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RESEARCH ARTICLE

Assessing the response of five tree species to air pollution in Riyadh City, Saudi Arabia, for potential green belt application

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Abstract

Tree species (including *Eucalyptus camaldulensis*, *Ziziphus spina-christi*, *Albizia lebbeck*, *Prosopis juliflora*, *Pithecellobium dulce*, and *Ficus altissima*) were investigated to elucidate their appropriates for green belt application. Leaf samples were collected from four different locations in Riyadh: (1) residential; (2) dense traffic; (3) industrial; and (4) reference sites located approximately 20 km away from the city of Riyadh. Leaves collected from the industrial site showed the highest leaf area reduction. The smallest reduction of leaf areas was observed for *F. altissima* (11.6%), while the highest reduction was observed for *P. juliflora* (34.8%). Variations in the air pollution tolerance index (APTI) coupled with the anticipated performance index (API) for each species were examined. The APTI value of *Z. spina-christi* was highest (58.5) at the industrial site while the lowest APTI value was for *P. juliflora* (14) at the reference site. Correlation coefficient and linear regression analyses determined that the correlation between the ascorbic acid content and APTI is positive and significantly strong. Our findings indicate that urban green planning in Riyadh should include growing *F. altissima* on roadsides as well as in heavy industrial locations followed by *Z. spina-christi* and *A. lebbeck* according to their API and APTI performances.

Keywords Air pollution tolerance index (APTI) · Anticipated performance index (API) · Air pollution · Leaf area · Riyadh City

Introduction

Global population growth has increased significantly in the past few decades, directly causing the level of pollutants to increase rapidly in the environment. The high level of pollutants has raised major concerns primarily because of the potential negative impact on human health as well as vegetation and other living organisms. The impact that could be, or is being, caused by pollutants can be mitigated to a significant degree through efficient use of appropriate techniques in environmental management.

Several studies illustrate the effectiveness of a green belt strategy in addressing air pollution through planting tolerant trees in areas that are polluted (Prajapati and Tripathi 2008; Pathak et al. 2011). Such species of trees have been found to be effective in acting as a natural filter of hazardous or harmful air gases that pollute the air; therefore, they represent a sustainable approach for removing air pollutants through mechanisms such as leaf sorption, vegetation fallout, and deposition over the leaf surface (Ram et al. 2014; Li et al. 2019; Baraldi et al. 2019). Leaves are considered as the most effective part of trees for sensitively indicating air pollution levels due to resulting leaf morphological and physiological changes, such as leaf area, color, and numbers, as well as leaf stomatal density and pore opening (Seyyednejad and Koochak 2011; Chavan and Sonwane 2012). Gostin (2009) found that air pollution released from cement factories combined with general pollutants (e.g., motor vehicles) adversely influence the anatomy and leaf structure of

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Lotus corniculatus L., *Trifolium montanum* L., *T. pratense* L., and *T. repens* L. With endless exposure to industrial and vehicular emissions, many tree species are extensively reported as bio-indicators of atmospheric pollutants and represent various levels of responses.

The selection of tree species for planting in any polluted area must consider the response of the tree species to pollutants (Kaur and Nagpal 2017). Collectively, the air pollution tolerance index (APTI) is a method applied by Singh and Rao (1983) for the classification of trees based on their response to pollutants (starting with sensitive, followed by resistant, and ending with tolerant tree species). Sensitive tree species are essential as early indicators of pollution, but because they are severely harmed by small to medium levels of pollution, tolerant tree species are needed for determining (and reducing) heavy pollution levels (Singh and Rao 1983). The role of APTI for determining tree species responses and developing an effective green space area in urban environments is widely reported (Noor et al. 2015; Sanghi et al. 2015; Kaur and Nagpal 2017).

For determining the APTI of tree species, various biochemical and physiological parameters within tree leaves, including total chlorophyll, ascorbic acid, leaf pH, and relative water contents, can be usefully determined (Pandey et al. 2015; Joshi and Swami 2009). Under environmental stress, decreased chlorophyll content resulting from reactive oxygen species in the chloroplast occurs, while simultaneously, a high concentration of ascorbic acid is released from the photosynthetic apparatus against reactive oxygen species to protect thylakoid membranes from damage by oxidative processes (Joshi and Swami 2009; Patidar et al. 2016). Panda et al. (2018) indicated that leaves of tolerant plants under air pollution stress contain large amounts of ascorbic acid. Considering APTI as one strategic tool for selecting appropriate trees, Enete et al. (2012) selected trees with high APTI values for urban heat reduction.

pt?>Tsega and Prasad (2014) and Panda et al. (2018) support another index called the anticipated performance index (API), which is useful for developing a green belt strategy as well as for selecting particular tree species in any region. Calculating the level of API utilizes the APTI value combined with other parameters of trees such as biological and socio-economic dimensions. In that regard, various species of trees exhibit differences in their manner of responses to pollutants. Many studies conducted in the past have determined that API, as well as APTI, is appropriate indicators during the evaluation of tree species seeking to determine their responses to air pollution (Pandey et al. 2015; Joshi and Swami 2009). API and APTI together can represent an effective green belt development (Prajapati and Tripathi 2008; Ogunkunle et al. 2015). Furthermore, APTI is useful to provide information for selecting tolerant species for landscaping and urban planning (Enete et al. 2013; Kaur and Nagpal 2017; Sharma et al. 2019).

The Kingdom of Saudi Arabia (KSA) has declared a sustainable plan for the next decade called "2030 Vision" to accomplish many internal and international goals including cultural, economic, and geostrategic aspects (Saudi Arabia Vision 2016). The expected increase of industrial projects has the potential to produce enormous environmental pollutants within the KSA. Therefore, one goal of this vision is "achieving environmental sustainability" to preserve and develop the environment of the KSA. Recently, one of the biggest urban greening projects has been established in the KSA, namely, "Green Riyadh," to increase green space within Riyadh City by planting 7.5 million trees by 2030 (Riyadh Green 2019). A common green belt strategy includes the growth of tolerant tree species to reduce air pollution in major cities worldwide.

To ensure the success of the "Green Riyadh" project, investigation of which particular tree species should be planted is required. To our knowledge, studies for developing recommendations of tree species that efficiently perform in greening projects are limited. Therefore, the objectives of this study were (1) to assess the API and APTI of five tree species that are commonly found along roadsides, as well as around residential and industrial areas of Riyadh, and (2) to select effective and tolerant species for use in the "Green Riyadh" project.

Materials and methodology

Area of study

Riyadh is the capital city of Saudi Arabia. It is the largest metropolitan city in the Kingdom and serves as the center for political and economic activities. Longitude and latitude dimensions (physical or geographical location) are 24° 28′ N to 24° 58′ N and 46° 30′ E to 46° 56′ E. The population of the Riyadh region was estimated to be about 8.5 million in 2018 according to the General Authority for Statistics in KSA (GAStat 2018). Khan (2002) has statistically indicated that based on population growth trends in the past half-decade, the Riyadh population will exceed 10 million by 2020. Population growth and urbanization have grown exponentially in the past three decades and that trend is associated with an increase in pollutant levels (Ali et al. 2016; Verma and Singh 2006). In this study, four sites were used as the study area, with three sites (sites one, two, and three) located in Riyadh while the other site (fourth site) was selected to be a reference site and is located approximately 20 km from Riyadh. To improve the general applicability of our findings and ensure that a wide range of influential factors is taken into consideration, the sites chosen for the study were situated distantly from each other (geographically) and vary in properties (such as industrial activities, residential activities, and traffic density). Table 1 and Figure 1 show the description of the selected sites and the particular location of each site (with reference to other locations in Riyadh), respectively.

Riyadh is mostly hot and dry in the summer while in the winter, the city is cold with minimal precipitation. During the summer, the relative humidity in Riyadh averages approximately 12% (Alharbi et al. 2015). Dust storms with the hot and arid climate in Riyadh (central region of Saudi Arabia) can place extreme stress on the atmospheric environment (Al Jassir et al. 2005; Maghrabi 2009; Alharbi et al. 2015; Modaihsh et al. 2015). Pollutants from industrial and traffic activities are released into the environment within the form of particulate matter (PM) in various liquid or solid states (Duong and Lee 2011). Many studies have been conducted in Riyadh to determine the atmospheric pollutants such as lead, sulfur, and nickel present within PM (El-Shoboksy 1985; Rushdi et al. 2013; Alharbi et al. 2014; Alharbi et al. 2015). Likewise, 20 metals averaged 21.5% of PM concentrations that were emitted over the city of Riyadh (Alharbi et al. 2015). In a comparative study, the air quality of Riyadh has been recently assessed using five monitoring network stations (Alharbi et al. 2014). This study reported PM concentrations estimated in Riyadh as high as three times over the levels of the KSA ambient air quality, and PM concentrations were 84% higher in summer compared with winter. Emissions from heavy traffic roads (King Fahad road) at the city center of Riyadh led to twofold higher PM concentrations compared with the rural site (Modaihsh et al. 2016).

Sampling and analysis

Leaf samples of five tree species, namely, *Albizia lebbeck* (L.) Benth, *Eucalyptus camaldulensis* Dehn, *Ficus altissima* Blume, *Prosopis juliflora* (Sw) Dc, and *Ziziphus spina-christi* (L.) Desf, were collected during July and August 2017, which ensured that temperature, as well as rain conditions, was similar at the time of collection. These five species were found in all four study sites (see Table 1 and Fig. 1 for descriptions of the study sites). Samples of fully developed (mature) leaves were randomly collected in three replicates from all sides of the individual tree species using polyethylene gloves and stainless steel scissors (Deljanin et al. 2016). During collection, leaves showing surface blemishes as well as atypical morphologies were avoided. Samples were then immediately taken to the lab using a heatproof container to assess relative leaf water content, ascorbic acid content, pH and total chlorophyll, and measurements of leaf area.

Leaf area

Only mature, fully exposed fresh leaves were used for leaf area measurements. Prior to measurement, leaves were delicately cleansed with moist tissue paper in the laboratory. The approximate leaf area (cm^2) of ten leaves per tree was measured in triplicates using leaf area meter following the method described by Laghari and Zaidi (2013).

Ascorbic acid content (*A*)

We used HPLC (high-performance liquid chromatography) for determining ascorbic acid in the leaf samples (Bozan et al. 1998). HPLC analysis involved the following equipment: a Shimadzu (Agilent1100, USA) 20A series HPLC, fitted with LC-solution software, 2 LC-20A pumps, diode array detector (SPD-M20A), and NUCLEODUR®100-5 C_{18}ec separation column. The dimensions of the separation column were 150 by 4.6 mm, with a 25 °C column temperature. The pH of the eluent was adjusted to 3 using HCl. Isocratic elution was used for separating sample components, and the ultraviolet detector wavelength was set at 245 nm. A mobile phase consisting of acetonitrile 95:5 v/v and 20 mM NaHH2PO4 was used for detecting ascorbic acid. The flow rate was maintained at 1.9 mL/min and the injection volume was 10 μL.

In extracting ascorbic acid, 10 g of fresh leaves was extracted in 25 mL of 5% MPA (metaphosphoric acid). The extract was shaken for approximately 6 h, and a 0.45-μm Supor® membrane filter was used to filter the extracted samples. The extracts were then incubated in the dark at 4 °C. After the two phases (extraction and filtering) were completed, 4 standard solutions (0.1, 0.3, 0.5, and 0.8 mg L^{-1}) were prepared for performing HPLC quantitative analysis. Next, the peak areas from the chromatograms were compared with an external standard for quantification (see Figs. 2 and 3). A linear correlation of response was obtained (for ascorbic acid

Table 1 Details of the study sites

No.	Site	Latitude (N)	Longitude (E)	Classification
1	King Saud University	24.71280°	46.61990°	Residential/study area
2	King Fahad road and Al-washem road	24.65005°	46.70231°	Roadside area
3	Cement industry	24.61685°	46.77261°	Industrial area
4	Derab agricultural research station	24.42622°	46.65303°	Outside the city of Riyadh

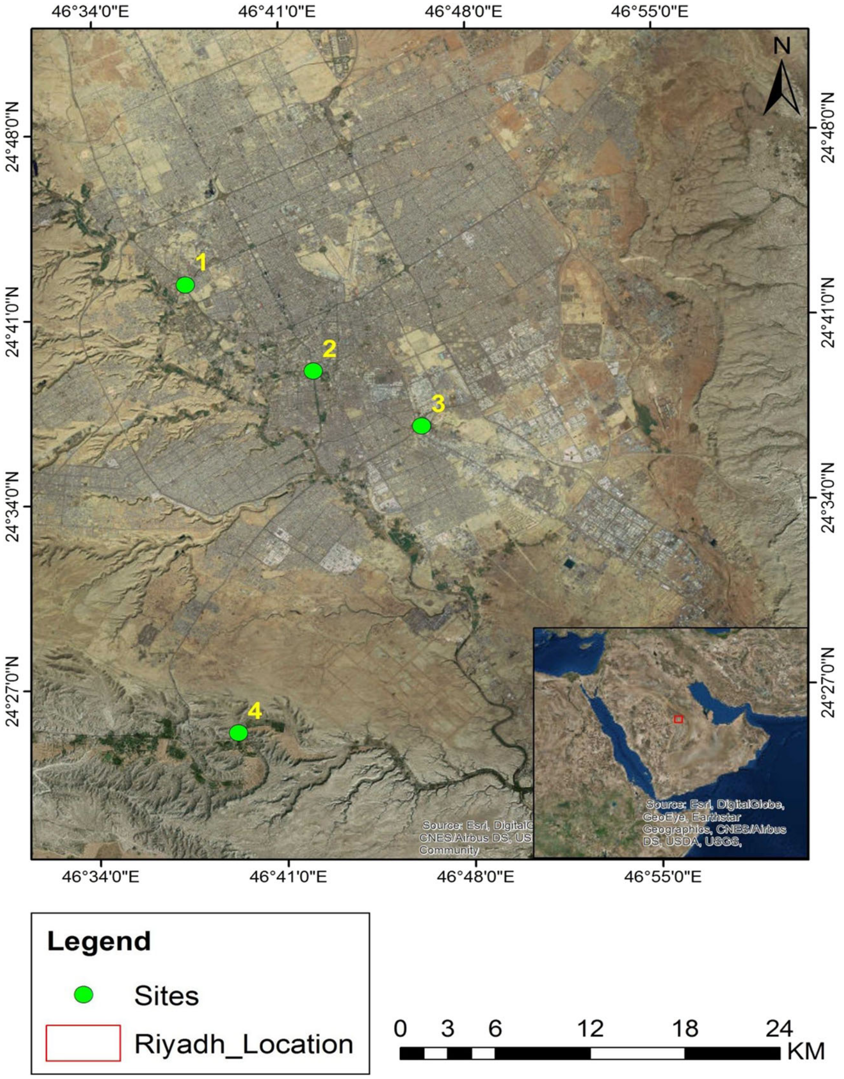


Fig. 1 Map of Riyadh City (location of the four sites)

over the standard solutions), and the correlation coefficient (R^2) was found to be 0.994.

pH of leaf extracts

Five grams of fresh samples of leaves was homogenized using 10 mL of deionized water. The extracted leaves were then filtered. A pH buffer solution with an acid-base ratio of 4:9 was used to calibrate the pH meter for pH determinations of the leaf samples (Prasad and Rao 1982).

Total chlorophyll content (T)

Chlorophyll content was quantified using a technique described by Arnon (1949). Fresh leaf samples (3 g) were blended, followed by extraction using a solution of 80% acetone (10 mL). The extract was then incubated for 15 min. The supernatant was decanted and centrifuged (at 2500 rpm) for 3 min. The supernatant absorbance was then measured (at wavelengths of 645 nm and 663 nm), using a spectrometer. The following formulae were then utilized in making calculations.

$$\text{Chlorophyll a}\left(\text{mg g}^{-1}\right) = 12.7 \times A_{663} - 2.69 \times A_{645} \tag{1}$$

$$\text{Chlorophyll b}\left(\text{mg g}^{-1}\right) = 22.9 \times A_{645} - 4.68 \times A_{663} \tag{2}$$

$$\text{Total content of chlorophyll}\left(\text{mg g}^{-1}\right) = 20.2 \times A_{645} + 8.02 \times A_{663} \tag{3}$$

Relative water content (*R*)

The technique explained by Henson et al. (1981) was used to calculate the relative water content (variable *R*) based on methods by Singh (1977) using the formula given below:

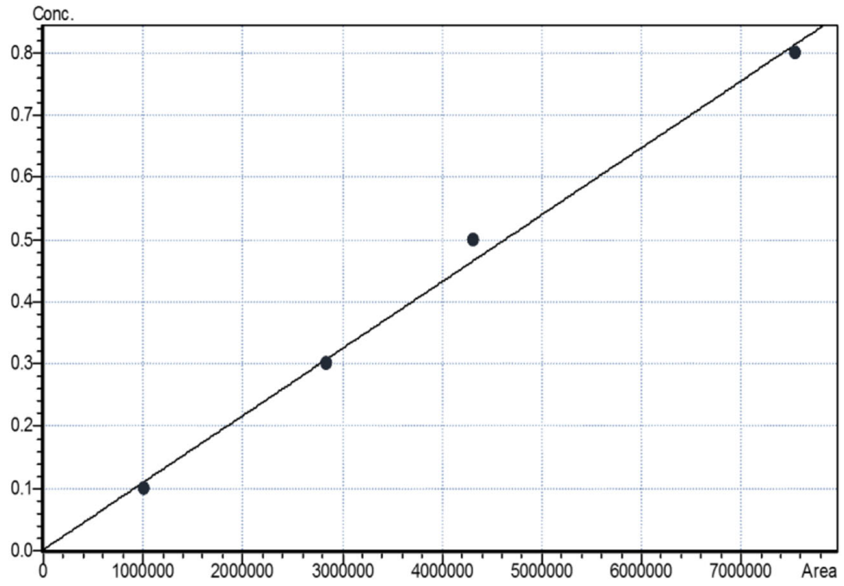


Fig. 2 Calibration curve of ascorbic acid (*A*) standard solutions

$$R = [(FW - DW)/(TW - DW)] \times 100 \tag{4}$$

where FW represents the fresh weight; DW represents the dry weight; and TW represents the turgid weight.

Immediately after transport to the lab, the fresh leaves were weighed to determine the fresh weight of each sample. Then, the leaves were immersed in water overnight. The leaves were then blotted dry, and to obtain the turgid weights, leaves were again weighed. The final step was drying the leaves overnight using an oven set at 70 °C and reweighing the leaves to obtain the dry weights of each sample.

APTI

APTI was calculated by determining the concentrations of chlorophyll, ascorbic acid, pH, and the relative water content in the collected leaf samples. The equation developed by Singh and Rao (1983) was utilized to calculate APTI by the following formula:

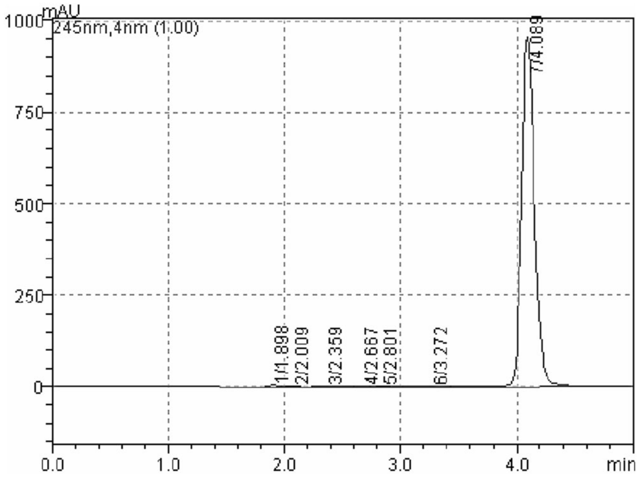


Fig. 3 Peak area of chromatography for *A* (245 nm)

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

where *A* represents ascorbic acid (mg g^{-1}); *T* represents total chlorophyll (mg g^{-1}); *P* represents pH; and *R* represents the relative content of water (%).

API

API was calculated based on the APTI values in addition to other factors such as the plants' socio-economic values and morphological characters (including canopy structure, plant habit, and plant type). Grades were then assigned (ranging from − to +) for the individual characteristics based on a technique (or criteria) described by Gupta et al. (2011), Pandey et al. (2015), and Kaur and Nagpal (2017), and the results were tabulated (Table 2). The maximum grade that a tree species could manifest was up to 16 points. The value of API in a specific species was determined using a percentage score that the tree species can obtain according to its grade points. In calculating the percentage score, the following formula was used:

$$\text{Score (\%)} = (\text{obtained plant species grade}/\ \text{highest possible grade for any plant species}) \times 100 \tag{5}$$

Using the percentage score, each tree species was assigned an API value and that value was utilized in assigning the plant species to one of several performance categories (ranging from not recommended to best) as described by Prajapati and Tripathi (2008) (Table 3).

Table 2 Use of API and APTI parameters to grade and assess (+ or −) the species

Grading character		Pattern of assessment	Grade allotted
Tolerance	APTI	16–20	+
		20.1–30.0	++
		30.1–40.0	+++
		40.1–50.0	++++
		> 50	+++++
Biological and socio-economic	Tree habit	Small	−
		Medium	+
		Large	++
	Canopy structure	Sparse/irregular/globular	−
		Spreading crown/open/semi-dense	+
		Spreading dense	++
	Type of tree	Deciduous	−
		Evergreen	+
Laminar structure	Size	Small	−
		Medium	+
		Large	++
	Texture	Smooth	−
		Coriaceous	+
	Hardiness	Delineate	−
		Hardy	+
	Economic value	Up to 3 uses	−
		3–4 uses	+
		> 4 uses	++

Statistical analysis

A general randomized complete design (RCD) with three replications was applied for analyzing the interaction between five tree species and four study sites. Data were statistically analyzed using the mixed procedure in SAS software version 9.4 (SAS Institute 2013). Tukey's statistical method was used for the pairwise comparison of the interaction levels exploring the least significant difference ($p \leq 0.05$). Variations between tree species at each site separately and for each tree across all study sites were statistically analyzed. To determine the correlation matrix of APTI and biochemical parameters (pH, relative water content, total chlorophyll, and ascorbic acid contents in the investigated tree leaves), regression analyses were performed using MS Excel software. In addition, variation of leaf area for the tree species across all study sites was determined by MS Excel software.

Table 3 API score, grade, and category for plant species

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

Results and discussion

Wolch et al. (2014) explained that the air quality in an urban area is improved by the presence of urban trees due to the substantial volumes of oxygen that such plants release into the immediate environment. Jim and Chen (2008) and Roy et al. (2012) added that green plants might be perceived as living filters that lessen air pollution by adsorbing, absorbing, accumulating, and detoxifying pollutants while remaining in a healthy condition.

Leaf area

To observe if atmospheric pollution affected leaf area (cm^2) in the urban environments of Riyadh, the reduction change (%) of leaf areas for the selected trees in the study sites was

Table 4 Leaf area change (%) in urban sites (sites 1, 2, and 3) compared with the reference site (site 4)

Tree Specie	LA (cm^2) in S4 ± SD	Reduction percentage (%) of leaf area		
		S4 to S1	S4 to S2	S4 to S3
A. lebbeck	88.1 ± 1.7	9.1	13.1	18.7
E. camaldulensis	92.2 ± 0.55	10.5	17.7	23.3
F. altissima	203.8 ± 1.76	5.01	9.2	11.6
P. juliflora	20.4 ± 1.06	13.7	25.5	34.8
Z. spina-christi	48.6 ± 0.67	9.8	15.4	21.4

LA, leaf area. Tree species: *A. lebbeck* (*Albizia lebbeck* (L.) Benth), *E. camaldulensis* (*Eucalyptus camaldulensis* Dehn), *F. altissima* (*Ficus altissima* Blume), *P. juliflora* (*Prosopis juliflora* (Sw) Dc), and *Z. spina-christi* (*Ziziphus spina-christi* (L.) Desf). S1, site 1 (King Saud University); S2, site 2 (King Fahad Road and Al-Washem Road); S3, site 3 (Cement Industry); S4, site 4 (reference site; Derab Agricultural Research Station)

measured (Table 4). The reduction of leaf area was found to be variable among all tree species at all study sites. Leaves from urban sites (S1, S2, and S3) were significantly smaller than those collected from the reference site (S4) (see description of the study sites in Area of study). Across the study sites, leaves collected from trees grown around the cement factory (S3) showed the highest reduction in leaf area. These results indicate that air pollutants at the industrial site significantly influence leaf growth. Among all tree species, the smallest reduction of leaf areas was reported for *F. altissima* (11.6%) while the highest reduction was observed for *P. juliflora* (34.8%). Similar findings, namely, reduction of leaf area, have been significantly recorded in contaminated areas for *Eucalyptus* sp., *Platanus acerifolia*, *Guaiacum officinale*, and *Ficus benghalensis* trees (Ninova et al. 1983; Jahan and Iqbal 1992). These findings suggest that the differences in the reduction in leaf areas between tree species at different locations may be due to the availability of leaf surface area and the capacity of leaves for capturing air pollutants (Weerakkody et al. 2017).

Pollutants significantly impact leaf growth in sensitive species (Tiwari et al. 2006). A study by Honour et al. (2009) reported that heavy traffic in urban environments was related to decreased leaf senescence, photosynthetic rate, stomatal conductance, and chlorophyll content. Decreased leaf area resulted from a reduction of absorbed radiation and ultimately a reduction in photosynthetic activity (Tiwari et al. 2006). In this study, the reduction of leaf area measured in the contaminated sites agrees with studies by Dineva (2004) and Tiwari et al. (2006).

Ascorbic acid content (*A*)

As shown in Table 5, the ascorbic acid content varied significantly for the five tree species across the four sites. High ascorbic acid contents were observed in the leaf samples from all tree species from site 3, with 84.6 mg g^{-1} for Z. *spina-christi*, 47 mg g^{-1} for *A. lebbeck*, 29.1 for *E. camaldulensis*, 24.8 for *F. altissima*, and 16 mg g^{-1} for *P. juliflora*. The highest ascorbic acid value was found at site 3 for Z. *spina-christi* (84.6 mg g^{-1}) while the lowest value was recorded at site 4 (reference site) for *P. juliflora* (10.4 mg g^{-1}). Leaves collected from site 3 (cement factory area) showed the highest ascorbic acid content followed by site 2 (roadside area), site 1 (residential and university campus area), and site 4 (reference site). According to suggestions raised by Achakzai et al. (2017), Kaur and Nagpal (2017), and Sharma et al. (2019), the increased ascorbic acid contents observed in leaves collected from polluted areas represented the tolerance response of tree species against the elevated air pollution levels of their growing environment.

Likewise, a study conducted in Baroda city of Gujarat, India, showed that high ascorbic acid content was associated with responses to environmental pollution stress such as traffic stress in several plant species including *Acacia arabica*, *Azadirachta indica*, *Ficus benghalensis*, *Peltophorum pterocarpum*, and *Polyalthia longifolia.* (Bhattacharya et al. 2013). Adamsab et al. (2011) determined that traffic stress caused plants to increase ascorbic acid content, as manifested in the following 14 plant species that were collected from a city in India (Shivamogga city in Karnataka): *Azadirachta indica*; *Mangifera indica*; *Carica papaya*; *Ricinus communis*; *Polyalthia longifolia*; *Calotropis gigantean*; *Eucalyptus mysoresins*; *Nerium indicum*; *Psidium guajava*; *Parthenium hysterophorus*; *Bougainvillea glabra*; *Mutangia calabra*; *Terminalia catappa*; and *Tamarindus indica*. Numerous other studies report similar findings regarding the ascorbic acid contents in plant leaves (or trees), as illustrated in Cheng et al. (2007) and Kaur and Nayyar (2014), among other studies.

Jyothi and Jaya (2010), Palit et al. (2013), and Sanghi et al. (2015) demonstrated that ascorbic acid is a powerful antioxidant and upholds the stability of cell division as well as cell membranes in plants when conditions are strenuous (difficult or tough). Antioxidants achieve this objective by scavenging cytotoxic free radicals as well as reactive oxygen species that are created by the photo-oxidation of SO_2 to SO_3 (Aguiar-Silva et al. 2016; Aghajanzadeh et al. 2016). Additionally, ascorbic acid has the potential to thwart harmful effects

Table 5 Mean values of biochemical parameters with APTI of investigated between trees at each study location as well as for each tree across all sites

Tree species	Site	A (mg g^{-1})	pH	T (mg g^{-1})	R (%)	APTI
A. lebbeck	1	32.9^{bC}	5.48^{bA}	1.47^{aB}	84.6^{aB}	31.3^{bC}
E. camaldulensis		20.9^{cC}	5.11^{cA}	0.54^{eB}	75.0^{cB}	19.3^{dC}
F. altissima		18.2^{dC}	6.20^{aA}	0.67^{dB}	78.2^{bB}	20.3^{cB}
P. juliflora		12.9^{eC}	5.02^{dA}	0.73^{cB}	66.9^{cB}	14.1^{eB}
Z. spina-christi		52.1^{aC}	5.54^{bA}	0.87^{bB}	78.6^{bB}	41.3^{aC}
A. lebbeck	2	41.9^{bB}	5.58^{bA}	0.95^{aC}	77.9^{aC}	34.7^{bB}
E. camaldulensis		25.6^{cB}	5.09^{cA}	0.41^{eC}	63.7^{dC}	20.5^{dB}
F. altissima		22.9^{dB}	6.21^{aA}	0.48^{dC}	67.9^{cC}	22.1^{cA}
P. juliflora		15.1^{eB}	5.03^{cA}	0.58^{cC}	63.2^{dC}	14.8^{eA}
Z. spina-christi		78.6^{aB}	5.55^{bA}	0.69^{bC}	72.0^{bC}	56.2^{aB}
A. lebbeck	3	47.0^{bA}	5.49^{cA}	0.74^{aD}	76.4^{aD}	36.9^{bA}
E. camaldulensis		29.1^{cA}	5.10^{dA}	0.28^{eD}	61.9^{dD}	21.8^{dA}
F. altissima		24.8^{dA}	6.20^{aA}	0.41^{dD}	67.3^{cC}	23.1^{cA}
P. juliflora		16.0^{eA}	5.03^{eA}	0.42^{cD}	60.6^{eD}	14.8^{eA}
Z. spina-christi		84.6^{aA}	5.55^{bA}	0.54^{bD}	69.5^{bD}	58.5^{aA}
A. lebbeck	4	22.4^{bD}	5.44^{cA}	1.78^{aA}	94.8^{aA}	25.7^{bD}
E. camaldulensis		18.4^{cD}	5.14^{dA}	0.67^{eA}	81.9^{dA}	18.9^{cD}
F. altissima		14.5^{dD}	6.18^{aA}	0.89^{dA}	87.0^{cA}	18.9^{cC}
P. juliflora		10.4^{eD}	4.95^{eB}	0.91^{cA}	78.9^{eA}	14.0^{dB}
Z. spina-christi		35.3^{aD}	5.52^{bA}	1.08^{bA}	89.1^{bA}	32.2^{aD}

Tree species: *A. lebbeck* (*Albizia lebbeck* (L.) Benth), *E. camaldulensis* (*Eucalyptus camaldulensis* Dehn), *F. altissima* (*Ficus altissima* Blume), *P. juliflora* (*Prosopis juliflora* (Sw) Dc), and *Z. spina-christi* (*Ziziphus spina-christi* (L.) Desf). Site 1 (King Saud University); site 2 (King Fahad Road and Al-Washem Road); site 3 (Cement Industry); site 4 (reference site; Derab Agricultural Research Station). *A*, ascorbic acid; *pH*, pH of leaf extract; *T*, total content of chlorophyll; *R*, relative content of water; *APTI*, air pollution tolerance index. Values within each column followed by the same letters are not significantly different at LSD ($p \leq 0.05$), whereas letters with lower case (a, b, c, d, and e) are corresponding to the variation between trees at each site separately and letters with upper case (A, B, C, and D) are corresponding to the variations of each specie across all sites

resulting from air pollution; hence, it plays a major role in developing plant tolerance to air pollution. The findings of the present study align with previous studies (Laghari et al. 2015; Achakzai et al. 2017).

pH

Variations in pH values were observed among the different species (Table 5). This finding suggests that the variation in extracted leaf pH values can be attributed to the differences in responses between each tree species to the same pollutant stress from similar sources of pollution (Kaur and Nagpal 2017). PH values of all leaf samples across all sites did not exceed 6.3. Similarly, a study focused on roadside trees determined that leaf samples from *Cassia angustifolia*, *Mangifera indica*, *Khaya senegalensis*, *Azadirachta indica*, *Eucalyptus* spp., and *Anacardium occidentale* yield pH values ranging between 4.6 and 6.7 (Aji et al. 2015). This study was conducted with a particular focus on whether the leaf samples were exposed to high, moderate, or low levels of pollution.

Across all tree species, the lowest pH value (4.95) was observed for the sensitive species (*P. juliflora*) according to APTI grade, as shown in Tables 5 and 6. Other studies including Dhankhar et al. (2015), Mondal et al. (2011), Shannigrahi et al. (2004), Pathak et al. (2011), Kulkarni and Ingawale (2014), and Prajapati and Tripathi (2008) match the findings of this study. The role of pH is that it participates in the regulation of the sensitivity of a plant to pollution (Das and Prasad 2010). Researchers like Swami et al. (2004) share the perspective that when gaseous air pollutants in the cell sap, such as SO_2, NO_2, and CO_2 diffuse, they convert into acidic radicals that explain the acidic pH observed in the present study. Low pH values may offer the inference that a challenge exists (or a decline will be observed) with regard to hexose sugar conversion within leaves of sensitive species (Jyothi and Jaya 2010). Verma and Singh (2006) indicated that variations in leaf pH might be due to the impact of air pollution on stomatal sensitivity. Collectively, leaves, with lower pH values are more influenced by atmospheric pollutants, while those with higher pH are more tolerant to pollutants (Govindaraju et al. 2012).

Table 6 APTI value and API grade of tree species investigated in this study as well as previously conducted research

Tree	APTI value	API category	Study area	Reference
Albizia lebbeck (L.) Benth	36.9	Good	Cement industry	This study
Eucalyptus camaldulensis	21.8	Good		
Ficus altissima	23.1	Excellent		
Prosopis juliflora	14.8	NR		
Ziziphus spina-christi	58.5	Good		
Morus alba L.	22.66	Excellent	University campus	Leghari et al. (2019)
Morus nigra L.	22.53	Very good		
Fraxinus angustifolia Vahl.	23.29	Good		
Robinia pseudoacacia L.	20.39	Poor		
Alstonia scholaris L. R. Br.	38.34	Excellent	Heavy population and industrialization areas	Kaur and Nagpal (2017)
Nerium oleander L.	37.25	Good		
Tabernaemontana coronaria R. Br.	50.57	Good		
Thevetia peruviana	41.47	Poor		
Ficus benghalensis L.	26.01	Excellent	Residential and commercial areas	Pandey et al. (2015)
Ficus glomerata (Roxb.)	19.22	Very good		
Cassia fistula L.	24.52	Good		
Azadirachta indica Juss.	15.08	Moderate		
Madhuca indica	11.01	Poor		
Bauhinia variegata	12.11	NR		
Mimusops elengi L.	19.03	Excellent	Industrial area	Govindaraju et al. (2012)
Anacardium occidentale L.	12.24	Very good		
Morinda coreia Buch.-Ham	14.88	Good		
Bambusa bambos (L.) Voss	10.58	Moderate		
Lagerstroemia speciosa (L.) Pers	8.95	Poor		
Millingtonia hortensis L. f.	10.77	Very poor		
Anacardium occidentale L.	11.13	NR		
Ficus religiosa L.	19.13	Excellent	Traffic area	Pathak et al. (2011)
Polyanthia longifoliasonn	23.58	Very good		
Croton bompladianum Baill	15.7	Good		
Cassia siamea Lamk.	14.52	Moderate		
Madhuca indica Gmelin.	10.27	Poor		
Acacia ferruginea DC.	11.28	Very poor		
Adina cardifolia Hook. f.	12.78	NR		

NR, not recommended

Total chlorophyll content (*T*)

The findings made at the four sites illustrate the varying levels of chlorophyll contents in leaves as follows: *A. lebbeck* (0.74–1.78 mg g^{-1}); *E. camaldulensis* (0.67–0.28 mg g^{-1}); *F. altissima* (0.41–0.89 mg g^{-1}); *P. juliflora* (0.41–0.91 mg g^{-1}); and *Z. spina-christi* (0.54–1.08 mg g^{-1}). From the results above, it is evident that the total content of chlorophyll varies significantly for the different species of trees that were included in the study and that were collected from the four different sites. The chlorophyll contents of the leaf samples collected from site 4 were comparatively higher than samples from the other sites and should be considered in light of the findings shown in Table 1. The results of this study are in agreement with a recent study conducted by Achakzai et al. (2017), where they observed that the *T* contents of nine plant species decreased when the source of pollution increased. High *T* in the collected samples from our study may be associated with low air pollution volumes or a lack of accumulation of many dust particles on the surface of the leaves (Shyam et al. 2006). One of the key constituents found in plants is chlorophyll, and it is expected to enable plants to maintain a green exterior in addition to helping the plants to trap sunlight and convert it to chemical energy.

Bakiyaraj and Ayyappan (2014) and other studies such as Noor et al. (2015) established that the low *T* identified in some leaf samples that were collected at other sites might be due to factors such as stomatal pore blockage, high moisture content, and high pollutant loads. When the volume of air pollutants is high, chlorophyll molecules may become degraded to pheophytin as two hydrogen atoms replace Mg++ ions (Rahmawati et al. 2014). Chloroplast efficiency becomes reduced by air pollution; hence, the rate of photosynthesis and the conductance of stomata are affected. Additionally, leaves fall prematurely, and productivity is observed to decline (Tripathi and Gautam 2007; Bora and Joshi 2014; Giri et al. 2013). The chlorophyll content may differ between varying species and with levels of pollution, and the abiotic and biotic circumstances that are inherent in the particular region (Rai and Panda, 2015). Our study identifies the same trend as it demonstrates that species that were collected from highly polluted urban sites have low *T*.

Relative water content (*R*)

The data collected showed that the value of *R* (as a percentage) varies across different species of trees and different sites (Table 5). The results from this study demonstrated that the highest value of *R* of all species was found at site 4 (the reference site) followed by sites 1 and 2, while the lowest *R* was noticed at site 3 (cement industry site). Among all species, *R* across all study sites were observed, with the highest and the lowest *R* found for *A. lebbeck* at site 4 and *P. juliflora* at site 3, respectively.

Water is a critical element that facilitates the maintenance of plant physiological balance when conditions are strenuous (difficult or stressful) due to air pollution. When *R* is high, it represents an advantage, especially for plants that are resistant to drought (or dry conditions) (Geravandia et al. 2011). High water content in plants enables the plant to dilute acidity that may occur in the cytoplasm of leaf cells (Palit et al. 2013). The status of leaf water in plants is directly linked to numerous physiological conditions such as respiration, transpiration, and growth (Dhankhar et al. 2015). The authors found a direct relationship between protoplasmic permeability and the relative water content. When the relative water content is high, the plant becomes more tolerant of air pollution under tough conditions (Jyothi and Jaya 2010; Singh et al. 1991). The findings made in this study regarding *R* are in agreement with previous findings including those of Seyyednejad et al. (2011), Dwivadi and Tripathi (2007), and Chandawat et al. (2011).

APTI

APTI was calculated by determining the content of chlorophyll, the relative water content, the ascorbic acid content, and the pH of each sample. Table 5 shows the results from analyzing these biochemical parameters as well as the calculated APTI of each leaf sample. As the statistical analyses of these results were performed for each separate site as well as for each specific tree, significant variations between the biochemical parameters and APTI values among the five tree species and across the study sites were observed.

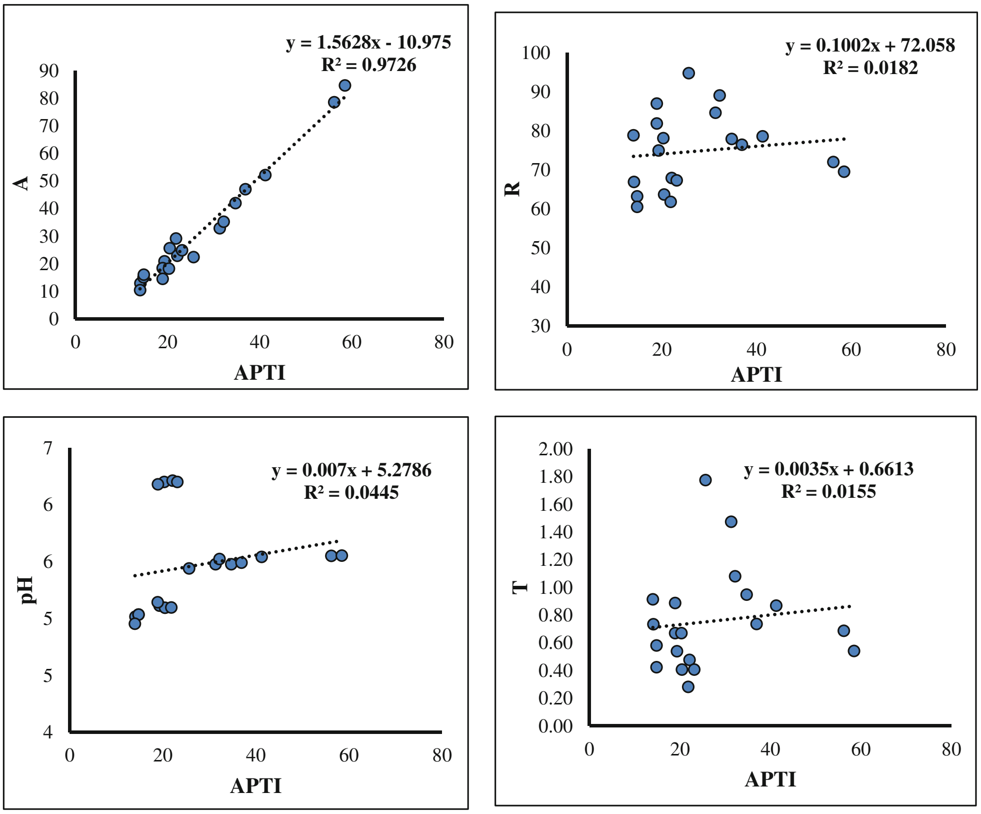


Fig. 4 Correlation of biochemical parameters across study sites with APTI values

The correlation of biochemical parameters with APTI and leaf area

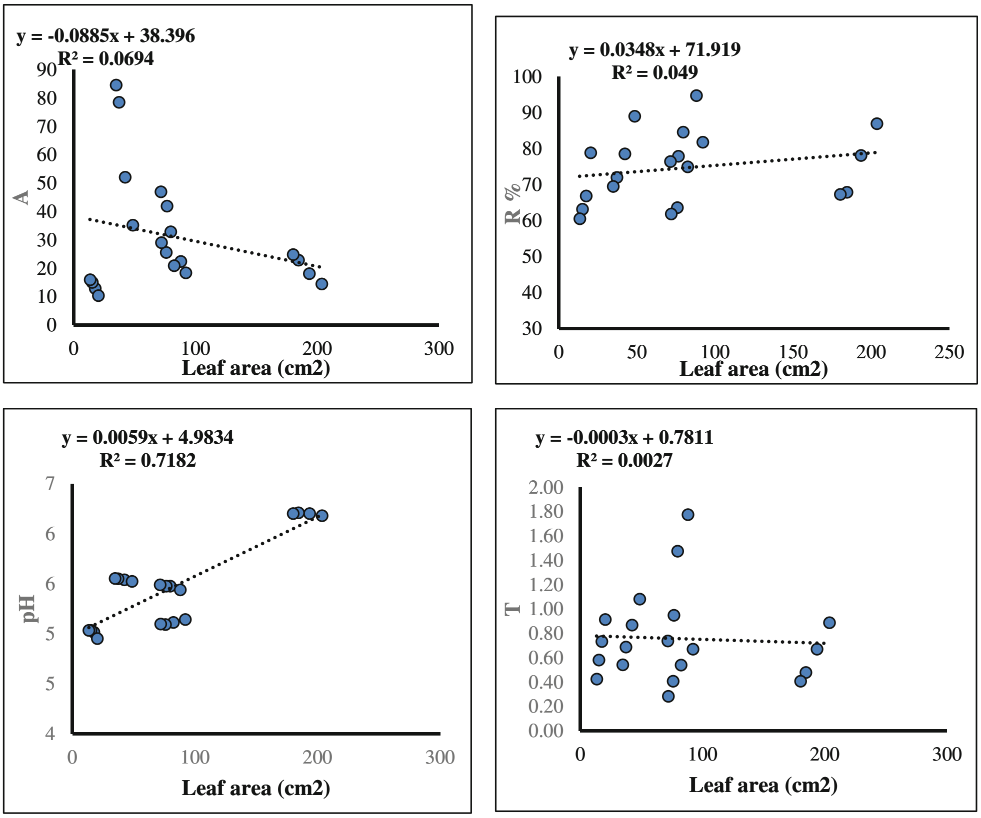
Figure 4 shows the impact that ascorbic acid content ($R^2 = 0.9726$) has on APTI is positive, as well as significantly strong (based on linear regression). Linear regression analysis illustrates that pH ($R^2 = 0.0445$), *R* values ($R^2 = 0.0182$), and *T* values ($R^2 = 0.0155$) have no significant impact on APTI. The same trend or outcome was determined by Kaur and Nagpal (2017) regarding the relationship between APTI and ascorbic acid content, the total content of chlorophyll, the relative water content, and pH.

Correlation analyses were also performed between leaf area (cm^2) and biochemical parameters (ascorbic acid (*A*), pH (*P*), total chlorophyll (*T*), and relative water content (*R*)) (Fig. 5). While *A*, *T*, and *R* did not show a significant correlation with leaf area of tree species across study locations, leaf pH was positively correlated with leaf area ($r = 0.718$). These results are in agreement with the findings of a previous study conducted by Boutraa (2013). In conflict, Mishra et al. (2018) documented that there was no significant correlation between leaf area and chlorophyll and leaf water content. Conversely, Cornelissen et al. (2006) suggested that the positive correlation between leaf area and leaf pH can stem from a plant phenotype under variable environmental stress conditions. Relevant studies have considered that leaf pH is an effective biochemical indicator of leaf growth in more than 90 plant species (Cornelissen et al. 2006; Cornelissen et al. 2011). An early study undertaken by Van Volkenburgh and Boyer (1985) indicated that the impact of drought environments on the pH of apoplastic inside leaves ultimately affected leaf growth. During dry weather, a significant relationship between apoplastic pH and leaf expansion rate can be exhibited (Bacon et al. 1998). This suggests that leaf pH can influence leaf physiological changes.

Tolerant categories of tree species

APTI is applicable as a criterion that guides the selection of plants that are tolerant to air pollution (Singh et al. 1991). Table 5 presents detailed information about the individual tree species' APTI. Increased APTI values were recorded for each tree collected from sites 3, 2, and 1 respectively while their lower APTI's were found in the reference site (site 4). Tolerance of *Z. spina-christi* to air pollution was found to be high for each of the four sites, and similarly, *A. lebbeck* exhibited high air pollution tolerance for the sites except in site 4 (where tolerance was intermediate). An alternative explanation may be that in sites 2 (roadside) and 3 (industrial area), the collected leaf samples showed high tolerances for air pollution

Fig. 5 Correlation of biochemical parameters across study sites with leaf area



in comparison with site 4 because of the high content of ascorbic acid that the leaf samples contained.

Previous studies have made similar findings as is evident in the study by Pandey et al. (2015) whereby three species (*Ficus religiosa*, *P. longifolia*, and *F. benghalensis*) that were obtained from urban areas in India (specifically, Varanasi City) showed high APTI scores. In the study by Enete et al. (2013), eight species of trees (*Catalpa bungei*, *Thuja pine*, *Yellow Ficus*, *Pinus* sp., *Masquerade pine*, *Yellow bush*, and *Anacardium occidentale*) collected from major roads within the region (in the Enugu urban area) were found to have high APTI scores. Plants that show high APTI values are air pollution tolerant and may act as filters in reducing air pollution. On the other hand, plants that have low APTI values are considered to be sensitive and may be appropriate bio-indicators. In our study, the leaf samples that we collected from two sites (roadsides and industrial areas) showed varying degrees of sensitivity and tolerance. *P. juliflora* exhibited sensitivity while intermediate tolerance was observed in *E. camaldulensis* and *F. altissima*. Tripathi and Gautam (2007), Karthiyayini et al. (2005), and Chauhan (2010) are among researchers who conducted similar studies and determined that plants exhibited changes in the accumulation of particular metabolites because of the impact that particular pollutants have.

Investigations of API and APTI have been widely applied to evaluate the responses of several trees in various polluted areas (Table 6). Previously, published work has been conducted for measuring the appropriateness of many tree species for use in a green belt strategy. The APTI value and API grade of tree species investigated in this study, along with other recently conducted studies, are shown in Table 6. This study is considered as the first work investigating API and APTI of five tree species grown in the city of Riyadh.

API

The tree species were allocated varying grades (+ or −) in relation to APTI and the parameters (morphological and socio-economic), as shown in Tables 2 and 3. Table 7 shows several relevant parameters (including API grades, the total plus (+), and percentage scores).

The choice species found in this study was *F. altissima* due to its excellent performance on all parameters. Species such as *Z. spina-christi*, *E. lebbeck*, and *E. camaldulensis* also

Table 7 Use of API as well as APTI parameter to grades tree species

site	Tree species*	APTI	Tree habit	Canopy structure	Type of tree	Laminar		Economic importance	Hardiness	Grade allotted		API** grade
						Size	Texture			Total plus (+)	Score %	
1	*A. lebbeck*	+++	++	+	−	+	+	++	+	11	68.75	(G)
	E. camaldulensis	+	++	+	+	+	+	++	+	10	62.5	(G)
	F. altissima	++	++	++	+	++	+	++	+	13	81.25	(E)
	P. juliflora	+	−	+	−	−	−	−	−	2	12.5	(NR)
	Z. spina-christi	++++	+	−	+	−	+	++	+	10	62.5	(G)
2	*A. lebbeck*	+++	++	+	−	+	+	++	+	11	68.75	(G)
	E. camaldulensis	++	++	+	+	+	+	++	+	11	68.75	(G)
	F. altissima	++	++	++	+	++	+	++	+	13	81.25	(E)
	P. juliflora	+	−	+	−	−	−	−	−	2	12.5	(NR)
	Z. spina-christi	+++++	+	−	+	−	+	++	+	11	68.75	(G)
3	*A. lebbeck*	+++	++	+	−	+	+	++	+	11	68.75	(G)
	E. camaldulensis	++	++	+	+	+	+	++	+	11	68.75	(G)
	F. altissima	++	++	++	+	++	+	++	+	13	81.25	(E)
	P. juliflora	+	−	+	−	−	−	−	−	2	12.5	(NR)
	Z. spina-christi	+++++	+	−	+	−	+	++	+	11	68.75	(G)
4	*A. lebbeck*	++	++	+	−	+	+	++	+	10	62.5	(G)
	E. camaldulensis	+	++	+	+	+	+	++	+	10	62.5	(G)
	F. altissima	+	++	++	+	++	+	++	+	12	75	(VG)
	P. juliflora	+	−	+	−	−	−	−	−	2	12.5	(NR)
	Z. spina-christi	+++	+	−	+	−	+	++	+	9	56.52	(M)

*Tree species: *A. lebbeck* (*Albizia lebbeck* (L.) Benth), *E. camaldulensis* (*Eucalyptus camaldulensis* Dehn), *F. altissima* (*Ficus altissima* Blume), *P. juliflora* (*Prosopis juliflora* (Sw) Dc), and *Z. spina-christi* (*Ziziphus spina-christi* (L.) Desf)

**API grade: *E*, excellent; *VG*, very good; *G*, good; *M*, moderate; *NR*, not recommended exhibited good performance. A species that was not recommended according to the findings of this study is *P. juliflora*. Based on an environmental perspective, planting *F. altissima* and other three recommended species (*Z. spina-christi*, *A. lebbeck*, and *E. camaldulensis*) in areas in which air pollution is high (such as industrial areas, urban areas, and heavy roadsides) would result in reduced air pollution loads. A study by Gupta et al. (2011) shared a similar perspective, and the species that they recommended for planting in industrial areas which are characterized by pollution linked with various heavy metals is *A. scholaris*. Their justification is similar to the one made in this study—high tolerance to air pollution. The recommendation of *A. scholaris* as the best candidate or tree species to be planted in such areas is slightly contested by Pandey et al. (2015), as well as Mondal et al. (2011), who argue that *A. scholaris* has a good to moderate performance and does not represent the best candidate. The study conducted by Dhankhar et al. (2015) completely contest the recommendations by explaining that their findings (based on leaf samples from the university campus of Rohtak, Haryana) show that *A. scholaris* has poor performance and *N. oleander* has a moderate performance. Presently (and with reference to current information or research available), there has been no other study conducted in Riyadh that has addressed this subject—except for the one we have conducted. Consequently, it would be appropriate to conduct repeated studies to obtain more data on the plant species, their varying degree of tolerance and sensitivity, and their application in mitigating air pollution and its effects.

Conclusions

As demonstrated in this study, different tree species react in various ways to air pollution. According to the results of our study, contaminated urban locations resulted in a reduction of leaf area, total chlorophyll content, and leaf relative water content. As implied in the findings, the sorting of candidate tree species should be conducted based on their tolerance relative to pollution load and using APTI as well as API indicators. Thus, locations that experience higher pollution can grow plants that exhibit higher APTI and API values. Therefore, the current study is relevant in determining the suitability of plants for different locations based on their APTI and API values. This finding implies determining what plants to grow, where to grow them, and why. For instance, plants that exhibit higher APTI and higher API values can be applied as part of bioresistance techniques for pollution that comes from automobiles and can be planted in urban, commercial, and industrial areas where there is more air pollution as a result of vehicles and other polluting machinery. From the values of the plants examined in the study, the three plant species recommended for Riyadh are *F. altissima*, *Z. spina-christi*, *A. lebbeck*, and *E. camaldulensis*. Significantly, these trees can be incorporated into the green belt design of Riyadh to enhance long-term atmospheric pollution mitigation practices. For identifying effective atmospheric-pollutant-tolerant trees and reducing pollution levels all over the city in an appropriate manner, further investigations on the numerous plant species growing around various pollution sources such as industries and vehicular emissions are required.

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References

Achakzai K, Khalid S, Adrees M, Bibi A, Ali S, Nawaz R, Rizwan M (2017) Air pollution tolerance index of plants around brick kilns in Rawalpindi. Pakistan J Environ Manage 190:252–258

Adamsab MP, Kousar H, Shewetha DS, Sinajuddin MH, Ravichandram M (2011) APTI of some selected plants in Shivamogga city, South Asia. In: Proceeding of International Conference on Advance Sciences. Engineering and Information Technology, pp 668–671

Aghajanzadeh T, Hawkesford MJ, De Kok LJ (2016) Atmospheric H2S and SO2 as sulfur sources for Brassica juncea and Brassica rapa: regulation of sulfur uptake and assimilation. Environ Exp Bot 124:1–10

Aguiar-Silva C, Brandão SE, Domingos M, Bulbovas P (2016) Antioxidant responses of Atlantic Forest native tree species as indicators of increasing tolerance to oxidative stress when they are exposed to air pollutants and seasonal tropical climate. Ecol Indic 63:154–164

Aji MM, Adamu AM, Borkoma MB (2015) Determination of air pollution tolerance index of selected trees in selected locations in Maiduguri. Int J Sci Res Sci Tech 4:249–254

Al Jassir M, Shaker A, Khaliq M (2005) Deposition of heavy metals on green leafy vegerables sold on roadsides of Riyadh City, Saudi Arabia. Bull Environ Contam Toxicol 75:1020–1027

Alharbi B, Pasha M, Tapper N (2014) Assessment of ambient air quality in Riyadh City, Saudi Arabia. Curr World Environ 9:227–237

Alharbi B, Shareef MM, Husain T (2015) Study of chemical characteristics of particulate matter concentrations in Riyadh, Saudi Arabia. Atmos Poll Res 6:88–98

Ali HS, Law SH, Zannah TI (2016) Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO 2 emissions in Nigeria. Environ Sci Pollut Res 23:12435–12443

Arnon DI (1949) Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. Plant Physiol 24:1–15

Bacon MA, Wilkinson S, Davies WJ (1998) ph-regulated leaf cell expansion in droughted plants is abscisic acid dependent. Plant Physiol 118:1507–1515

Bakiyaraj R, Ayyappan D (2014) Air pollution tolerance index of some terrestrial plants around an industrial area. Int J Mod Res Rev 2:1–7

Baraldi R, Neri L, Costa F, Facini O, Rapparini F, Carriero G (2019) Ecophysiological and micromorphological characterization of green roof vegetation for urban mitigation. Urban For Urban Green 41:127–138

Bhattacharya T, Kriplani L, Chakraborty S (2013) Seasonal variation in air pollution tolerance index of various plant species of Baroda City. Univers J Environ Res Technol 3:199–208

Bora M, Joshi M (2014) A study on variation in biochemical aspects of different tree species with tolerance and performance index. Bioscan 9:59–63

Boutraa T (2013) Effects of water stress on root growth, water use efficiency, leaf area and chlorophyll content in the desert Shrub Calotropis procera. J Int Environ App Sci 5:124–132

Bozan B, Sagdullaev BT, Kozar M, Aripov KHN, Baser KHC (1998) Comparison of ascorbic and citric acid contents in Rosa canina L. fruits growing in central Asian region. Chem Nat Compd 34:687–689

Chandawat DK, Verma PU, Solanki HA (2011) Air pollution tolerance index (APTI) of tree species at cross road of Ahmedabad city. Life Sci Leaflets 20:935–943

Chauhan A (2010) Tree as bioindicator of automobile pollution in Dehradun city: a case study. J N Y Sci 3:88–95

Chavan BL, Sonwane NS (2012) Anticipated performance index (API) of some tree species grown in Aurangabad city. Int J Environ Reh Cons 3:9–13

Cheng FY, Burkey KO, Robinson JM, Booker FL (2007) Leaf extracellular ascorbate in relation to O3 tolerance of two soyabean cultivars. Environ Pollut 150:355–362

Cornelissen JHC, Quested HM, Van Logtestijn RSP, Perez-Harguindeguy N, Gwynn-Jones D, Dıaz S, Callaghan TV, Press MC, Aerts R (2006) Foliar pH as a new plant trait: can it explain variation in foliar chemistry and carbon cycling processes among subarctic plant species and types? Oecologia 147:315–326

Cornelissen JGC, Sibma F, Van Logtestijn RSP, Broekman RA, Thompson K (2011) Leaf pH as a plant trait: species-driven rather than soil-driven variation. Funct Ecol 25:449–455

Das S, Prasad P (2010) Seasonal variation in air pollution tolerance indices and selection of plant species for industrial areas of Rourkela. Ind J Environ Prot 30:978–988

Deljanin D, Antanasijevic A, Bjelajac UMA, Nikolic M, Peric-Grujic A, Risti CM (2016) Chemometrics in biomonitoring: distribution and correlation of trace elements in tree leaves. Sci Total Environ 545: 361–371

Dhankhar R, Mor V, Narwal S (2015) Anticipated performance index of selected plant species in university campus area, Rohtak, Haryana, India. Int J Adv Multidiscip Res 2:32–41

Dineva SB (2004) Comparative studies of the leaf morphology and structure of white ash Fraxinus americana L. and London plane tree Platanus acerifolia Willd growing in polluted area. Dendrobiol 52: 3–8

Duong TT, Lee BK (2011) Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manag 92:554–562

Dwivadi AK, Tripathi BD (2007) Pollution tolerance and distribution pattern of plants in surrounding area of coal- fired industries. J Environ Biol 28:257–263

El-Shobokshy M (1985) Atmospheric lead pollution in area of children's school in the city of Riyadh. In: In 78th Annual Meeting. APCA, Detroit

Enete IC, Alabi MO, Chukwudelunzu VU (2012) Tree canopy variation effects on urban heat island in Enugu City, Nigerian. Dev Count Stud 2:12–18

Enete IC, Chukwudeluzu VU, Okolie AO (2013) Evaluation of air pollution tolerance index of plants and ornamental shrubs in Enugu City: implications for urban heat island effect. World Environ 3: 108–115

Geravandia M, Farshadfara E, Kahrizi D (2011) Evaluation of some physiological traits as indicators of drought tolerance in bread wheat genotypes. Russ J Plant Physiol 58:69–75

Giri S, Shrivastava D, Deshmukh K, Dubey P (2013) Effect of air pollution on chlorophyll content of leaves. Curr Agric Res J 1:93–98

Gostin IN (2009) Air pollution effects on the leaf structure of some Fabaceae species. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37:57–63

Govindaraju M, Ganeshkumar RS, Muthukumaran VR, Visvanathan P (2012) Identification and evaluation of air-pollution-tolerant plants around lignite-based thermal power station for greenbelt development. Environ Sci Pollut Res 19:1210–1223

Gupta S, Nayek S, Bhattacharya P (2011) Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index. Chem Ecol 27:381–392

Henson IE, Mahalakshmi V, Bidinger FR, Alagarswamy G (1981) Genotypic variation in pearl miller (Pennisetum americanum L.) Leeke in the ability to accumulate abscisic acid in response on water stress. J Exp Bot 32:899–910

Honour SL, Bell JNB, Ashenden TW, Cape JN, Power SA (2009) Responses of herbaceous plants to urban air pollution: effects on growth, phenology and leaf surface characteristics. Environ Pollut 157:1279–1286

Jahan S, Iqbal MZ (1992) Morphological and anatomical studies of leaves of different plants affected by motor vehicles exhaust. Med J Islamic World Acad Sci 5:21–23

Jim C, Chen WY (2008) Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J Environ Manag 88: 665–676

Joshi PC, Swami A (2009) Air pollution induced changes in the photosynthetic pigment of selected plant species. J Environ Biol 30:295–298

Jyothi SJ, Jaya DS (2010) Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. J Environ Biol 1:379–386

Karthiyayini R, Ponnammal NR, Joseph R (2005) Air pollution tolerance index of certain plants of Coimbatore Ooty highways, near ITI area, Coimbatore, T. N. Poll Reso 24:363–365

Kaur M, Nagpal AK (2017) Evaluation of air pollution tolerance index and anticipated performance index of plants and their application in development of green space along the urban areas. Environ Sci Pollut Res 24:18881–18895

Kaur R, Nayyar H (2014) Ascorbic acid: a potent defender against environmental stresses. In: Ahmad P (ed) Oxidative damage to plants. Academic Press, San Diego, pp 235–287

Khan MGA (2002) Riyadh population to cross 11m by 2020. https://www.arabnews.com/node/225397. Accessed 21 Dec 2018

Kulkarni SD, Ingawale A (2014) Biomonitoring of air pollutionin by correlating the pollution tolerance of some commonly grown trees in Waluj industrial area near Aurangabad, India. Int J Res Environ Sci Tech 4:102–106

Laghari S, Zaidi M (2013) Effect of air pollution on the leaf morphology of common plant species of Quetta city. Pak J Bot 45:447–454

Laghari KS, Zaidi AM, Razaq G (2015) Impact of solid waste burning air pollution on some physio- anatomical characteristics of some plants. Pak J Bot 47:225–232

Leghari SK, Akbar A, Qasim S, Ullah S, Asrar M, Rohail H, Ahmed S, Mehmood K, Ali I (2019) Estimating anticipated performance index and air pollution tolerance index of some trees and ornamental plant species for the construction of green belts. Pol J Environ Stud 28: 1759–1769

Li Y, Wang Y, Wang B, Wang Y, Yu W (2019) The response of plant photosynthesis and stomatal conductance to fine particulate matter (PM2.5) based on leaf factors analyzing. J Plant Biol 62:120–128

Maghrabi AH (2009) Parameterization of a simple model to estimate monthly global solar radiation based on meteorological variables, and evaluation of existing solar radiation models for Tabouk, Saudi Arabia. Energy Conserv Manage 50:2754–2760

Mishra BK, Srivastava JP, Lal JP (2018) Drought resistance in lentil (Lens culinaris Medik.) in relation to morphological, physiological parameters and phenological developments. Int J Curr Microbiol App Sci 7:2319–7706

Modaihsh AS, Al-Barakah FN, Nadeem MEA, Mahjoub MO (2015) Spatial and temporal variations of the particulate matter in Riyadh City, Saudi Arabia. J Environ Prot 6:1293–1307

Modaihsh AS, Mahjoub MO, Nadeem MEA, Ghoneim AM, Al-Barakah FN (2016) The air quality, characterization of polycyclic aromatic hydrocarbon, organic carbon, and diurnal variation of particulate matter over Riyadh City. J Environ Prot 7:1198–1209

Mondal D, Gupta S, Datta JK (2011) Anticipated performance index of some tree species considered for green belt development in an urban area. Plant Sci 2:99–106

Ninova DJ, Dushkova PI, Kovacheva CV (1983) Anatomical, morphological studies of Platanus acerifolia at various degrees of air pollution. Ekologiya (Sofia) 6:35–47

Noor MJ, Sultana S, Fatima S, Ahmad M, Zafar M, Sarfraz M (2015) Estimation of anticipated performance index and air pollution tolerance index and of vegetation around the marble industrial areas of Potwar region: bioindicators of plant pollution response. Environ Geochem Health 37:441–455

Ogunkunle CO, Suleiman LB, Oyedeji S, Awotoye OO, Fatoba PO (2015) Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. Agrofor Syst 89:447–454

Palit D, Kar D, Misra P, Banerjee A (2013) Assessment of air quality using several bio monitor of selected sites of Duragapur, Burdwan district by air pollution tolerance index approach. Indian J Sci Res 4: 149–152

Panda LRL, Aggarwal RK, Bhardwaj DR (2018) A review on air pollution tolerance index (APTI) and anticipated performance index (API). Curr World Environ 13:55–65

Pandey AK, Pandey M, Mishra A, Tiwary SS, Tripathi BD (2015) Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. Urban Fact Urban Green 14:866–871

Pathak V, Tripathi BD, Mishra VK (2011) Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. Urban For Urban Green 10:61–66

Patidar S, Bafna A, Batham AR, Panwar K (2016) Impact of urban air pollution on photosynthetic pigment and proline content of plants growing along the A.B road Indore City, India. Int J Curr Microbiol App Sci 5:107–113

Prajapati SK, Tripathi BD (2008) Anticipated performance index of some tree species considered for green belt development in and around an urban area: a case study of Varanasi city, India. J Environ Manag 88: 1343–1349

Prasad BJ, Rao DN (1982) Relative sensitivity of a leguminous and a cereal crop to sulphur dioxide pollution. Environ Pollut 29:57–70

Rahmawati N, Rosmayati D, Basyuni M (2014) Chlorophyll content of soybean as affected by foliar application of ascorbic acid and inoculation of arbuscular mycorrhizal fungi in saline soil. Int J Sci Technol Res 3:127–131

Rai PK, Panda LLS (2015) Roadside plants as bio indicators of air pollution in an industrial region, Rourkela, India. Int J Adv Res Technol 4:14–36

Ram SS, Majumder S, Chaudhuri P, Chanda S, Santra SC, Maiti PK, Sudarshan M, Chakraborty MA (2014) Plant canopies: biomonitor and trap for re-suspended dust particulates contaminated with heavy metals. Mitig Adapt Strat Glo 19:499–508

Riyadh Green project (2019) http://www.riyadhgreen.sa/en/. Accessed 28 Jul 2019

Roy S, Byrne J, Pickering C (2012) A systematic quantitative review of urbantree benefits, costs, and assessment methods across cities in different climaticzones. Urban For Urban Green 4:351–363

Rushdi AI, Al-Mutlaq KF, Al-Otaibi M, El-Mubarak AH, Simoneit BRT (2013) Air quality and elemental enrichment factors of aerosol particulate matter in Riyadh City, Saudi Arabia. Arab J Geosci 6:585–599

Sanghi SB, Sharma C, Sanghi SK (2015) Comparison of APTI values of some medicinal plants of industrial areas and Ratapani wild life sanctuary in Raisen district of Madhya Pradesh. Int J Pharm Life Sci 6:4157–4160

SAS Institute I (2013) SAS statistical software v. 9.4. SAS Institute, Inc, Cary

Saudi Arabia Vision 2030 (2016) http://vision2030.gov.sa/en. Accessed 20 Jan 2017

Seyyednejad SM, Koochak H (2011) A study on air pollution-induced biochemical alterationsin Eucalyptus camaldulensis. Aus J Basic Appl Sci 5:601–606

Seyyednejad SM, Majdian K, Koochak H, Nikneland M (2011) Air pollution tolerance indices of some plants around industrial zone in south of Iran. Asian J Biol Sci 4:300–305

Shannigrahi AS, Fukushima T, Sharma RC (2004) Anticipated air pollution tolerance of some plant species considered for green belt development in and around an industrial/urban area in India: an overview. Int J Environ Stud 61:125–137

Sharma B, Bhardwaj SK, Sharma S, Nautiyal R, Kaur L, Alam NM (2019) Pollution tolerance assessment of temperate woody vegetation growing along the National Highway-5 in Himachal Pradesh, India. Environ Monit Assess 191:177–185

Shyam S, Verma HN, Bhargava SK (2006) Air pollution and its impact on plant growth. New India Publishing Agency, New Delhi

Singh A (1977) Practical plant physiology. Air pollution tolerance indices (APTI) of some plants. Kalyari Publishers, New Delshi

Singh SK, Rao DN (1983) Evaluation of plants for their tolerance to air pollution. In: In: Proceedings Symposium on Air Pollution Control, 1st edn. Indian Association for Air Pollution Control, New Delhi, pp 218–224

Singh SK, Rao DN, Agrawal M, Pandey J, Narayan D (1991) Air pollution tolerance index of plants. J Environ Manag 32:45–55

Swami A, Bhatt D, Joshi PC (2004) Effects of automobile pollution on sal (Shorea robusta) and rohini (Mallotus phillipinensis) at Asarori, Dehradun. Himal J Environ Zool 18:57–61

The General Authority for Statistics (GAStat) (2018) Population in Riyadh region by gender, age group, and nationality (Saudi/Non-Saudi) - Mid 2018 A.D, Preliminary estimates the middle of the year based on demographic survey 2016. https://www.stats.gov.sa/en/1007–0. Accessed 28 Dec 2018

Tiwari S, Agrawal M, Marshall FM (2006) Evaluation of ambient air pollution impact on carrot plants at a sub urban site using open top chambers. Environ Monit Assess 119:15–30

Tripathi AK, Gautam M (2007) Biochemical parameters of plants as indicators of air pollution. J Environ Biol 28:127–132

Tsega YC, Prasad AGD (2014) Variation in air pollution tolerance index and anticipated performance index of roadside plants in Mysore, India. J Environ Biol 35:185–190

Van Volkenburgh E, Boyer JS (1985) Inhibitory effects of water deficit on maize leaf elongation. Plant Physiol 77:190–194

Verma A, Singh SN (2006) Biochemical and ultrastructure changes in plant foliage exposed to autopollution. Environ Monit Assess 120: 585–602

Weerakkody U, Dover JW, Mitchell P, Reiling K (2017) Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. Urban For Urban Green 27:173–186

Wolch JR, Byrne J, Newell JP (2014) Urban green space, public health, and environmental justice: the challenge of making cities “just green enough”. Landsc Urban Plan 125:234–244