



Assessing the air pollution tolerance index (APTI) of trees in residential and roadside sites of Lahore, Pakistan

Adnan Zahid¹ · Sajid Ali¹ · Waheed Anwar² · Ammara Fatima³ · Muhammad Bilal Chattha¹ · Asma Ayub¹ · Ahmad Raza¹ · Kashif Ali¹ · Maroof Siddique²

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Abstract

Industrialization and extensive use of automobiles cause air pollution which indicates the inability of trees plants due to changes in their biochemical and physiological processes for absorbing the air pollutants. Air Pollution Tolerance Index (APTI) is an important indicator for determining the ability of trees plants for their efficient ability for controlling air pollution. To estimate it and its effects a comparative study of the air pollution tolerance index was examined in 14 species of plants between residential areas (University of the Punjab) and roadside areas (orange train line). To calculate the APTI value, four physiological and biochemical parameters—ascorbic acid, relative water content (RWC), pH, and chlorophyll concentration of leaf samples—were integrated. Present study results reveal that the plant tolerance against pollution is site specific, and that integrating a number of biochemical parameters give more accurate results as compared to single. Results show that *Alstonia scholaris* show maximum and *Magnifera indica* show minimum APTI values in residential areas while *Magnifera indica* shows maximum and *Bougainvillea glabra* shows minimum APTI value in roadside areas. Present study results show that plants with higher APTI values are tolerant of pollution, whereas those with lower APTI values are susceptible to it. Thus Plants with more APTI values are tolerant and use as a sink to control pollution in urban and industrial sites.

Article Highlights

1. Air pollution tolerance index (APTI) is the key parameter for assessing resistant or susceptibility of trees plant.
2. *Alstonia scholaris* and *Magnifera indica* trees species are more susceptible to air pollution along residential and roadside.
3. The results of study are helpful for planning of green belt and controlling of air pollution.

Keywords Air pollution tolerance index · Traffic areas · Residential areas · Biochemical parameters · Permeability · Source and sink

✉ Adnan Zahid, adnan.iags@pu.edu.pk | ¹Department of Agronomy, Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan. ²Department of Plant Pathology, Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan. ³Department of Environmental Science, Lahore College for Women University, Lahore, Pakistan.



1 Introduction

The term “air pollution” refers to the environmental contamination caused by any biological, chemical, or physical agent that could be harmful to humans or other living organisms [1]. Major sources of air pollutants are carbon mono oxide, Sulphur oxides, heavy metals which are emitted by vehicles [2, 3]. There are two types of pollutants: primary and secondary. Primary pollutants are those which are released into the atmosphere and cause direct air pollution, whereas secondary pollutants are those that are created in the atmosphere due to interactions between primary pollutants [1]. When these pollutants are discharged into the atmosphere, they not only worsen the quality of the air, which has an impact on the ecosystem, but also put people’s health at risk, especially those with respiratory and cardiovascular conditions, at danger [4, 5]. Air pollution can harm plants indirectly through soil acidity or directly through their leaves [6].

Millions of people in Pakistan are affected by the serious health issues of air pollution. Experts caution that the consequences of insufficient effort to address the issue might be terrible for the nation. Pakistan most populated cities i.e., Lahore and Karachi ranking among the most polluted worldwide. Rapidly growing industries and vehicular density in urban areas of Lahore disturbs air quality and causes air pollution. Air pollution in Lahore induces major health problems including asthma. Smog is a major problem in Lahore due to burning crop residues and vehicles emitted gases which causes air pollution.

As part of their regular operations, trees remove a substantial quantity of pollutants from the environment, which helps to significantly reduce air pollution. The vast leaf surface allows for the deposition of particles and the removal of gases. Nearly every tree component, including the roots, soil and vegetative components, removes pollution. Plants can clean the air pollutants including SO₂, PAN (Peroxyacetyl Nitrate), HF and heavy metals like lead and mercury (Hg) [7]. However, some air pollutants may alter a plant’s biochemical make-up, rate of seed germination, photosynthetic response, quantity of flowers on a florescence, stomata and length of pedicles, which may have an impact on a plant’s ability to grow [8]. Through the stomata, or holes, on their leaves, trees breathe and exchange gases, including both those required for the tree to operate and other gaseous air contaminants. Once inside the leaf, gases seep into the spaces between the cells, where they can be absorbed by water films or chemically altered by plant tissues. By capturing airborne pollutants and holding them on the surface of their leaves, trees can help to

lessen air pollution. By translocating through the xylem and phloem, pollutants move through plants. Chemical pollutants which are taken up by leaves are transported to the root zone, where soil microbes can deteriorate them. When chemical pollutants are taken by roots, they may also be deteriorated and transferred to leaves where they may release their toxins into the air [9].

It has also been noted that many plants incur physiological changes when unveiled to polluted air, displaying apparent damages to plant leaves [10]. It’s important to select the appropriate plant characteristics to analyze how various plant species respond to air pollution. The APTI shows the susceptibility of plants against polluted air. High-index plants are typically tolerant of air pollution. They may live off of contaminated air. Low-index plants exhibit susceptibility to air pollution. According to APTI, they can endure air pollution [11–13]. Low-index plants exhibit susceptibility to air pollution. Plants are categorized as sensitive (< 12), intermediate (13–20), and tolerant (> 20) based on their APTI score. Plants are divided into three categories based on their APTI value: sensitive (< 12), intermediate (13–20), and tolerant (> 20) [14].

While more tolerant plant species operate as sinks for airborne contaminants and can be employed to create green belts, whereas sensitive plant species acts as bio indicator of air pollution [15–18]. The aforementioned parameters are computed collectively in one formula to obtain a significant value that indicates the APTI of plant species, after understanding the contributions of ascorbic acid; chlorophyll content; RWC and leaf extract pH, to pollution tolerance in plants.

The whole study indicates that plants having higher tolerance indices were tolerant to air pollution while those having lower tolerance indices were susceptible to it. This study’s objective is to ascertain the APTI values of several species of plant in the vicinity of University of the Punjab and along the roadside areas in Lahore, Pakistan. Several researchers concur that air pollution have a negative impact on plant development [19–23]. Landscapers choose those species of plant which are more tolerant to air pollution using the air pollution tolerance index [24].

As a result, we have concentrated on the potential of plant species flourishing in Pakistan’s largest city, Lahore, to resist air pollution. So, Ascorbic acid concentration (AAC), total chlorophyll content (TCC), relative water content (RWC), and pH of leaf extract were used to calculate the air pollution tolerance index (APTI) for the chosen plant species (*Azadirachta indica*, *Magnifera indica*, *Eucalyptus* sp., *Saraca asoca*, *Psidium guajava*, *Melia azedarach*, *Morus alba*, *Alstonia scholaris*, *Bougainville*, *Dalbergia sissoo*, *Java plum*, *Ficus benghalensis*, *Ziziphus mauritiana* and *Pongamia pinnata*). The findings of this study may aid in

selecting plants for the city of Lahore's green belt and prevent the extinction of pollution-sensitive plants.

2 Materials and methods

2.1 Meteorology & sampling site

The location of Lahore, the capital of Punjab province and the second-largest city in Pakistan, is 31°15'–31°45'N and 74°01'–74°39'E. The city district experiences an average annual temperature of 24.3 °C, which is warm and semi-arid [25]. While the average temperature in the winters is between 15 °C and 22 °C, the maximum temperature during the warm season ranges from 33 to 40 °C and the minimum temperature ranges from 22 to 28 °C.

2.2 Sample collections

Automobile exhaust, local enterprises, railroad traffic, burning of wastes, and home heating are the main sources of pollution in Lahore. A study investigated the trees' susceptibility to air pollution in two separate locations selected on the basis of exposure to pollutants (Residential area (University of the Punjab, New campus), 31.493187°N, 74.297154°E is taken as control for comparison with high traffic road side (orange train track, 31.32131°N, 74.17269°E). The University of the Punjab campus is approximately 10 km away from the orange train track. A local species survey was conducted in and around the town, and it was verified by existing literature and data received from the Forest Department's Lahore Division, Government of Punjab and Parks and Horticultural Authority (PHA). Based on their prevalence throughout all of the sites, the survey's findings led to the selection of 14 tree species. Trees near roads and those exposed to traffic were chosen for the research in each location. Leaf

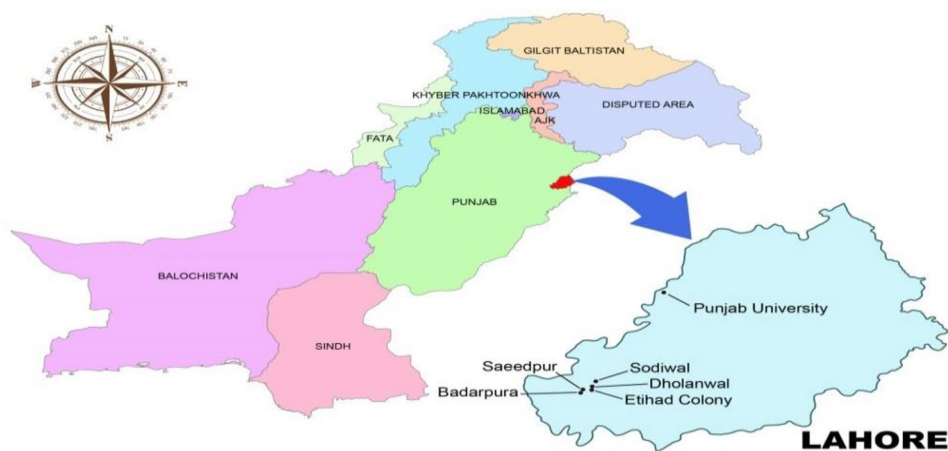
samples of numerous randomly selected plants of selected areas, residential (university campus) area, and roadside (highly polluted side orange train track) area (Fig. 1). The leaf samples of *Azadirachta indica*, *Magnifera indica*, *Eucalyptus sp.*, *Saraca asoca*, *Psidium guajava*, *Melia azedarach*, *Morus alba*, *Alstonia scholaris*, *Bougainvillea glabra*, *Dalbergia sissoo*, *Java plum*, *Ficus benghalensis*, *Ziziphus mauritiana* and *Pongamia pinnata* were collected manually from the bottom of the tree's canopy, about 6–8 feet above the ground, from selected areas. The leaves were given the utmost attention to keep them free from any obvious fungi or leaf diseases. When fresh leaves were brought to the lab, the weight of those leaves was instantly recorded. The remaining material was kept chilled in a polythene bag for future examination.

2.3 Chemical analysis

2.3.1 Ascorbic acid determination

The ascorbic acid concentration (mg/g dry weight) was calculated by following the method explained by Keller and Schwager [26] while using 2, 6-dichlorophenol indo-phenol (DCPIP). In short, 0.5 g of fresh leaf sample was homogenized with 20 ml of the extraction solution, which was made by mixing 5.0 g of oxalic acid and 0.75 g of EDTA in 1000 ml of distilled water. To collect the supernatant, the above solution was centrifuged at 10,000 rpm (rev/min) for 30 min. 1 ml of supernatant solution was added to 5 ml of DCPIP (prepared by adding 6.0 mg of DCPIP in 200 ml distilled water) and mixed by vibration. When the solution turned pink, a spectrophotometer was used to measure absorbance at 520 nm (E_s). A few drops of 1% ascorbic acid were added to the mixture to totally remove the pink hue, and absorbance was then measured once again at 520 nm (E_t). Mix the extract solution and the DIP

Fig. 1 Geographical locations of sampling sites (ArcGIS software version 10.5; <https://www.arcgis.com>)



solution and measure as a blank (E_0). Ascorbic acid content is determined by:

$$\text{Ascorbic acid} \left(\frac{\text{mg}}{\text{g}} \right) = [E_0 - (E_s - E_t)] * \frac{V}{W \times V1 \times 1000}$$

where, W = Fresh leaf weight. V1 = Supernatant Solution volume. V = Mixture volume.

$$\text{Relative water content}(\%) = \left[\frac{\text{Initial weight} - \text{Dry weight}}{\text{Saturated weight} - \text{Dry weight}} \right] \times 100$$

2.3.2 Chlorophyll content determination

Total chlorophyll content (mg/g) was calculated following the procedure of Singh et al. [27]. After blending 1.0 g leaf sample, 10 ml of 80% acetone was used to extract chlorophyll to determine chlorophyll content. At 645 nm and 663 nm, the filtered extract's absorbance was measured spectrophotometrically. The formula mentioned below was used to perform the calculations:

$$\text{Total chlorophyll} \left(\frac{\text{mg}}{\text{g}} \right) = \frac{[(20.2 \times A_{645}) + (8.02 \times A_{663}) \times V]}{1000 \times W}$$

where, A_{645} = Absorbance at 645 nm. A_{663} = Absorbance at 663 nm. V = Total volume of extract. W = Fresh leaf weight in gram.

2.3.3 Relative water content (RWC)

RWC was measured by following the procedure of Sivakumaran and Hall [28]. Fresh weight of entire leaves was measured instantly (initial weight). Then Leaves were soaked in water overnight and dried off, so weight can be measured to determine their saturated weight. Same leaf samples were placed in oven at 80 °C for 24 h to measure oven dry weight. The formula which was mentioned below was used to determine RWC:

2.3.4 Leaf pH determination

50 ml of distilled water was used to homogenize 5.0 g of leaf sample to determine the pH of the suspension, which was then determined by using digital pH meter.

2.3.5 Air pollution tolerance index (APTI)

Species' air pollution tolerance indexes were measured by following the Singh and Rao [29] formula as mentioned below:

$$\text{Air pollution tolerance index} = [A(T + P)] + R / 10$$

A = Ascorbic acid content (mg/g).

T = Total chlorophyll content (mg/g).

P = pH of leaf extract.

Table 1 Comparison of biological parameters of plant species between residential and roadside areas

Plant species	Residential sites				Roadside (orange train) site			
	RWC (%)	TCC (mg/g)	AA (mg/g)	APTI	RWC (%)	TCC (mg/g)	AA (mg/g)	APTI
<i>Saraca asoca</i>	82.38abc	1.69a	0.06ab	8.29ab	84.13abc	1.27cd	0.059a	8.45abcd
<i>Psidium guajava</i>	84.918abc	0.85g	0.06ab	8.54ab	74.13cde	0.99f	0.059a	7.45ef
<i>Melia azedarach</i>	83.103abc	1.43cde	0.06ab	8.36ab	84.31abc	1.47a	0.061a	8.47bc
<i>Morus alba</i>	87.903ab	1.29ef	0.06ab	8.84a	77.2bcde	1.08ef	0.060a	7.76cdef
<i>Alstonia scholaris</i>	91.02a	1.49bcd	0.063a	9.15a	85.21ab	1.39abc	0.060a	8.56abc
<i>Bougainvillea glabra</i>	80.55bc	1.21f	0.057b	8.11abc	56.99f	1.31bc	0.06a	5.75g
<i>Dalbergia sissoo</i>	89.72ab	1.51bc	0.06ab	9.02a	72.56de	1.02ef	0.059a	7.27ef
<i>Syzygium cumini</i>	70.103de	0.89g	0.063a	7.05cd	79.91abcd	1.27cd	0.059a	8.03abcde
<i>Ficus benghalensis</i>	86.559ab	0.94g	0.06ab	8.7ab	78.21bcde	0.73g	0.060a	7.86bcde
<i>Azadirachta indica</i>	64.88e	1.33def	0.06ab	6.52d	67.53ef	1.35abc	0.060a	6.79f
<i>Eucalyptus sp.</i>	87.75ab	0.82g	0.06ab	8.81ab	87.15ab	0.72g	0.060a	8.76ab
<i>Magnifera indica</i>	64.71e	1.31ef	0.06ab	6.51d	89.08a	1.44ab	0.059a	8.95a
<i>Ziziphus mauritiana</i>	76.03cd	1.53abc	0.06ab	7.65bcd	74.36cde	0.99f	0.060a	7.57def
<i>Pongamia pinnata</i>	89.75ab	1.62ab	0.06ab	9.02a	71.66de	1.16de	0.060a	7.21ef
LSD (0.05%)	10.08	0.165	0.0063	1.678	10.72	0.15	0.0076	0.99

R= Relative water content of leaf (%).

3 Results

The four biochemical parameters (ascorbic acid, pH, RWC and total chlorophyll content) were used to estimate the APTI value shown in (Table 1) as this method is less costly and more convenient in field condition as compare to other costly gadgets and tools which are used as a fore-caster of air pollution.

3.1 Ascorbic acid

The result of ascorbic acid is presented in the Fig. 2. The data showed that ascorbic acid was not significantly different between residential and roadside samples. In the residential area (University of the Punjab) *Melia azedarach* has the maximum (0.06035 mg/g) ascorbic acid followed by *Ziziphus mauritiana* (0.06025) > *Saraca asoca* and *Dalbergia sissoo* whereas minimum value is shown by *Eucalyptus* (0.0598) < *Ficus benghalensis* and *Bougainvillea glabra* while in road side areas (orange line train) *Saraca asoca*, *Azadirachta indica*, *Ficus benghalensis*, *Bougainvillea*

Fig. 2 Comparison of ascorbic acid in residential & roadside plant species

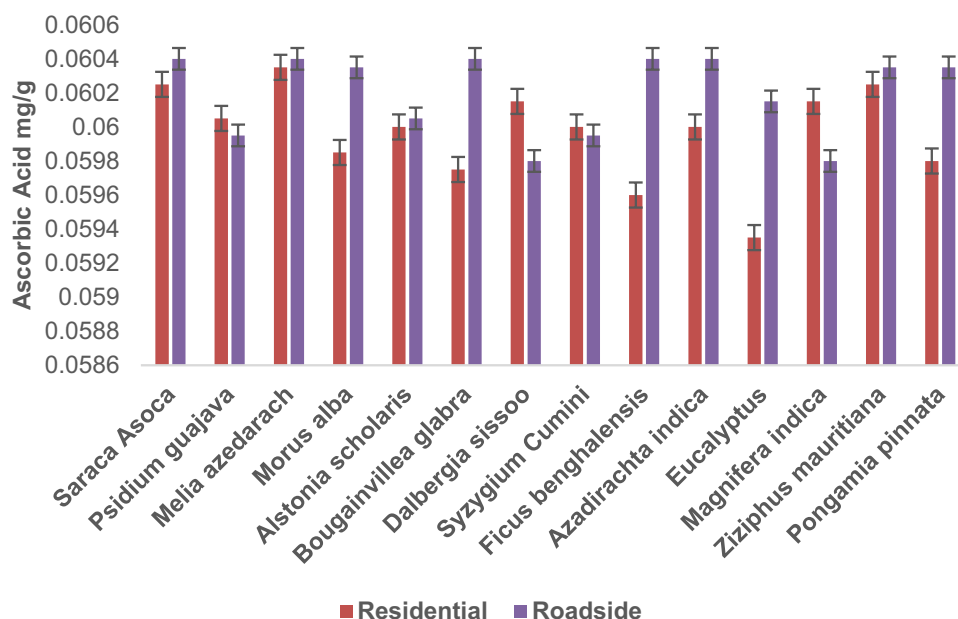
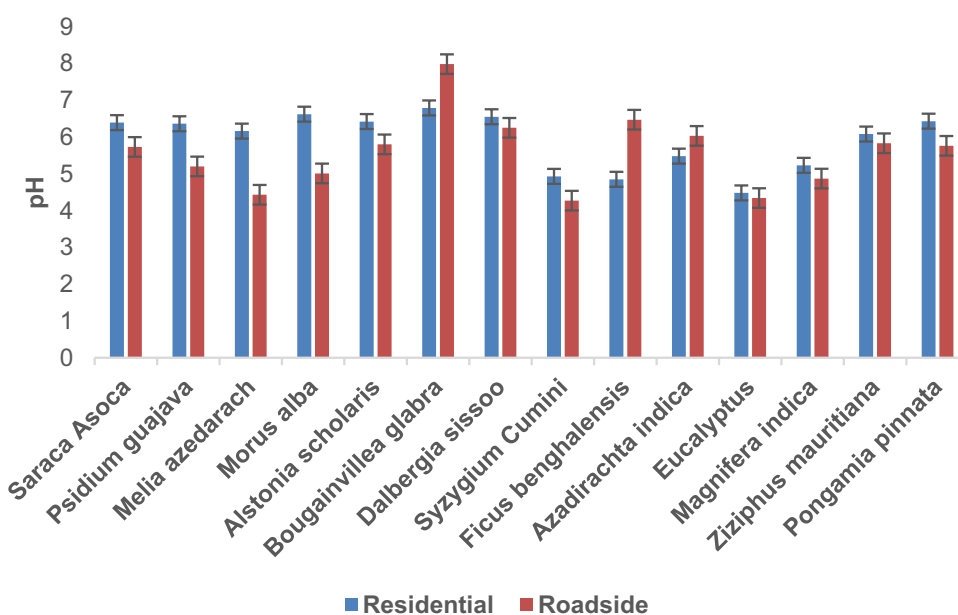


Fig. 3 Comparison of pH in residential & roadside plant species



glabra and *Melia azedarach* show same maximum value 0.0604 mg/g and minimum value is shown by *Magnifera indica* and *Dalbergia sissoo*.

3.2 pH

The results of pH parameters showed in the Fig. 3. The results showed that *Bougainvillea glabra* has highest pH value 6.79 as followed by *Morus alba* and *Dalbergia sissoo* in residential area and minimum value (4.48) is shown by *Eucalyptus* < *Ficus benghalensis* and *Syzygium cumini* while in road side areas *Bougainvillea glabra* shows maximum value 7.98 as followed by *Ficus benghalensis* > *Dalbergia*

sissoo and *Azadirachta indica* and minimum value (4.27) is shown by *Syzygium cumini* < *Eucalyptus* < *Melia azedarach* and *Ficus benghalensis*.

3.3 Total chlorophyll content (TCC) (mg/g)

Maximum chlorophyll content is obtained in *Saraca asoca* (1.624108 mg/g) as followed by *Pongamia pinnata* > *Ziziphus mauritiana* and *Alstonia scholaris* and the minimum content is in *Eucalyptus* (0.82144 mg/g) as followed by *Psidium guajava* < *Syzygium cumini* and *Ficus benghalensis*. While in road side areas maximum chlorophyll content is show by *Melia azedarach* (0.73453 mg/g)

Fig. 4 Comparison of chlorophyll content in residential & roadside plant species

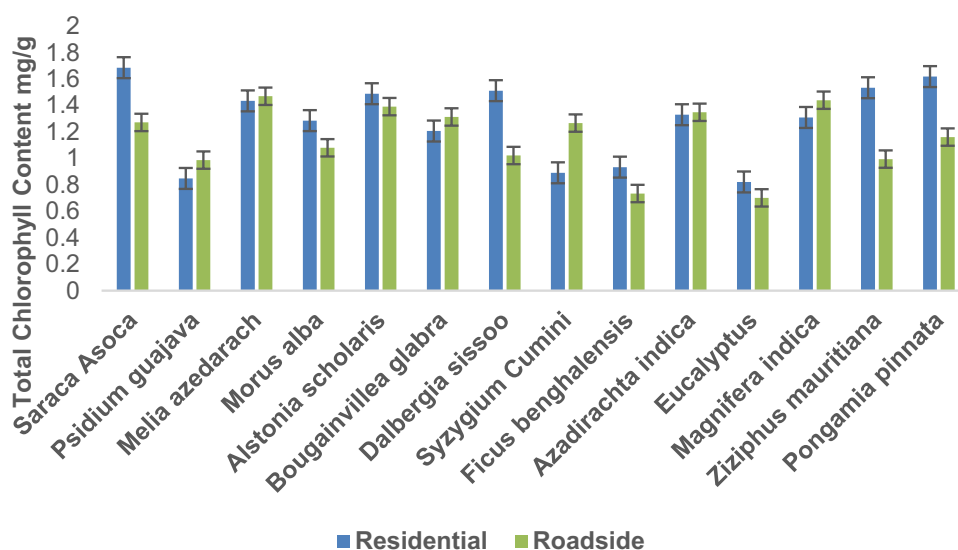
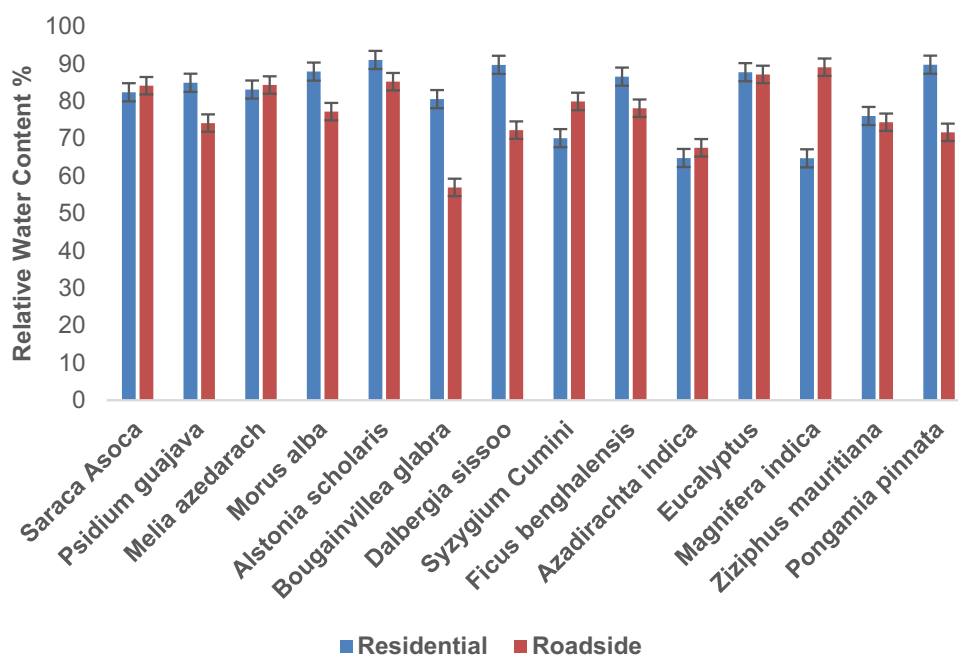


Fig. 5 Comparison of RWC in residential & roadside plant species



as followed by *Magnifera indica* > *Alstonia scholaris* and *Azadirachta indica* and minimum content is in *Ficus benghalensis*, *Psidium guajava* and *Ziziphus mauritiana* (Fig. 4).

3.4 Relative water content (%)

The results of RWC is shown in Fig. 5. *Alstonia scholaris* showed maximum (91.0204%) as followed by *Pingamia pinnata* > *Dalbergia sissoo* and *Morus alba* whereas minimum value is in *Magnifera indica* < *Azadirachta indica* and *Ziziphus mauritiana*. While in road side area *Magnifera indica* (89.0805%) shows maximum value as followed by *Eucalyptus* > *Alstonia scholaris* and *Melia azedarach* and minimum value is (56.923%) in *Bougainvillea glabra* < *Azadirachta indica* and *Pongamia pinnata*.

3.5 Air pollution tolerance index

Figure 6 shows that the value of APTI in residential area is decreasing as *Alstonia Scholaris* > *Pongamia pinnata* > *Dalbergia sissoo* > *Morus alba* > *Eucalyptus* > *Ficus benghalensis* > *Psidium guajava* > *Melia azedarach* > *Saraca asoca* > *Bougainvillea glabra* > *Ziziphus mauritiana* > *Syzygium cumini* > *Azadirachta indica* > *Magnifera indica* while in case of road side areas the value is decreasing as *Magnifera indica* > *Eucalyptus* > *Alstonia Scholaris* > *Melia azedarach* > *Saraca asoca* > *Ficus benghalensis* > *Morus alba* > *Ziziphus mauritiana* > *Psidium guajava* > *Dalbergia sissoo* > *Pongamia pinnata* > *Azadirachta indica* > *Bougainvillea glabra*. Figure 7 displays a seasonal cluster analysis using Euclidean distance. According to a cluster analysis, the majority of plants in the category of sensitive plants

form the largest cluster throughout each of the two sites. Hence, the majority of the plants in this research had a sensitive degree. The factors that are most impacted by air pollution were found using a cluster heat map, making a plant more resilient to stress. The results of residential and traffic sites are shown in Fig. 8. The heat map of residential site showed that *Psidium guajava* and *Magnifera indica* have higher value of fresh weight and dry weight respectively while more APTI and RWC (%) are present in *Magnifera indica* and *Azadirachta indica*. The heat map of roadside site showed that *Bougainvillea glabra* has higher value of APTI and RWC (%) respectively while more TCC and pH are present in *Eucalyptus* and *Bougainvillea glabra*.

4 Discussion

Ascorbic acid has a strong reducing power [30] that is dependent on pH because ascorbic acid is the primary redox buffer and activates a variety of physiological and defense mechanisms, including regulating photosynthesis; hormone biosynthesis and the regeneration of other antioxidants. Plants with higher concentrations of ascorbic acid and higher pH are more resilient to air pollution than those with lower concentrations [31]. In our study, ascorbic acid of *Melia azedarach* has maximum (0.06035 mg/g) and *Eucalyptus* has minimum content (0.0593 mg/g) in residential area while at road side areas five species showed maximum ascorbic acid content whereas *Magnifera indica* and *Dalbergia sissoo* show minimum value 0.0598 mg/g. In the present results showed that low ascorbic in different plant species resulted sensitivity to air pollution which is similarly explained by Verma et al. [32] that ascorbic acid

Fig. 6 Comparison of APTI in residential & roadside plant species

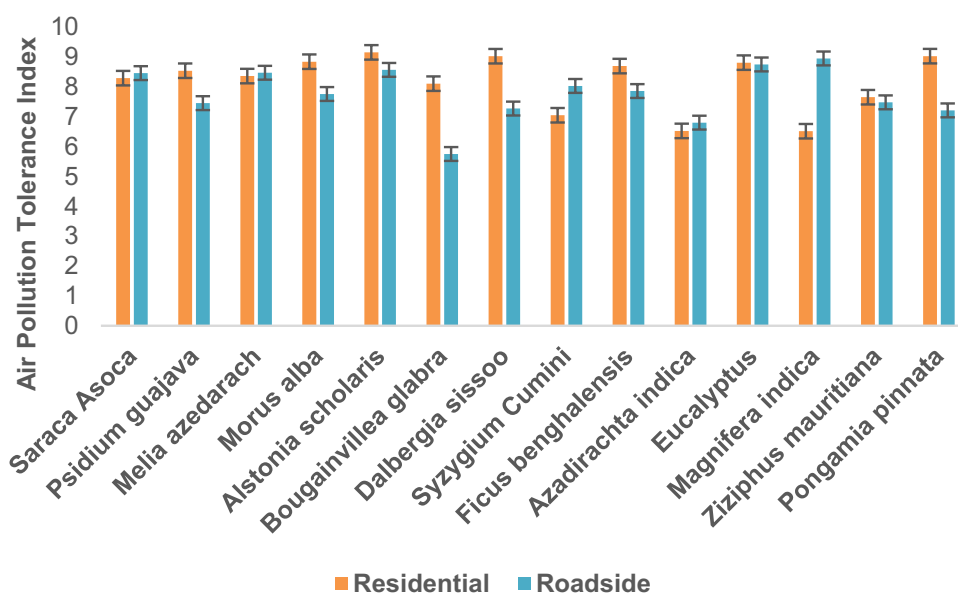
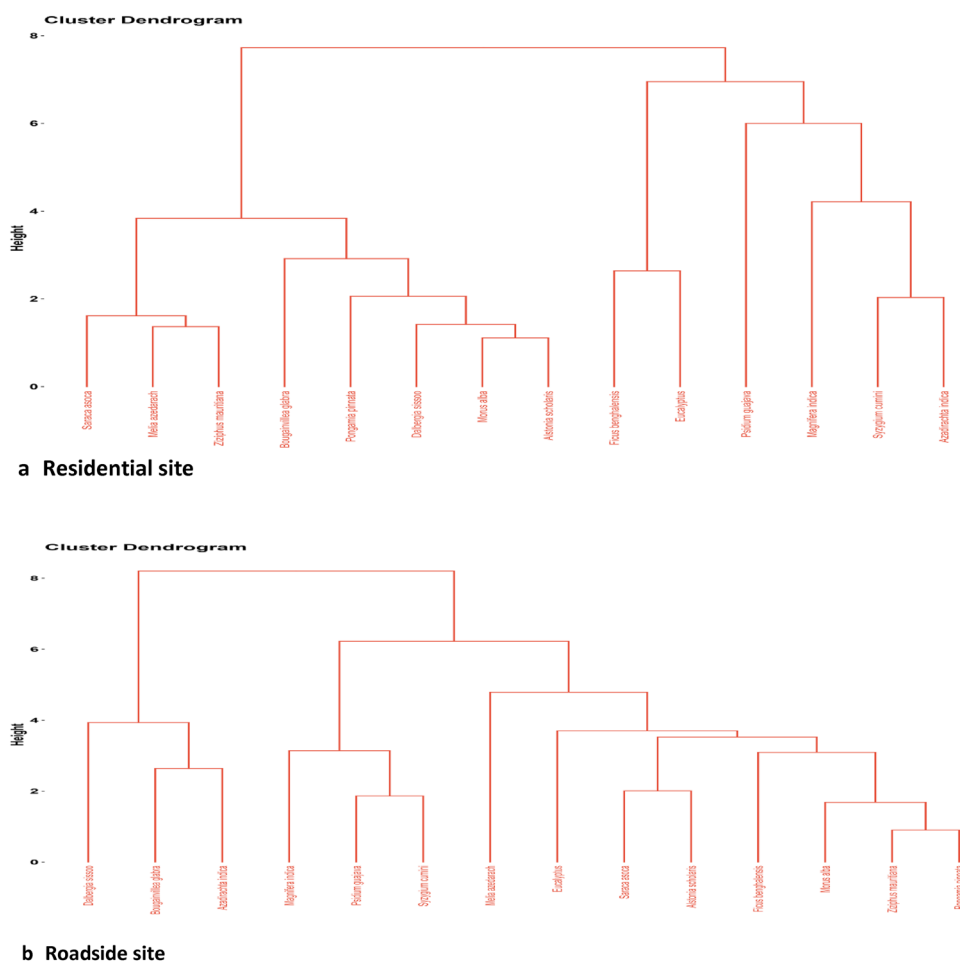


Fig. 7 **a** Residential site. **b** Roadside site



is natural detoxifier which play a vital role in reducing the air pollution effect in plant tissue.

The plant chlorophyll content potentially correlated with the pollution stress and type of pollutant. Our results related to chlorophyll showed that *Saraca asoca* at residential area while *Melia azedarach* at road side showed maximum chlorophyll content which is supported by Timilsina et al. [33] who described that chlorophyll synthesis or degradation linked with the concentration of SO_2 . Similarly Agbaire and Esiefarienrhe [15] reported that SO_2 pollutant decrease the chlorophyll content in plant species. Moreover, under pollution stress chlorophyll level decreases in plants [17]. Acebron et al. [34] found that *Azadirachta indica* is more tolerant as compare to other 13 samples in road side areas because it has maximum chlorophyll content, which is an index of productivity of plants. The result of RWC are similar with the finding of [17, 35] who reported that air pollutants increases cell permeability, which causes water and dissolved nutrients being lost and early leaf senescence occur as a result. pH results indicated that *Bougainvillea glabra* in traffic areas is more tolerant which is in accordance with study of [36, 37] who reported

that low pH show good correlation with sensitivity which reduce the photosynthesis.

The overall findings of this study support the idea that different plants react to air pollution in various ways in different geographical areas [37] and also with in the same area as it depend on different factors such as plant age, metabolic functions [38] and concentration of different pollutants such as CFC, NO and CO. Thus low APTI plants are susceptible to pollution [39] while high APTI plants are tolerant of it. The APTI is the key indicator for identifying the air pollution tolerance of the plant species. In the present study, *Magnifera indica* is tolerant to air pollution in road side area as compare to others and *Alstonia scholaris* is more tolerant in residential areas as compare to other plant species. All these results are supported by the findings of [40, 41] who found that air pollution tolerant plants show high APTI value thus they can be used as sink to control pollution in traffic and industrial areas while air pollution less tolerance plant show less APTI value which act as bio indicator to check the quantity of air pollution.

Overall residential area has maximum value of APTI as compare to road side area with the exception that some

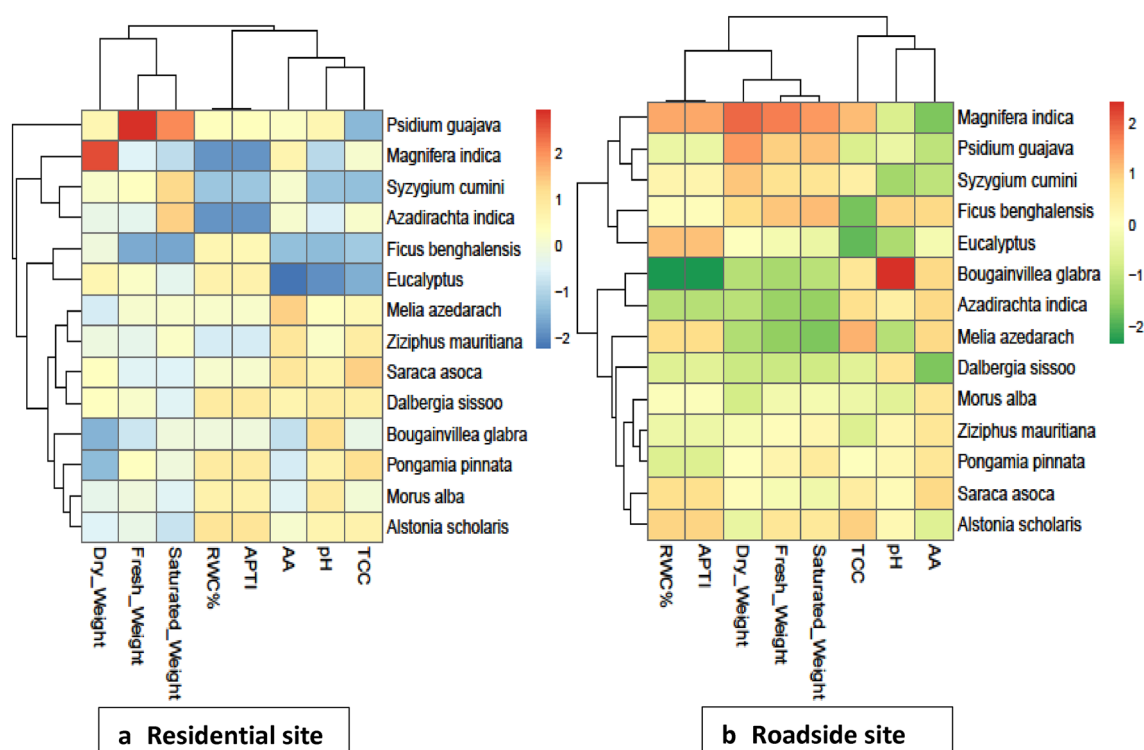


Fig. 8 Cluster heat maps of plants with their APTI elements in residential and roadside sites: **a** Residential and **b** Roadside

samples show reverse results which show that road side trees are sensitive to air pollution as these plants are indicative of higher pollution exposure such as dust pollution and gaseous pollutants which alter the functioning, biochemical makeup and tolerance capacity of plants to the air pollution [42]. Thus road sides (Lahore) are suffering from a more severe case of air pollution as a result of heavy vehicle and industrial emission as compared residential areas (University of the Punjab) which are heavily planted and there are no industries.

According to World air quality report in 2018 Lahore ranked 10 in IQAir Air Visual [43]. Overall the second-most polluted nation in the world is Pakistan due to air pollution which increase in winters in the form of smog and due to reduced air dispersion on the leaf surface [44]. Natural system is adversely effected by deprived air quality and it did not only effects the plants but also human and animals as well [45] and it is more challenging to control it as compare to soil and water pollution.

5 Conclusion

Plants trees are constantly exposed to air contaminants; these pollutants build up inside of them. The leaves' natural characteristics are changed, and they become more vulnerable to pollution as a result. Plant life is threatened

by pollutants from traffic emissions because they make plants sensitive. This sensitivity was determined using the air pollution tolerance index (APTI) and several biochemical parameter measurements. However, the vulnerability levels of various plant species growing near traffic and residential regions in Lahore city had assessed on the basis of APTI. It is possible to determine which species are more sensitive to air pollution and which are more tolerant by comparing the APTI values of various species. The study's findings showed that every sampled species was found to be particularly sensitive to air pollution in areas near roads, indicating that they are very vulnerable to the negative impacts of air pollution from vehicle emissions. Results show that *Alstonia scholaris* show maximum (9.15) and *Magnifera indica* show minimum (6.51) APTI values in residential areas while *Magnifera indica* shows maximum (8.95) and *Bougainvillea glabra* shows minimum (5.75) APTI value in roadside areas. The importance of APTI assessments is due to the growing risk of deforestation brought on by air pollution with rising urbanisation. The outcomes of such research are therefore useful for planning the future and may be useful in identifying potential control measures.

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Data availability The writers will provide the information you need on the data that backs up the study's conclusions.

Code availability In response to a valid request, the authors will provide the codes supporting the software used in this work.

Declarations

Conflict of interest The authors declare that there is no conflict of interest. The authors have no relevant financial or non-financial interests to disclose.

Ethical approval Not applicable in the present work.

Consent to participate All individuals taking part in the study gave their informed permission.

Consent for publication Not applicable.

Plant ethics Author's confirm that the use of plants in the present study complies with international, national and/or institutional guidelines.

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