape management of highly polluted urbanized city (Lahore), Pakistan (#104062)

First submission

Guidance from your Editor

Please submit by **23 Sep 2024** for the benefit of the authors (and your token reward) .

Structure and Criteria
Please read the 'Structure and Criteria' page for guidance.

Raw data check
Review the raw data.

Image check
Check that figures and images have not been inappropriately manipulated.

If this article is published your review will be made public. You can choose whether to sign your review. If uploading a PDF please remove any identifiable information (if you want to remain anonymous).

Files
Download and review all files from the materials page.

8 Figure file(s)
2 Raw data file(s)

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- **Impact and novelty is not assessed.** Meaningful replication encouraged where rationale & benefit to literature is clearly stated.
- All underlying data have been provided; they are robust, statistically sound, & controlled.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	*Example*
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult. I suggest you have a colleague who is proficient in English and familiar with the subject matter review your manuscript, or contact a professional editing service.*
Organize by importance of the issues, and number your points	*1. Your most important issue* *2. The next most important item* *3. …* *4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

Physiochemical screening of road avenue plants in better landscape management of highly polluted urbanized city (Lahore), Pakistan

Bushra Munam [1] , **Sohaib Muhammad** [Corresp., 1] , **Muhammad Tayyab** [1] , **Hafiza Komal Hanif** [1] , **Mahrukh** [1] , **Muhammad Zahid** [1] , **Hassan Nawaz** [1] , **Summiya Faisal** [1] , **Muhammad Hasnain** [1] , **Sarah Maryam Malik** [1] , **Muhammad Bilal** [1] , **Muhammad Jawad Tariq Khan** [1]

[1] Department of Botany, Government College University Lahore, Lahore, Punjab, Pakistan

Corresponding Author: Sohaib Muhammad
Email address: dr.sohaibmuhammad@gcu.edu.pk

Lahore has been consistently ranked as the world's most polluted city. Because of combative ideas to construct highways, underpasses and flyovers, Lahore had lost a remarkable percentage of its tree cover over the past 15 years. The present study focuses on the outcomes of rapidly increasing air pollution on roadside vegetation. In current study, species such as *Alstonia scholaris* L., *Bougainvillea spectabilis* Willd., *Dalbergia sissoo* Roxb. *Eucalyptus globulus* Labill., *Ficus virens* Aiton, *Ficus benjamina* L., *Ficus religiosa* Linn., *Morus alba* L., *Murraya paniculata* L., *Putranjiva roxburghii* Wall., *Polyalthia longifolia* Sonn., *Rubia tinctorum* L. found on the seven busiest roads of Lahore were selected for biomonitoring. Variation on biochemical parameters like chlorophyll a, b, total chlorophyll content & carotenoids and physiological parameters like stomatal conductance, transpiration rate and photosynthetic rate were found to be pollution load dependent. By analyzing these parameters air quality can also be assessed. In this study the dust load was maximum on the leaves of *Alstonia scholaris* L., *Ficus religiosa* Linn. and *Morus alba L.* Reduction in chlorophyll was noticed in *Alstonia scholaris* L. and *Polyalthia longiflia* Sonn. while the chlorophyll concentration of *Eucalyptus globulus* Labill. followed by *Ficus benjamina* L., *Ficus religiosa* Linn., *Ficus virens* Aiton., *Morus alba* L. and *Putranjiva roxburghii* Wall. was higher at polluted sites. The reduction in carotenoid content was found in *Murraya paniculata* L. while it was highest in *Eucalyptus globulus* Labill. Due to the pollution stress the changes in photosynthetic rate of *Alstonia scholaris* L., *Bougainvillea spectabilis* Willd., *Dalbergia sissoo* Roxb., *Murraya paniculata* L., *Polyalthia longifolia* Sonn. and *Rubia tinctorum* L. was observed. The current research distinctly signifies *Eucalyptus globulus* Labill., *Ficus benjamina* L., *Ficus religiosa* Linn., *Ficus virens* Aiton., *Morus alba* L. and *Putranjiva roxburghii* Wall. have capability to hold on the stress triggered by roadside pollutants. The findings are useful to urban greenspace landscapers

in harsh climates as they choose appropriate species that can offer a variety of ecosystem services, such as resistance to air pollution and lowering of temperature without compromising plant survival.

Physiochemical screening of road avenue plants in better landscape management of highly polluted urbanized city (Lahore), Pakistan
Plants role in pollution mitigation

Bushra Munam[1], Sohaib Muhammad[1], Muhammad Tayyab[1], Hafiza Komal Hanif[1], Mahrukh[1], Hassan Nawaz[1], Muhammad Jawad Tariq Khan, Summiya Faisal[1], Muhammad Hasnain[1], Sarah Maryam Malik[1], Muhammad Bilal[1], Muhammad Zahid[1]

[1] Dendrochronology Lab., Department of Botany, Government College University Lahore, Pakistan
Corresponding Author:
Sohaib Muhammad[1]
Street Address, Lahore, Punjab, 54000, Pakistan
Email address: dr.sohaibmuhammad@gcu.edu.pk

Abstract
Lahore has been consistently ranked as the world's most polluted city. Because of combative ideas to construct highways, underpasses and flyovers, Lahore had lost a remarkable percentage of its tree cover over the past 15 years. The present study focuses on the outcomes of rapidly increasing air pollution on roadside vegetation. In current study, species such as *Alstonia scholaris* L., *Bougainvillea spectabilis* Willd., *Dalbergia sissoo* Roxb. *Eucalyptus globulus* Labill., *Ficus virens* Aiton, *Ficus benjamina* L., *Ficus religiosa* Linn., *Morus alba* L., *Murraya paniculata* L., *Putranjiva roxburghii* Wall., *Polyalthia longifolia* Sonn., *Rubia tinctorum* L. found on the seven busiest roads of Lahore were selected for biomonitoring. Variation on biochemical parameters like chlorophyll a, b, total chlorophyll content & carotenoids and physiological parameters like stomatal conductance, transpiration rate and photosynthetic rate were found to be pollution load dependent. By analyzing these parameters air quality can also be assessed. In this study the dust load was maximum on the leaves of *Alstonia scholaris* L., *Ficus religiosa* Linn. and *Morus alba L.* Reduction in chlorophyll was noticed in *Alstonia scholaris* L. and *Polyalthia longiflia* Sonn. while the chlorophyll concentration of *Eucalyptus globulus* Labill. followed by *Ficus benjamina* L., *Ficus religiosa* Linn., *Ficus virens* Aiton., *Morus alba* L. and *Putranjiva roxburghii* Wall. was higher at polluted sites. The reduction in carotenoid content was found in *Murraya paniculata* L. while it was highest in *Eucalyptus globulus* Labill. Due to the pollution stress the changes in photosynthetic rate of *Alstonia scholaris* L., *Bougainvillea*

spectabilis Willd*., Dalbergia sissoo* Roxb*., Murraya paniculata* L*., Polyalthia longifolia* Sonn. and *Rubia tinctorum* L. was observed. The current research distinctly signifies *Eucalyptus globulus* Labill*., Ficus benjamina* L., *Ficus religiosa* Linn., *Ficus virens* Aiton., *Morus alba* L. and *Putranjiva roxburghii* Wall. have capability to hold on the stress triggered by roadside pollutants. The findings are useful to urban greenspace landscapers in harsh climates as they choose appropriate species that can offer a variety of ecosystem services, such as resistance to air pollution and lowering of temperature without compromising plant survival.

Introduction

The AQI (Air Quality Index) does not fulfill WHO air quality recommendations in many cities of Pakistan such as Lahore, Peshawar, Karachi and Islamabad, especially throughout the winter and autumn months The AQI (Air quality index) does not fulfill WHO air quality recommendations in many cities of Pakistan such as Lahore, Peshawar, Karachi and Islamabad, especially throughout the winter and autumn months (*Farrow, Miller & Myllyvirta, 2020*). As the capital of the Punjab province, Lahore has the highest aggregation of transportation in the city, contributing to the growth in air pollution. In the last decade, Lahore has been regarded as one of the most polluted cities in the world. Inevitably, this region of the world has received the least attention and lacks an adequate air quality monitoring network. It is critical to analyze the degraded ambient air quality on a regular basis and to assess the effectiveness of mitigation strategies (*Fanaei et al., 2020*). The purpose of present initiative is to find metabolically active plants that can survive in harsh environmental condition and reduce the air pollution.

Air pollution is one of the most serious environmental complications worldwide, which need immediate attention in order to be addressed by adapting environmental friendly strategies. The majority of urban locations in both developing as well as developed countries have air pollution concerns worldwide (*Singh et al., 2020*). Toxic contaminants released by various human activities such as vehicle traffic flow, easily target roadside soils (*Nazarpour et al., 2019; Kaur et al., 2022*). The growing number of vehicles and particulate matter loads contributes significantly to both regional and global environmental pollution. As one of the air contaminants, particulate matter in the atmosphere ($PM_{2.5}$) is projected to cause 3.3 million premature deaths per year primarily in Asia and has a variety of harmful consequences on the well-being of humans (*Nowak et al., 2018*). Hence, biomonitoring of air pollution is crucial for urban restoration of ecosystems as pollutants scatter and adversely impact, when discharged into the environment (*Sekhar & Sekhar, 2019*). Various researchers have recognized and speculated on the significance of plants in air pollution reduction. Air pollution poses an imminent danger to mankind and reduces human life tenure (*He et al., 2020*).

The rapidly rising population, random urbanization and extensive automobile use are contributing to a range of environmental challenges. Urban spaces are marked by increased population density and air pollution, which is one of the key factors negatively affecting the quality of the environment, with serious consequences for human well-being and regional biodiversity, particularly plants in urban environments (*Skrynetska et al., 2018*). Industries emit massive amounts of harmful contaminants and toxins into the natural environment, including CO, PM, and hydrocarbons, causing greenhouse emissions (*Munsif et al., 2021*). The sharp rise in number of vehicles, industrial exhaust and the reduction in plant cover in metropolitan areas, are the primary contributors to air quality issues in cities (*Sass et al., 2017*). The principal contributions to air pollution concentrations in the atmosphere include anthropogenic and certain natural activities (*Vardhan, Kumar & Panda, 2019*). Among the largest and most common sources of these heavy metals are vehicular emissions that can have a negative impact on roadside vegetation (*Sarhan, Elhafeez & Bashanday, 2021*). Air pollution caused by vehicles is an extremely sensitive threat to the environment for human society (*Mukherjee et al., 2019*). In addition to their sedentary nature, plants are the major consumers of pollution from vehicles (*Khalil et al., 2022*). Roadside plants offer an essential role in reducing air pollution since their enzymatic activity, physiological and anatomical characteristics aid in establishing and maintaining mitigation techniques towards vehicular emissions (*Mahrukh et al., 2023*).

Modification of leaf anatomical features can also be used to control plant physiological activity (*Kumar et al., 2022*). When plants are subjected to lethal air pollution, they change their physiological and morphological parameters including photosynthetic rate, transpiration rate, and chlorophyll concentration (*Khalid et al., 2019*). Vehicle exhaust causes environmental harm in countries like Pakistan due to inadequately maintained automobiles and the usage of low-quality fuel. CO_2, NOx, CO, SO_2, HCs, PM and VOCs are all emitted by vehicles and account for 60% to 70% of metropolitan air pollution (*Uk, Belford & Hogarh, 2019*).

Polluting substances from various sources cause substantial internal as well as external damage to plants and plant cells. Although leaves are more prone to the impacts of pollutants than any other part of plants, particularly the roots and stem, especially plants alongside roads (*Wei et al., 2021*). Researchers can acquire insight into the physiological, metabolic, and genetic mechanisms that allow these plants to thrive in polluted environments by examining air pollution tolerant species. Several physicochemical characteristics, such as chlorophyll concentration, influence plant species' pollution tolerance potential. Air pollution resistant plant species can help us learn more about how plants react to and deal with pollution in the environment. This knowledge can subsequently be applied to the development of new strategies for preserving other plant species against pollution. After receiving micronutrients from soil to plant species via roots, the relative water content aids in transpiration, offering a cooling sensation to the plant and regulating dehydration events. For various plant species, ascorbic acid represents oxidative stress and is required for cell wall development and cell division. Chlorophyll also plays a crucial role in photosynthesis and represents ongoing stress (*Roy, Battacharya & Kumari 2020; Sahu, Basti & Sahu, 2020*). In order to measure the air contamination fungi, lichens, tree rings, leaves, and barks of trees are studied. Vulnerable species, such as lichens, cannot thrive in densely crowded commercial and metropolitan environments. As a result, trees may be used as ecological indicator species in urban settings to assess air quality. Pollution changes the morphological and metabolic properties of plant species, allowing plants to test the durability of their leaves to air pollution (*Ghafari et al., 2021*). Some species of plants that are grown near industrial sites significantly reduce air pollution. With the help of air pollution tolerance index (APTI) it's easy to distinguish plants that could lower air pollution. Researchers, environmentalists, and policymakers strongly urge constructing green belts of specific plant species around urban areas to reduce the impact of dangerous airborne pollutants (*Bharti, Trivedi & Kumar, 2018*). The primary goal of the current research is to provide an in-depth knowledge of the connection within air pollution and its mitigation efforts by roadside plant species. The objectives of this research: (1) to make rapid decisions on the use and preservation of green belt (2) vegetative traffic barrier across the roads for decreasing the levels of air pollutants distribution (3) evaluate the capability of numerous species of plants along roadways to reduce air pollution. It also briefly discusses the capacity of plants to reduce pollution by lowering dust trapping capability. The utilization of plants to reduce and absorb pollutants from the atmosphere has been advocated as the only ecomanagement solution (a method of reducing the adverse impact of human activity on the environment) for air pollution. This is a safe sustainable approach, which can save the environment via energy conservation and cheaper pollutant reduction, has no negative environmental effects and employs a renewable source of energy (*Tundele, 2015*).

Materials & Methods

The influences of vehicular pollution upon physicochemical features of plants were investigated by selecting multiple roads of Lahore city.

Study site

Seven main roads of city were chosen based on traffic volume to explore how automobile pollution impacts the landscaping along roads. Selected roads were Main Boulevard Allama Iqbal Town Road 1, Main Boulevard Allama Iqbal Town Road 2, Fazl-e-Haq road, Moulana Hasrat Mohani Road, Wahdat Road1, Wahdat Road 2 and Moulana Shoukat Ali Road. Control site plant samples were collected from less contaminated locations, such as neighboring parks. The samples were collected in triplicates from the selected roadside plants.

Floristic composition

A survey of seven selected roadways was done to acquire a knowledge of plant types on study site. The available literature was then used to identify annual and perennial species (Nasir and Ali, 1970–1989; Ali and Nasir, 1990–1992; Ali and Qaiser, 1992–2007). Subsequently, plants were chosen depending on the percentage and uniformity throughout the route and sampling was carried out around the spring season, when the plants were at their peak of growth.

Selection of plant species

Plant species were chosen according to their frequency of occurrence and commonness after (*Muller-Dombois & Ellenberg, 1974*). From each location, roadside plants were picked, bagged and labeled. Depending on the basis of abundance and distribution of plants, the following species were selected on the study sites for analysis: *Alstonia scholaris* L., *Bougainvillea spectabilis* Willd., *Dalbergia sissoo* Roxb. *Eucalyptus globulus* Labill., *Ficus benjamina* L., *Ficus virens* Aiton., *Ficus religiosa* Linn., *Morus alba* L., *Murraya paniculata* L., *Putranjiva roxburghii* Wall., *Polyalthia longifolia* Sonn., *Rubia tinctorum* L. as shown in table 1.

Design of experiment

Although selected plant species had been collected from seven distinct areas based on their accessibility, the entire experimental study was carried out using an entirely random design. Plant species were gathered in three replicates. Various physio-chemical, bio-chemical assessments were performed in order to find the effect of air pollution on common species. Fresh mature leaves from control (least polluted) and sample plants were taken during the day's peak rush hour. These were instantly transported to the laboratory for examination. For every species, a combined sample of nine leaves was taken for analysis. All plants under examination were subjected to ecological conditions in terms of light, water, soil, and pollution exposure.

Physiological parameters

By using leaf area meter, leaf length, leaf width and leaf area index was measured.

Dust content

By using weighing balance, filter paper was weighed. Dust from leaves was removed with help of camel hairbrush and reweighed filter paper. Amount of dust was calculated by subtracting both values (filter paper without dust and filter paper with dust) (Hussain, Illahi & Rashid, 1989).

Physiochemical assessments

The Infrared Gas Analyzer (IRGA, LCA-4) was used to assess physiological features such as photosynthetic rate, transpiration rate and stomatal conductance (Muhammad et al., 2014).

Biochemical assessments

In order to determine carotenoids content, chlorophyll a, b and total chlorophyll biochemical parameters were assessed.

Total chlorophyll content (mg/g)

Chlorophyll content was determined by using the method of acetone extraction (*Singh et al., 1991*). 2 grams of fresh leaves were taken and crushed in 20ml of 80% acetone by using pestle and mortar. Through filtration, extract of plant leaves was obtained. The absorbance of the filtrate was determined with the help of spectrophotometer at the wavelengths of 663nm and 645nm. The whole process was repeated for each plant sample.

To determine the total chlorophyll content following equation was used:

$$\text{Chl. a} = (A_{663} \times 0.0127 + A_{645} \times 0.00269) \times 10 \times W \quad (1)$$

$$\text{Chl. b} = (A_{645} \times 0.0229 + A_{663} \times 0.00468) \times 10 \times W \quad (2)$$

$$\text{Total chlorophyll content} = (20.2 \times A_{645} + 8.02 \times A_{663}) \times V/1000 \times W \quad (3)$$

Where, A_{663} = Absorbance at 663nm, A_{645}= Absorbance at 645

V= Total volume of extract, W= Fresh weight of leaves (g)

Carotenoid content

1 g leaves were grinded by using 100% acetone. Through filtration extract of plants were obtained and raise the final volume of extraction solution up to 50 ml. The carotenoid content was determined by spectrophotometer at the wavelength of 440.5nm (*Zofia, Kmiecik & Korus, 2006*).

To measure the carotenoid content following equation was used:

$$\text{Carotenoids contents: } [V \times 383 \times (As- Ab)] / (100 \times W) \quad (4)$$

Where, 'V' = volume

'383' = carotenoids extinction coefficient

'As' = sample absorbance

'Ab' = cuvette error

'W' = weight of sample (g)

Results

From the busiest roadways plant samples were taken and the leaf area, chlorophyll content, carotenoids content along with photosynthetic rate, transpiration rate and stomatal conductance of these samples were checked. Total numbers of 85 plants species were recorded in floristic composition by roadside surveys. For this research work, 12 dominant and common plants species found on all the selected road sites were chosen. On the seven selected study sites the common plants of urban landscape were: *A. scholaris* L., *B. spectabilis* Willd., *D. sissoo* Roxb., *E. globulus* Labill, *F. virens* Aiton., *F. benjamina* L., *F. religiosa* L., *M. alba* L., *M. paniculata* L., *P. roxburghii* Wall., *P. longifolia* Sonn., *R. tinctorum* L. The selected plant species and their data are presented in table 1. Several parameters regarding air pollution were assessed by keeping an eye on the increasing atmospheric pollution and its harsh impacts on flora of Lahore city.

A. scholaris: The amount of dust deposited on the leaf of *A. scholaris* was higher at polluted site (0.02 g) and lower (0.004 g) at control site. Leaf area index shows there was a maximum decrease in size of leaf present at polluted site (543.13 mm^2) and the leaf size of control site was (1693 mm^2). In *A. scholaris* stomatal conductance (mol m^{-2} s^{-1}) was 0.04, transpiration rate (mol m^{-2} s^{-1}) was 0.17 and photosynthetic rate (μmol m^{-2} s^{-1}) was 25.36 found in polluted sites while, in control sites, the value of stomatal conductance, transpiration rate and photosynthetic rate was 0.07, 0.25, 34.07 which was higher than experimental sites. The chlorophyll content (mg/g) and carotenoid content (mg/g) of *A. scholaris* at polluted sites was 0.44, 5.94 while at control site the chlorophyll and carotenoid content were 1.20, 6.88.

B. spectabilis: Determination of the dust load shows that *B. spectabilis* present at the polluted sites was 0.015 (g) and control site was 0.004 (g). Leaf area index shows that the leaf size of polluted site (312.9 mm^2) was reduced as compared to leaf area of control site (532.33 mm^2). Stomatal conductance, transpiration rate and photosynthetic rate in *B. spectabilis* at polluted sites were 0.05, 0.18 and 34.37 respectively. But at the control sites a gradual increase found in these parameters, the value of stomatal conductance, transpiration rate and photosynthetic rate was 0.15, 0.48 and 35.88 which shows high pollution rate at the polluted sites. The chlorophyll and carotenoids content in *B. spectabilis* was 1.29 (mg/g), 6.04 (mg/g) at experimental site while at control site the value was 2.21 (mg/g) and 9.07(mg/g).

D. sissoo: Dust deposited on the leaf of *D. sissoo* at polluted site (0.014 g) were greater as compared to the dust load of control site (0.003 g). There was also a decrease in the leaf area index of polluted site (271.04 mm^2) while at control site was (414.7 mm^2). In *D. sissoo* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.03, 0.21 and 28.23 while at control site the values were increased such as 0.08, 0.32 and 51.58 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.56 (mg/g) and 7.15(mg/g) while at control sites the values were 0.82 (mg/g) and 11.18 (mg/g).

E. globulus: Dust accumulation on the leaf of *E. globulus* was found to be (0.014 g) at polluted site while there was a reduction (0.003) in dust amount at control site. Same goes with the leaf area index at polluted site was (294.73 mm^2) higher (436.6 mm^2) than control site. In *E. globulus* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.09, 0.26 and 27.88 while at control site the values were decreased such as 0.08, 0.22 and 27.64 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.71 (mg/g) and 9.12(mg/g) while at control sites the values were 0.65 (mg/g) and 6.20 (mg/g). Maximum increases in all parameters were shown at all polluted sites as compared to control site.

F. benjamina: Dust accumulation on the leaf of *F. benjamina* was 0.011 g at polluted sites and control site was 0.003 g. The leaf area index was lower (257.84 mm^2) at polluted site while the leaf area at control site was (341.8 mm^2). Stomatal conductance, transpiration rate and photosynthetic rate in *F. benjamina* at polluted sites were 0.17, 0.86 and 56.60 respectively. But at the control sites the value of stomatal conductance, transpiration rate and photosynthetic rate was 0.16, 0.85 and 53.73 which shows a slight reduction in transpiration rate and photosynthetic rate at control site. The chlorophyll and carotenoids content in *F. benjamina* was 0.80 (mg/g), 5.25 (mg/g) at experimental site while at control site the value was 0.75 (mg/g) and 5.22(mg/g).

F. religiosa: At experimental site the average dust found on the leaf of *F. religiosa* was 0.02 (g) and at control site was 0.004 (g) and leaf area index was 201.93 (mm^2) at experimental site and 341.8 (mm^2) at control site. In *F. religiosa* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.62, 0.67 and 60.22 while at control site the values were 0.58, 0.59 and 50 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.81 (mg/g) and 5 (mg/g) while at control sites the values were 0.65 (mg/g) and 5.82 (mg/g).

F. virens: The amount of dust present on the leaf of *F. virens* were 0.016 (g) at polluted site and 0.004 at control site. The leaf area index was 1670 (mm^2) at control site and maximum reduction 958.82(mm^2) found in leaf area index of polluted site. The values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.19, 0.42 and 44.41 while at control site the values were decreased such as 0.17, 0.41 and 44.26 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.64 (mg/g) and 7.76(mg/g) while at control sites the values were 0.61 (mg/g) and 7.17 (mg/g).

M. alba: Amount of dust determined on the leaves of *M. alba* at polluted site were 0.02 (g) while its control value was 0.006 (g) and the calculations of leaf area index were 997.8 (mm^2) at experimental site and 1172.86 (mm^2) at control site. In *M. alba* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.15, 0.54 and 63.01 while at control site the values were decreased such as 0.14, 0.48 and 59.73 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 1.80 (mg/g) and 7.91 (mg/g) while at control sites the values were 1.36 (mg/g) and 7.18 (mg/g).

M. paniculata: The leaves of *M. paniculata* captured the amount of dust at polluted site were 0.011 (g) while the dust at control site leaves were 0.004 (g) and leaf area index was 88.86 (mm^2) at polluted site and the control value of leaf area index were 97.96 (mm^2). In *M. panniculata* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.04, 0.24 and 26.80 while at control site the values were increased such as 0.13, 0.62 and 45.14 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.75 (mg/g) and 4.12 (mg/g) while at control sites the values were 1.14 (mg/g) and 4.45 (mg/g).

P. longifolia: On the leaves of *P. longifolia* the amount of dust accumulated at polluted and control site were 0.016 (g) and 0.005 (g) and the leaf area index at polluted and control site were 1071.2 (mm^2) and 1182.5 (mm^2). In *p. longifolia* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.08, 0.10 and 42.27 while at control site the values were increased such as 0.09, 0.13 and 43.89 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 0.41 (mg/g) and 6.29 (mg/g) while at control sites the values were 0.44 (mg/g) and 7.43 (mg/g).

P. roxburghii: The average amount of dust accumulated on the foliage leaves of *P. roxburghii* at experimental site were higher (0.012 g) as compared to control site (0.004 g) and the leaf area index of polluted site were also higher 496.66 (mm^2) than control site 611.66 (mm^2).In *P. roxburghii* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.17, 0.34 and 56.90 while at control site the values were increased such as 0.15, 0.32 and 57.91 respectively. The biochemical parameters such as chlorophyll and carotenoids contents at polluted sites were 2.55 (mg/g) and 7.60 (mg/g) while at control sites the values were 2.33 (mg/g) and 7.48 (mg/g).

R. tinctorum: Examination of dust accumulation shows that the leaf of *R. tinctorum* present at the road site loaded with dust more than the control site. The values were 0.013 (g) and 0.007 (g). The leaf area index was 306.55 (mm^2) at the road sites and 351.11(mm^2) at the control site**.** In *R. tinctorum* the values of stomatal conductance, transpiration rate and photosynthetic rate at polluted sites was 0.08, 0.59 and 30.60 while at control site the values were increased such as 0.17, 1.61 and 40.12 respectively. The chlorophyll and carotenoids contents at polluted sites were 0.67 (mg/g) and 7.84(mg/g) while at control sites the values were 0.98 (mg/g) and 9.69 (mg/g).

Discussion

Planting trees is one of the key elements in the planning of a sustainable city; choosing the right species and allotting enough room for them to grow is crucial to the design of ecologically sound cities (Ong, 2003). The percentage of green space in an urban area especially the presence of trees determines its ecological performance (*Whitford, Ennos & Handley, 2001*), because the majority of solutions for improving the quality of the air in large metropolitan centers involve reducing emissions from main sources. The primary originators of air pollution in metropolis are soil dust, cement manufacturing, vehicle exhaust and combustion of fuel, each with varying contributions (*Arditsoglou & Samara, 2005*). Urban vegetation has the potential to influence pollutant deposition and dispersion, making it a valuable tool for improving air quality (*Janhall, 2015*). One trait that is thought to indicate a plant capacity for stress tolerance is the length of its leaves (*Seyyednejad, Niknejad & Yusefi, 2009*). In our experiment maximum reduction (1149.87 mm^2) in leaf area was found in *Alstonia scholaris* at polluted site. In woody plants, the long-term effects of various pollutants, such as SO_2 and heavy metals, result in a decrease in leaf size and the growth of aerial plants (*Kozlov, Zvereva & Niemela, 1999*).

The average amount of dust deposited on all plant species across a site was higher in the polluted zone than in the control zone. The unit of measurement for dust accumulating ability was mg of dust deposited per mm^2 of leaf area. Different tree species have notably differing amounts of dust deposited on their leaves. The dust capturing capacity of plant species in the present experiment fall in the range of 0.02–0.003 mg mm^{-2}. Although, in the present study dust load was highest on leaves of A*lstonia scholaris, Ficus religiosa* and *Morus alba* at all polluted sites. While *Ficus benjamina* and *Murraya paniculata* revealed the least amount of dust accumulation across all polluted sites. This is due to leaf area, the canopy structure, and morphological characteristics of leaves.

According to (*Tallis et al., 2011*) the uptake of particles by vegetation can be affected by several key features including particle size distribution, number of particles in airstream, wind speed and canopy area and structure (i.e. tree species). Furthermore, hairy structure on the surface of leaf, area of leaf and petiole length are considered as an important factor for deposition of dust on the surface of leaf. In current work the tree species like *Alstonia scholaris, Ficus religiosa* and *Morus alba* had high dust load. Examination of twelve tree species in capturing pollutant particles were examined in terms of leaf attributes like surface area of leaf, shape of leaf, size of petiole (*Beckett, Freer-Smith & Taylor, 2000*). Several researchers showed that lower surface area of leaf and length of petiole generates limited exposure of pollution particles. In this research, we also discovered that dust deposition is higher in plants that have larger leaf area, alternate arrangement, compound phyllotaxy, short petiole and rough surface. Dust load on the leaf of trees causes reduction in photosynthesis, lessen stomatal densities and stomatal pore width, resulting into drought sensitivity, because of thin cuticles (*Pourkhabbaz, Rastin & Olbrich, 2010*). In current experiment, we found that reduction in photosynthetic rate at polluted site induced decrement of carbon consumption and reduction in chlorophyll and carotenoids also seen in several species. Oxidative stress in plants cells is caused by reactive oxygen species due to air pollution (*Singh & Rathore, 2018*). Wind speed is also the reason for dust deposition on leaves. Dust particles from surrounding soil settled on the leaves of plants nearby roads because of wind (*Buccolieri et al., 2018*).

Over the next 20 years urban plantation can remove air pollution if appropriate forest management is planned (*Parsa et al., 2019*). The chlorophyll of sample plants was inversely correlated with the amount of dust present on the leaf. The amount of chlorophyll drops as the dust load rises. In every experimental tree, it was prominent. *Polyalthia longifolia* and *Alstonia scholaris* showed maximum reduction in chlorophyll concentration as a result of the dust load. As chlorophyll is essential to plant metabolism and any decrease in chlorophyll content immediately impacts plant growth, measuring chlorophyll content is a useful method for assessing air pollution impacts on plants (*Verma & Chandra, 2015*). In this way, leaf chlorophyll and carotenoids may deliver substantial details on the physiological state of plants. Plant productivity drops as soon as chlorophyll levels drop, and as a result, the plants lose stability. Thus, plants that maintain their chlorophyll despite being in an atmosphere that is polluted are considered tolerant (*Singh & Verma, 2007*). Decrease in the amount of carotenoid, total chlorophyll content, chlorophyll a, and chlorophyll b in the specimens from polluted locations containing vehicle exhaust noticed by (*Kapoor, 2014*). In present research the chlorophyll concentration of *Eucalyptus globulus, Ficus benjamina, Ficus religiosa, Ficus virens, Morus alba* and *Putranjiva roxburghii* was higher at polluted sites and lower in control site.

In the current work surprisingly the *E. globulus, Ficus benjamina, Ficus religiosa, Ficus virens, Morus alba* and *Putranjiva roxburghii* leaves collected from busy road areas showed a noteworthy increase in total chlorophyll content as compared to control. It suggested that the *E. globulus, Ficus benjamina, Ficus religiosa, Ficus virens, Morus alba* and *Putranjiva roxburghii* was more metabolically active and tolerant to polluted air. Species with higher levels of chlorophyll are more tolerant to environment with contaminants and are favorable to plant in that area (*Roy, Battacharya & Kumari 2020).* The amounts of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids in *E. globulus Ficus benjamina, Ficus religiosa, Ficus virens, Morus alba* and *Putranjiva roxburghii* leaves increased in polluted region. The primary components of energy synthesis in green plants are chlorophyll and carotenoids and environmental influences on plant metabolism greatly alter their concentrations (*Shweta, & Agrawal, 2006)*. Despite being an essential component of the plant's antioxidant defense mechanism, carotenes are highly vulnerable to oxidative damage. The highest reduction of carotenoids content was found in *Murraya paniculata* at all roads sites. While surprisingly the carotenoids content of *Eucalyptus globulus* was highest at polluted site which explains its adaptability in air pollution. Along with the chlorophyll and carotenoids, the change in shape and direction of thylakoids is also noticed in photoreactive stress (*Sagar & Briggs, 1990*). Low stomatal conductance in leaves of *Dalbergia sissoo*, *Alstonia scholaris* and *Murraya paniculata* was recorded at polluted site which reduced the photosynthetic rate.

In heavily polluted places plants limit transpiration to preserve the equilibrium of their physiological processes. The transpiration rate was low in *Alstonia scholaris*, *Bougainvillea*

spectabilis while *Polyalthia longifolia* had lowest rate of transpiration in both control and polluted sites as compared to other species. Pollutants impact the mechanism of plant transpiration and lower the relative water content of plants (*Gholami, Mojiri & Amini 2016; Abhijit et al., 2017*). Plant samples from contaminated areas had lower levels of chlorophyll due to vehicle exhausts (*Kamble et al., 2021*). Reduced photosynthetic rates result from various automotive pollution negatively affecting chlorophyll concentrations of plants. When photooxidative damage occurs inside chloroplasts, carotenoids shield the machinery from it. The carotenoid content reduced by a variety of contaminants, which leads to pigment degradation and the breakdown of the chloroplast cellular structure (*Sharma & Tripathi, 2009*).
The pollution stress commonly altered the photosynthetic rate of *Alstonia scholaris, Bougainvillea glabra, Dalbergia sissoo, Murraya paniculata, Polyalthia longifolia* and *Rubia tinctorum.* In harsh environmental situations photosynthesis is the fundamental element in analyzing the metabolism of plants and survival. Accumulation of air pollutants in leaves causes amendments in physiological and biochemical attributes of plants. The absorption of light radiation is blocked by the particulate matter accumulated on the surface of leaves cause reduction in photosynthesis. Restriction in photosynthetic activity is also due to closing of stomata and reduction in leaf area. The gaseous pollutants like SO_2, NO_X and O_3 causes closure of stomata and break CO_2 availability for photosynthesis (*Dhir, 2016*) Reduction in the rate of stomatal conductance and transpiration in some species at the polluted site was recorded in this study. The reason for the reduction in both features was particulate matter which blocked the stomatal pores that resulted in increase of sub-stomatal CO_2 (*Flowers et al., 2007*).

Conclusions

Air quality of Lahore is at worst in terms of particulate matter generated by high traffic volume. Such drastic change in the environment causes a serious threat to plants. Roadside plants assimilate maximum pollution as compared to the trees located away from avenue. The present study highlights the detrimental impacts of gaseous pollutants on the physiochemical and biochemical parameters of some selected species planted at roadsides of Lahore city. The selected plant species were categorized as pollution tolerant and sensitive by analyzing the results of these parameters. *E. globulus* followed by *Ficus benjamina, Ficus religiosa, Ficus virens, Morus alba* and *Putranjiva roxburghii* was more metabolically active and tolerant to air pollutants because the chlorophyll concentration of these plants was higher at polluted sites and lower in control site. There must be proper management of greenbelt to control and maintain the air quality index and these species are highly recommended for controlling air born pollution in urban climate.

Acknowledgements

Authors are grateful to department for providing necessary facilities in execution of lab. and field work.

References

Abhijit KV, Kumar P, Gallagher J, Mcnabola A, Baldauf R, Pilla F, Broderick B, Di-sabatino S, Pulvirenti B. 2017. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments-a review. *Atmospheric Environment* 162:71-86 https://doi.org/10.1016/j.atmosenv.2017.05.014.

Ali S I, Nasir Y J, Flora of Pakistan. Nos. 191-193. Department of Botany, University of Karachi and National Herbarium, PARC, Islamabad, **1990-92**.

Ali S I, Qaiser M Flora of Pakistan. Nos. 194-208. Department of Botany, University of Karachi and National Herbarium, PARC, Islamabad, **1992-2007**.

Arditsoglou A, Samara C. 2005. Levels of total suspended particulate matter and major trace elements in Kosovo: a source identification and apportionment study. *Chemosphere* 59: 669–678 https://doi.org/10.1016/j.chemosphere.2004.10.056.

Beckett KP, Freer-Smith PH, Taylor G. 2000. Particulate pollution capture by urban trees: effect of species and wind speed. *Global Change Biology* 6:995–1003 **https://doi.org/10.1046/j.1365-2486.2000.00376.x**.

Bharti SK, Trivedi A, Kumar N. 2018. Air pollution index of plants growing near an industrial site. *Urban Climate* 24:820-829 https://doi.org/10.1016/j.uclim.2017.10.007.

Buccolieri R, Jeanjean APR, Gatto E, Leigh RJ. 2018. The impact of trees on street ventilation, NOx and PM2.5concentrations across heights in Marylebone Rd street canyon, central London. *Sustainable Cities and Societies* 41:227-241 https://doi.org/10.1016/j.scs.2018.05.030.

Dhir B. 2016. Air pollutants and photosynthetic efficiency of plants. In: *Plant responses to air pollution.* Springer: Singapore, 71–84.

Fanaei F, Ghorbanian A, Shahsavani A, Jafari AJ, Abdolahnejad A, Kermani M, Fanaei F. 2020. Quantification of Mortality and Morbidity in General Population of Heavily-Industrialized City of Abadan: Effect of Long-Term Exposure. *Journal of Air Pollution and Health* 5:171–180 https://doi.org/10.18502/japh.v5i3.5390.

Farrow A, Miller KA, Myllyvirta L. 2020. *Toxic Air: The Price of Fossil Fuels*. Greenpeace Southeast Asia: Netherlands, 1–44

Flowers MD, Fiscus EL, Burkey KO, Booker FL, Dubois JJB. 2007. Photosynthesis, chlorophyll fluorescence, and yield of snap bean (*Phaseolus vulgaris* L.) genotypes differing in sensitivity to ozone. *Environmental and Experimental Botany* 61:190–198 https://doi.org/10.1016/j.envexpbot.2007.05.009.

Ghafari S, Kaviani B, Sedaghathoor S, Allahyari MS. 2021. Assessment of air pollution tolerance index (APTI) for some ornamental woody species in green space of humid temperate region (Rasht, Iran). *Environment, Development and Sustainability* 23:1579–1600 https://doi.org/10.1007/s10668-020-01098-x.

Gholami A, Mojiri A, Amini H. 2016. Investigation of the air pollution tolerance index (APTI) using some plants species in Ahvaz region. *Journal of Animal and Plant Sciences* 26:475-480 https://api.semanticscholar.org/CorpusID:89087591.

He C, Qiu K, Alahmad A, Pott R. 2020. Particulate matter capturing capacity of roadside evergreen vegetation during the winter season. *Urban Forestry & Urban Greening* 48:1-41 https://doi.org/10.1016/j.ufug.2019.126510.
Hussain FS, Ilahi I, Rashid A. 1989. Effect of cement dust on the chlorophyll contents, stomatal clogging and biomass of some selected plants. *Pakistan Journal of Scientific and Industrial Res*earch 32:542-545.
Janhall S. 2015. Review on urban vegetation and particle air pollution - deposition and Dispersion. *Atmospheric Environment* 105:130–137 https://doi.org/10.1016/j.atmosenv.2015.01.052.
Kamble P, Bodhane PS, Beig G, Awale M, Mukkannawar U, Mane AV, Mujumdarm M, Kuchekar SR, Patil VN. 2021. Impact of transport sector emissions on biochemical characteristics of plants and mitigation strategy in Pune, India. *Environmental Challenges* 4:1-8 https://doi.org/10.1016/j.envc.2021.100081.
Kapoor CS. 2014. *Ficus Benghalensis* L. Tree as an efficient option for controlling air pollution. *Research in health and nutrition* 2:1-11
Kaur J, Bhat SA, Singh N, Bhatti SS, Kaur V, Katnoria JK. 2022. Assessment of the heavy metal contamination of roadside soils alongside Buddha Nullah, Ludhiana, (Punjab) India. *International Journal of Environmental Research and Public Health* 19: 1-24 https://doi.org/10.3390/ijerph19031596.
Khalid N, Masood A, Noman A, Aqeel M, Qasim M. 2019. Study of the responses of two biomonitor plant species (*Datura alba* & *Ricinus communis*) to roadside air pollution. *Chemosphere* 235:832-841 https://doi.org/10.1016/j.chemosphere.2019.06.143.
Khalil M, Iqbal M, Turan V, Tauqeer HM, Farhad M, Ahmed A, Yasin S. 2022. Household chemicals and their impact.In: *Environmental Micropollutants.* 201-232. https://doi.org/10.1016/B978-0-323-90555-8.00022-2
Kozlov MV, Zvereva EL, Niemela P. 1999. Effects of soil quality and air pollution on the rooting and survival of *Salix borealis* cuttings. *Boreal Environment Research* 4:67-76 https://www.researchgate.net/publication/242247694.
Kumar A, Singh H, Kumari G, Bisht S, Malik A, Kumar N, Singh M, Raturi A, Barthwal S, Thakur A, Kaushal R. 2022. Adaptive resilience of roadside trees to vehicular emissions via leaf enzymatic, physiological, and anatomical trait modulations. *Environmental Pollution* 313:120191 https://doi.org/10.1016/j.envpol.2022.120191.
Mahrukh, Awan MUF, Luqman M, Sardar AA, Nawaz H, Rasool A, Faisal S, Younas H, Malik SM, Waheed M, Muhammad S. 2023. Air pollution mitigation potential of dominant landscape plants of an urban ecosystem (Lahore city) of Pakistan: An air pollution Tolerance Index (APTI) assessment. *Polish Journal of Environmental Studies* 32:3233-3245 DOI: https://doi.org/10.15244/pjoes/161980.
Muhammad S, Khan Z, Zaheer A, Siddiqi MF, Masood MF, Sargana AM. 2014. *Alstonia scholaris* (L.) R. Br. planted bioindicator along different roadsides of Lahore city. *Pakistan Journal of Botany* 46:869-873

Mukherjee S, Chakraborty A, Mondal S, Saha S, Haque A, Paul S. 2019. Assessment of common plant parameters as biomarkers of air pollution. *Environmental Monitoring Assess*ment 191:1-8. https://doi.org/10.1007/s10661-019-7540-y.

Muller-Dombois, D.; Ellenberg, H. *Aims and Methods of Vegetation Ecology*. John Wiley & Sons: Canada, **1974**, pp. 55.

Munsif R, Zubair M, Aziz A, Zafar MN. 2021. Industrial air emission pollution: potential sources and sustainable mitigation. In: *Environmental emissions*, Richard viskup, Austria. DOI:10.5772/INTECHOPEN.93104

Nasir E, Ali S I Flora of Pakistan Nos 1-190 National Herbarium, PARC, Islamabad and Department of Botany, University of Karachi, Pakistan, **1970-89.**

Nazarpour A, Watts MJ, Madhani A, Elahi S. 2019. Source, spatial distribution and pollution assessment of Pb, Zn, Cu, and Pb, isotopes in urban soils of Ahvaz city, a semi-air metropolis in southwest Iran. *Scientific Reports* 9:1-11 https://doi.org/10.1038/s41598-019-41787-w.

Nowak DJ, Hirabayashi S, Doyle M, McGovern M, Pasher J. 2018. Air pollution removal by urban forests in Canada and its effect on air quality and human health. *Urban Forestry & Urban Greening* 29:40–48 https://doi.org/10.1016/j.ufug.2017.10.019.

Ong BL. 2003. Green plot ratio: an ecological measure for architecture and urban Planning. *Landscape and Urban Planning* 63:197–211 https://doi.org/10.1016/S0169-2046(02)00191-3.

Parsa VA, Salehi E, Yavari AR, Bodegom PMV. 2019. Analyzing temporal changes in urban forest structure and the effect on air quality improvement. *Sustainable Cities and Societies* 48:1-13 https://doi.org/10.1016/j.scs.2019.101548.

Pourkhabbaz A, Rastin N, Olbrich A. 2010. Influence of environmental pollution on leaf properties of urban plane trees, *Platanus orientalis* L. *Bulletin Environmental Contamination and Toxicology* 85:251-255 DOI 10.1007/s00128-010-0047-4.

Roy A, Battacharya T, Kumari M. 2020. Air pollution tolerance, metal accumulation and dust capturing capacity of common tropical trees in commercial and industrial sites. *Science of the total environment* 722:1-15 https://doi.org/10.1016/j.scitotenv.2020.137622.

Sagar AD, Briggs WR. 1990. Effects of high light stress on carotenoid-deficient chloroplasts in *Pisum sativum*. *Plant Physiology* 94**:**1663-1670 https://doi.org/10.1104/pp.94.4.1663.

Sahu C, Basti S, Sahu SK. 2020. Air pollution tolerance index (APTI) and expected performance index (EPI) of trees in sambalpur town of India. *SN Applied Science* 2:1-14 https://doi.org/10.1007/s42452-020-3120-6.

Sarhan MGR, Elhafeez AA, Bashanday S. 2021. Evaluation of heavy metal concentration as affected by vehicular emission in alluvial soil at middle Egypt conditions. *Egyptian Journal of Soil* Science 61:337- 354 DOI: 10.21608/ejss.2021.89288.1460.

Sass V, Wirtz NK, Karceski SM, Hajat A, Crowder K, Takeuchi D. 2017. The effects of air pollution on individual psychological distress. *Health & Place* 48:72-79 https://doi.org/10.1016/j.healthplace.2017.09.006.

Sekhar P, Sekhar P. 2019. Evaluation of selected plant species as bio-indicators of particulate automobile pollution using Air Pollution Tolerance Index (APTI) approach. *International Journal for Research in Applied Science & Engineering Technolo*gy 7:57–67 DOI:10.22214/ijraset.2019.7011.

Seyyednejad SM, Niknejad M, Yusefi M. 2009. Study of air pollution effects on some physiology and morphology factors of *Albizia lebbeck* in high temperature condition in Khuzestan. *Journal of Plant Sciences* 4:122-126 DOI: 10.3923/jps.2009.122.126.

Sharma AP, Tripathi BD. 2009. Biochemical responses in tree foliage exposed to coal-fired power plant emission in seasonally dry tropical environment. *Environmental Monitoring and Assessment* 158:197-212 https://doi.org/10.1007/s10661-008-0573-2.

Shweta M, Agrawal SB. 2006. Interactive effects between supplemental ultraviolet-B radiation and heavy metals on the growth and biochemical characteristics of *Spinacia oleracea* L. *Brazil. Journal of Plant Physiology* 18:98-102 https://doi.org/10.1590/S1677-04202006000200007.

Singh H, Yadav M, Kumar N, Kumar A, Kumar M. 2020. Assessing adaptation and mitigation potential of roadside trees under the influence of vehicular emissions: a case study of *Grevillea robusta* and *Mangifera indica* planted in an urban city of India. *Plos One* 15:1-20 https://doi.org/10.1371/journal.pone.0227380.

Singh R, Rathore D. 2018. Oxidative stress defence responses of wheat (*Triticum aestivum* L.) and chilli (*Capsicum annum* L.) cultivars grown under textile effluent fertilization. *Plant Physiology and Biochemistry* 123:342–358 https://doi.org/10.1016/j.plaphy.2017.12.027.

Singh S, Verma A. 2007. Phytoremediation of Air pollutants: A review. In: *Environmental bioremediation technology.* Singh, SN, Tripathi RD, Springer: Berlin Heidelberg, 293-314.

Singh SK, Rao DN, Agrawal M, Pandey J, Naryan D. 1991. Air pollution index of plants. *Journal of Environmental Management* 32:45-55 https://doi.org/10.1016/S0301-4797(05)80080-5.

Skrynetska I, Ciepal R, Kandziora-Ciupa M, Barczyk G, Nadgorska-Socha A. 2018. Ecophysiological responses to environmental pollution of selected plant species in an industrial urban area. *International Journal of Environmental Res*earch 12:255-267 https://doi.org/10.1007/s41742-018-0088-9).

Tallis M, Taylor G, Sinnett D, Freer-Smith P. 2011. Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. *Landscape and Urban Planning* 103:129–138 https://doi.org/10.1016/j.landurbplan.2011.07.003.

Tundele S. 2015. Eco-Friendly Technology-Key for Sustainable Development. *International Journal of Research*-GRANTHAALAYAH 3:1-3 DOI:10.29121/granthaalayah.v3.i9SE.2015.3171.

Uka UN, Belford EJ, Hogarh JN. 2019. Roadside air pollution in a tropical city: physiological and biochemical response from trees. *Bulletin of the National Research Center* 43:1-12 https://doi.org/10.1186/s42269-019-0117-7.

Vardhan KH, Kumar PS, Panda RC. 2019. A review on heavy metal pollution, toxicity and remedial measures: current trends and future perspectives. *Journal of Molecular Liquids* 290:1-22 https://doi.org/10.1016/j.molliq.2019.111197.

Verma V, Chandra N. 2015. Biochemical and Ultrastructural Changes in *Sida ordifolia* L. and *Catharanthus roseus* L. to Auto Pollution. *International Scholarly Research Notices.* 2014:1-11 https://doi.org/10.1155/2014/263092.

Wei Z, Le QV, Peng W, Ynag Y, Yang H, Gu H, Lam SS, Sonne C. 20221. A review on phytoremediation of contaminants in air, water and soil. *Journal of Hazardous Material* 403:1-8 https://doi.org/10.1016/j.jhazmat.2020.123658.

Whitford V, Ennos AR, Handley JF. 2001. City form and natural process indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning* 57:91–103 https://doi.org/10.1016/S0169-2046(01)00192-X.

Zofia L, Kmiecik W, Korus A. 2006. Content of vitamin C, carotenoids, chlorophylls and polyphenols in green parts of dill (*Anethum graveolens* L.) depending on plant height. Journal of Food Composition and Analysis 19:134-140 https://doi.org/10.1016/j.jfca.2005.04.009.

Figure 1

PCA biplot analysis showing variation in plant physicochemical parameters (PR, photosynthetic rate; SC, stomatal conductance; TR, transpiration rate; Chl. a, chlorophyll a; Chl. b, chlorophyll b; Total chl., total chlorophyll content; Carot, carotenoids;

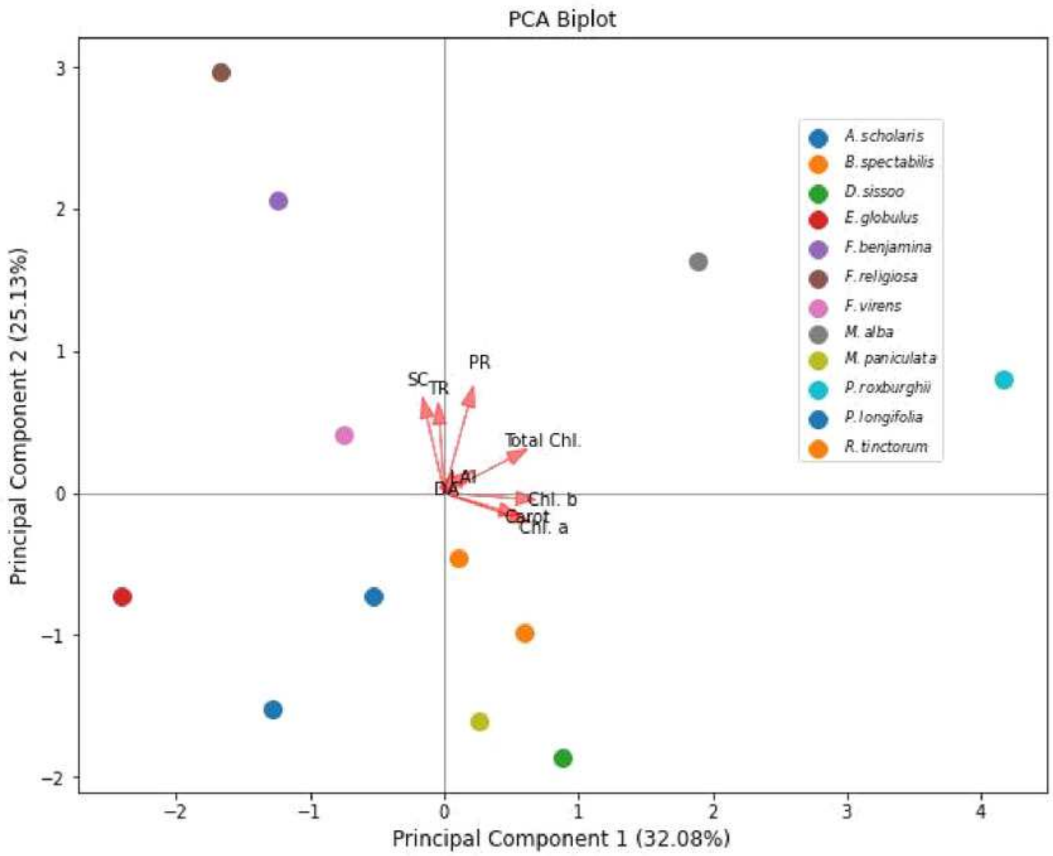

Figure 1: PCA biplot analysis showing variation in plant physicochemical parameters (PR, photosynthetic rate; SC, stomatal conductance; TR, transpiration rate; Chl. a, chlorophyll a; Chl. b, chlorophyll b; Total chl., total chlorophyll content; Carot, carotenoids; DA, dust amount; LAI, leaf area index) across various species.

Different species groups were identified by the PCA biplot according to their physicochemical traits. Similar physicochemical profiles of the species were revealed by their clustering in the biplot, implying that the measured variables showed recurrent variation patterns. Longer arrows on variables increased the observed variation in the dataset, highlighting crucial physiological traits that promote species divergence. The PCA biplot analysis provides a comprehensive framework for studying the complex link between species variability and plant physiology.

Figure 2

Radar map visualization for comparing carotenoid and chlorophyll level in different plant species (A.sch, *A. scolaris*; B.spe, *B. spectabilis*; D.sis, *D. sissoo*; E.glo, *E. globulus*; F.ben, [i]F. benjamina; F.rel, F. religiosa; F.vir,

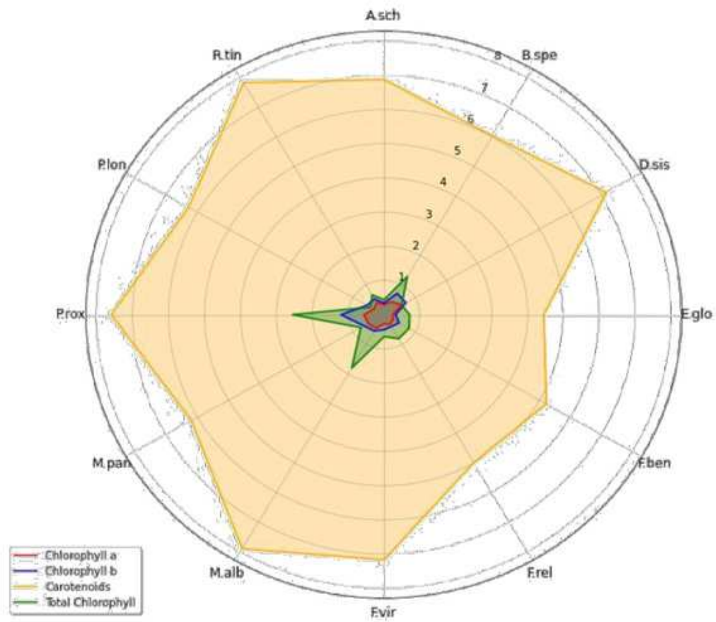

Figure 2: Radar map visualization for comparing carotenoid and chlorophyll level in different plant species (A.sch, *A. scolaris*; B.spe, *B. spectabilis*; D.sis, *D. sissoo*; E.glo, *E. globulus*; F.ben, *F. benjamina; F.rel, F. religiosa; F.vir, F.virens; M.alb, M. alba; M. pan, M. paniculata; P.rox, P. roxburghii*; P.lon, *P. longifolia*; R.tin, *R. tinctorum*.

Carotenoids and chlorophyll are essential pigments in photosynthesis, play important roles in energy transfer and light absorption. Determining the concentration and distribution of these pigments among various tree species is essential to understanding the physiological adaptations unique to each species and the dynamics of ecosystems. In this study, we utilized radar chart visualization to compare chlorophyll and carotenoid levels among various tree species, aiming to uncover underlying patterns and ecological implications.

Figure 3

Correlation coefficients heatmap of studied physicochemical parameters

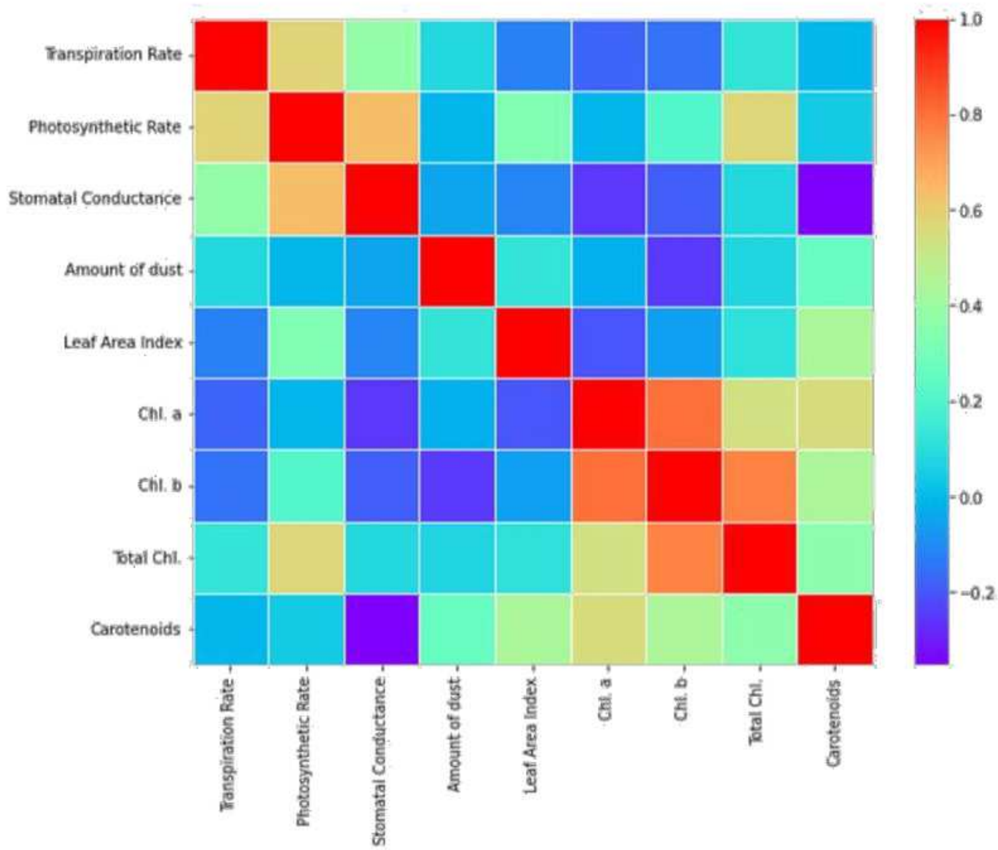

Figure 3: Correlation coefficients heatmap of studied physicochemical parameters.

Significant correlations were found between the variables under investigation in the correlation analysis: transpiration rate showed weak negative correlation with dust deposition amount ($r = -0.04$, $p > 0.05$), indicating a potential mitigating effect of dust on water loss through transpiration; photosynthetic rate showed significant positive correlation with leaf area index ($r = 0.55$, $p < 0.01$), emphasizing the importance of foliage density in carbon assimilation processes; and stomatal conductance and photosynthetic rate showed moderate positive correlations ($r = 0.41$, $p < 0.05$) and photosynthetic rate ($r = 0.37$, $p < 0.05$), indicating coordinated physiological responses to environmental conditions. Indicating their crucial role in photosynthesis and general tree health, the chlorophyll content (Chl. a, Chl. b, and total chlorophyll) also demonstrated strong associations with photosynthetic rate and other physiological indicators.

Figure 4

Taxonomic illustration of selected plants in urban ecosystem of Lahore (Pakistan)

Table 1: Taxonomic illustration of selected plants in urban ecosystem of Lahore (Pakistan)

Sr.no	Scientific name	Family	Common name	Habit
1.	*Alstonia scholaris* L.	Apocynaceae	Blackboard or devil tree	Perennial, Evergreen Large Trees
2.	*Bougainvillea spectabilis* Willd.	Nyctaginaceae	Paper flower	Woody climber, perennial shrub
3.	*Dalbergia sissoo* Roxb.	Fabaceae	North Indian rosewood or shisham	Deciduous tree
4.	*Eucalyptus globulus* Labill.	Myrtaceae	Tasmanian blue gum	Annual or seomtimes perennial Evergreen tree
5.	*Ficus virens* Aiton.	Moraceae	White fig	Medium sized tree, perennial evergreen tree
6.	*Ficus benjamina* L.	Moraceae	Weeping fig	Perennial evergreen shrub or tree
7.	*Ficus religiosa* L.	Moraceae	Peepal	Perennial and deciduous tree
8.	*Morus alba* L.	Moraceae	White mulberry	Deciduous tree or shrub
9.	*Murraya paniculata* L.	Rutaceae	Orange Jasmine, Mock Lime, China Box	Perennial shrub or small tree
10.	*Putranjiva roxburghii* Wall.	Putranjivaceae	Child life tree, Lucky Bean Tree	Moderate sized, evergreen tree
11.	*Polyalthia longifolia* Sonn.	Annonaceae	False Ashoka	Evergreen tree
12.	*Rubia tinctorum* L.	Rubiaceae	Rose madder or common madder	Evergreen herbaceous Perennial

Figure 5

Amount of dust (g) captured and leaf area index (mm^2) of the selected tree -species

Table 2: Amount of dust (g) captured and leaf area index (mm^2) of the selected tree -species.

Sr. no.	Plant species	Amount of dust (g)		Leaf area index (mm^2)	
		Pol. s	Cont. s	Pol. s	Cont. s
1.	*A. scholaris*	0.02±0.005	0.004±0.0005	543.13±306.6	1693±63
2.	*B. spectabilis*	0.015±0.003	0.004±0.0003	312.9±11.59	532.33±4.70
3.	*D. sissoo*	0.014±0.002	0.003±0.0006	271.04±66.50	414.7±43.006
4.	*E. globulus*	0.014±0.004	0.007±0.001	294.73±8213	436.6±22.48
5.	*F. benjamina*	0.011±0.0008	0.003±0.0003	257.84±12.10	341.8±3.19
6.	*F. religiosa*	0.02±0.003	0.004±0.0005	201.93±450.4	312.53±31.73
7.	*F. virens*	0.016±0.003	0.004±0	958.82±380.92	1670±23
8.	*M. alba*	0.02 ±0.003	0.006±0.0005	997.8±25.175	1172.86±58.69
9.	*M. paniculata*	0.011±0.0003	0.004±0.0003	88.86±19.7	97.96±4.88
10.	*P. roxburghii*	0.012±0.0003	0.004±0.0003	496.66±50.33	611.66±35.86
11.	*P. longifolia*	0.016±0.004	0.005±0	1071.2±139.6	1182.5±113.5
12.	*R. tinctorum*	0.013±0.006	0.007±0.0013	306.55±16.93	351.11±13.55

*Polluted site, **Control site

Figure 6

Physicochemical evaluation of plant species (polluted and control sites)

Table 3: Physicochemical evaluation of plant species (polluted and control sites)

Sr. no.	Plant species	Stomatal conductance (mol m^{-2} s^{-1})		Transpiration rate (mol m^{-2} s^{-1})		Photosynthetic rate (µmol m^{-2} s^{-1})	
		*Pol. s	**Cont. s	Pol. s	Cont. s	Pol. s	Cont. s
1.	*A. scholaris*	0.04±0.02	0.07±0.03	0.17±0.09	0.25±0.14	25.36±13.10	34.07±17.68
2.	*B. spectabilis*	0.05±0.01	0.15±0.006	0.18±0.04	0.48±0.13	34.37±19.92	35.88±8.12
3.	*D. sissoo*	0.03±0.003	0.08±0.03	0.21±0.04	0.32±0.01	28.23±11.25	51.58±20.53
4.	*E. globulus*	0.09±0.02	0.08±0.05	0.26±0.08	0.22±0.11	27.88±9.83	27.64±14.52
5.	*F. benjamina*	0.17±0.04	0.16±0.09	0.86±0.30	0.85±0.51	56.60±13.34	53.73±26.89
6.	*F. religiosa*	0.62±0.08	0.58±0.08	0.67±0.11	0.59±0.25	60.22±15.72	50.00±25.00
7.	*F. virens*	0.19±0.03	0.17±0.08	0.42±0.11	0.41±0.21	44.41±12.22	44.26±21.83
8.	*M. alba*	0.15±0.01	0.14±0.008	0.54±0.01	0.48±0.012	63.01±9.23	59.73±1.01
9.	*M. paniculata*	0.04±0.005	0.13±0.01	0.24±0.09	0.62±0.04	26.80±7.75	45.14±2.89
10.	*P. roxburghii*	0.17±0.005	0.15±0.01	0.34±0.03	0.32±0.01	56.90±12.19	57.91±6.13
11.	*P. longifolia*	0.08±0.01	0.09±0.04	0.10±0.04	0.13±0.06	42.27±22.87	43.89±24.00
12	*R. tinctorum*	0.08±0.05	0.17±0.09	0.59±0.24	1.61±0.22	30.60±4.07	40.12±0.22

Figure 7

Biochemical assessment of species from polluted and control sites

Table 4: Biochemical assessment of species from polluted and control sites

Sr. no.	Plant species	Chl. a		Chl. b		Total chlorophyll (mg/g)		Carotenoids (mg/g)	
		Pol. s	Cont. s	Pol. s	Cont. s	Pol. s	Cont. s	Pol. s	Cont. s
1.	*A. scholaris*	0.30± 0.15	0.38± 0.19	0.34± 0.17	0.55± 0.27	0.44± 0.22	1.20± 0.62	5.94± 0.07	6.88± 2.97
2.	*B. spectabilis*	0.43± 0.14	0.52± 0.16	0.72± 0.28	1.14± 0.31	1.29± 0.59	2.21± 0.73	6.04± 0.88	9.07± 2.23
3.	*D. sissoo*	0.56± 0.08	0.64± 0.01	0.70± 0.10	0.75± 0.10	0.56± 0.13	0.82± 0.01	7.15± 3.03	11.18± 3.31
4.	*E. globulus*	0.24± 0.09	0.23± 0.12	0.32± 0.10	0.30± 0.15	0.71± 0.16	0.65± 0.29	9.12± 0.71	6.20± 2.36
5.	*F. benjamina*	0.36± 0.14	0.44± 0.22	0.58± 0.24	0.64± 0.32	0.80± 0.25	0.75± 0.38	5.25± 1.64	5.22± 2.77
6.	*F. religiosa*	0.32± 0.16	0.40± 0.20	0.40± 0.21	0.55± 0.27	0.81± 0.30	0.65± 0.42	5.00± 2.01	5.82± 2.91
7.	*F. virens*	0.26± 0.14	0.30± 0.19	0.44± 0.22	0.38± 0.16	0.64± 0.22	0.61± 0.31	7.76± 2.91	7.17± 3.88
8.	*M. alba*	0.76± 0.09	0.67± 0.03	0.88± 0.13	0.83± 0.04	1.80± 0.27	1.36± 0.07	7.91± 1.61	7.18± 1.07
9.	*M. paniculata*	0.51± 0.01	0.73± 0.03	0.65± 0.11	0.87± 0.07	0.75± 0.12	1.14± 0.11	4.12± 2.18	4.45± 1.84
10.	*P. roxburghii*	0.56± 0.10	0.71± 0.06	1.20± 0.12	1.35± 0.10	2.55± 0.43	2.33± 0.07	7.60± 2.02	7.48± 0.83
11.	*P. longifolia*	0.33± 0.18	0.41± 0.21	0.55± 0.27	0.59± 0.27	0.41± 0.22	0.44± 0.25	6.29± 1.86	7.43± 3.72
12	*R. tinctorum*	0.41± 0.03	0.51± 0.008	0.53± 0.09	0.63± 0.06	0.67± 0.15	0.98± 0.16	7.84± 0.39	9.69± 0.21

Figure 8

Correlations of physicochemical parameters of selected plants

Table 5: Correlations of physicochemical parameters of selected plants

Variable	Transpiration Rate	Photosynthetic Rate	Stomatal Conductance	Amount of Dust	Leaf Area Index	Chl. a	Chl. b	Total Chl.	Carotenoids
Transpiration Rate	1.00	0.72	0.64	-0.53	0.81	0.45	0.62	0.57	0.68
Photosynthetic Rate	0.72	1.00	0.83	-0.61	0.92	0.76	0.85	0.89	0.94
Stomatal Conductance	0.64	0.83	1.00	-0.48	0.77	0.68	0.75	0.82	0.87
Amount of Dust	-0.53	-0.61	-0.48	1.00	-0.69	-0.57	-0.63	-0.58	-0.52
Leaf Area Index	0.81	0.92	0.77	-0.69	1.00	0.84	0.91	0.93	0.89
Chl. a	0.45	0.76	0.68	-0.57	0.84	1.00	0.93	0.80	0.69
Chl. b	0.62	0.85	0.75	-0.63	0.91	0.93	1.00	0.89	0.77
Total Chl.	0.57	0.89	0.82	-0.58	0.93	0.80	0.89	1.00	0.83
Carotenoids	0.68	0.94	0.87	-0.52	0.89	0.69	0.77	0.83	1.00