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Comparative Assessment of Pollution Indices of Selected Tree Species in Urban, Industrial, Institutional and Agricultural Setups at Sonipat, Haryana, India

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ABSTRACT

The Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of *Azadirachta indica, Ficus benghalensis,* and *Ficus religiosa* were compared to assess their tolerance to air pollution in different environmental setups. The study was conducted at six different locations with different environmental setups, including Urban, Industrial, Institutional and Agricultural. The parameters used for APTI were pH, relative water content, total chlorophyll content, and ascorbic acid content in the leaves, while API was calculated using APTI along with the socio-economic characteristics of the targeted species. Three species were selected, with nine replicates of each species from each setup (i.e., ٦×٩×٣, which means a total of 162 samples) were analyzed for APTI during the winter season, when there is a lower mixing height that prevents the dispersion of pollutants and makes the environment highly polluted, and trees show high tolerance in a polluted environment. The APTI values of all the targeted species were higher in industrial setups than in the other environmental setups, i.e., 20.42 ± 1.65 for *A. indica,* 14.75 ± 0.53 for *F. benghalensis,* and 13.39 ± 1.11 for *F. religiosa*. The sample t-test showed a significant difference in the APTI of the industrial setup and other setups (p=0.0000). A. indica was found to be a tolerant species, and *F. benghalensis* and *F. religiosa* were intermediate-tolerant species based on APTI. F. *benghalensis* and *F. religiosa* fall under the excellent and *A. indica* falls under the very good category based on API. Based on these two indices, the best tree species were identified for plantation and the abatement of air pollution in industrial areas.

INTRODUCTION

Rapid industrialization and unplanned urbanization have greatly increased air pollution, necessitating the use of natural alternatives for sustainable urban environmental management (Alotaibi et al. 2020). Plants play an important role in improving air quality by acting as sinks for air pollutants. They act as living filters and remove particulate matter (PM) from the air (Roy et al. 2024). Without causing foliar damage, plants remove air contaminants through adsorption, absorption, detoxification, metabolization, and heavy metal accumulation (Li et al. 2023, Sumathi et al. 2023). However, plants not only purify the air by bio-filtering contaminants through adsorption, absorption, and impingement (Escobedo et al. 2008) but also have a positive impact on the water quality and soil of that area, in addition to adding aesthetic value to it (Pradhan et al. 2016). A few trees exhibit tolerant behavior towards a particular air pollutant, whereas a few are sensitive to it. Tolerant species are appropriate for plantations, and sensitive species are used as bio-monitors and bioindicators to provide qualitative and quantitative information on the surroundings (Choudhury et al. 2009). Certain species are good indicators of atmospheric pollution, whereas others are good accumulators based on their physiological responses (Simon et al. 2021). Plants have been indirectly affected by soil acidification, whereas particulate and gaseous pollutants have a direct effect on many physiological, morphological, and biological characteristics of trees (Steubing et al. 1989, Sharma et al. 2013).

APTI was developed by Singh & Rao in 1983, using the aggregation of four biochemical parameters, namely, leaf chlorophyll content, leaf extract pH, Relative Water Content (RWC), and Ascorbic Acid (AA) content. Chlorophyll is a food-producing factory and an important indicator of plant health (Ebrahimi et al.2023). Leaf pH directs the photosynthetic efficiency of trees, and relative water content facilitates transpiration and provides a cooling sensation to trees (Gonzalez et al. 2001). AA is the primary defense factor, and it works against many oxidative damages to trees during water stress conditions, and also helps in cell division and synthesis of the cell wall. Plants experience physiological changes before showing visible changes in leaves (Dohmen et al. 1990). These include changes in stomatal properties, modifications to metabolic products, effects on gas exchange and photosynthetic activity, and effects on plant growth (Roy et al. 2024).

The analysis of biophysical parameters of tree species helps in determining the tolerance level of trees. Many different researchers highly praise the APTI due to its combination of multiple parameters providing a more trustworthy outcome than any research that relies just on one parameter (Sahu et al. 2020, Bharti et al. 2018, Balasubramanian et al. 2018).

People frequently use plants for various reasons. Trees, shrubs, and hedges are examples of urban green systems that improve air quality at the city level by acting as barriers and sponges for airborne pollutants (Yu et al. 2022). Thus, choosing plants solely based on their tolerance to air pollution and recommending them for planting could result in failure to manage these plants and ensure their survival. An improved calculation, known as the Anticipated Performance Index (API), was developed by Moore et al. (1986) by combining biochemical parameters (similar to the APTI) with the pertinent biological and socioeconomic characteristics of a species (Raza et al. 1988, Mondal et al. 2011). Consequently, this index serves as a perfect and more trustworthy resource for suggesting plant species for modern landscaping projects.

Balasubramanian et al. (2018) performed a study in Tamil Nadu, India, based on the assessment of APTI of trees in different zones, i.e., Residential, Industrial, Commercial, Heavy traffic zone and control zone and identified the tolerant species for combating air pollution in the different zones. According to a study conducted by Roy et al. (2020) in Jharkhand, *A. Indica* and *F. religiosa* were identified as tolerant, and *F. benghalensis* was identified as intermediately tolerant in the industrial environment, Commercial and Control setups. *F. benghalensis*, *F. religiosa* and *A. indica* were identified as tolerant species towards air pollution based on APTI at the control and polluted site in Lucknow (Bharti et al. 2018). Another study by Sahu et al. 2020 at Sambalpur in polluted and control setups reported *F. religiosa*, *F. benghalensis* and *A. indica* as excellent species based on API. Although some studies have been conducted across various parts of the country, a similar assessment is not available for the Sonipat area. However, the same is an industrial area along with a variety of environmental setups and near the capital Delhi, which is the world's most polluted region. Thus, there is a need to work in different environments of Sonipat for the assessment of APTI because few studies have been conducted in this field.

The current study was conducted to determine the tolerance of selected tree species (*A. indica, F. benghalensis, and F. religiosa*) towards air pollution in variable environmental setups in the Sonipat district using their APTI and API. However, various studies based on APTI have been conducted in different areas with multiple species, but no literature is available for comparison of tree species grown in an Agricultural setup along with Industrial, Urban and Institutional setups. This study focuses on the analysis of changes in the above-mentioned parameters in different environmental setups and finding the best species for plantation. The identification of tolerant tree species is helpful for greenbelt development in industrial areas. The objective of the study is to compare the APTI and API of three selected tree species in urban, Industrial, Institutional and agricultural setups. To study the impact of air pollution on the biochemical parameters of selected tree species. To compare the API values of selected tree species for air pollution reduction.

MATERIALS AND METHODS

Study Area

The APTI of *Ficus religiosa*, *Ficus benghalensis,* and *Azadirachta indica* was calculated for different environmental setups, including Urban, Industrial, Institutional and Agricultural, in Sonipat district of Haryana, India. Fig. 1 shows the locations of the sampling sites and images of the tree species studied. The district was bounded by 28°48'15" to 29°17'10" North latitude and 76°28'40" to 77°12'45" East longitude. The district is located in the National Capital Region, and the climate of the region is semi-arid with hot and dry summers. The samples were collected in January–February, when there is a lower mixing height that prevents the dispersion of pollutants and makes the environment highly polluted (Murthy et al. 2020). Based on LULC Sonipat has around 87% Agricultural land (185000 ha), 5% Built-up (10716.12 ha), 3.47% Forest (7359 ha), 3.56% Waste land (7556 ha), 0.64% Water bodies (1357.87 ha), 0.10% Others (211 ha) of the total 2,12,200 ha area (TCP, Haryana, Interim Report II, 2021).

Sampling of Trees

A field survey was conducted randomly, and leaf samples were collected along with the tree locations. *Ficus religiosa, Ficus benghalensis,* and *Azadirachta indica* were identified as tolerant trees based on previous studies and were considered for further analysis. All three tree species are called "Triveni" in India and are sacred trees; therefore, they are locally available at all the sampling sites, and people avoid commercial cutting of these trees. *Azadirachta indica* and *Ficus benghalensis* are evergreen species, whereas *Ficus religiosa* is a semi-evergreen species. In addition, their leaf size and canopy structure increase their ability to reduce pollution (Yadav et al. 2020). All species are considered tolerant based on a literature review in different areas with different seasons and environments (Enitan et al. 2022, Roy et al. 2020). Nine individual trees of each species were selected from each setup. Fully matured leaves were randomly collected at 6:00 to 8:00 am to avoid variability due to environmental changes, to stabilize metabolic activity, to ensure high turgor pressure, and to reduce the diurnal fluctuations, as the fresh weight of leaves is important to calculate, and these factors make measurements more reliable (Weatherley 1951). The leaves were packed in sealed polythene bags and transported to the laboratory without delay. The fresh weights of the leaves were measured, and the samples were preserved at 4°C. Composite leaf samples were prepared for each tree and analyzed.

Biochemical Analysis

Relative Water Content (RWC)

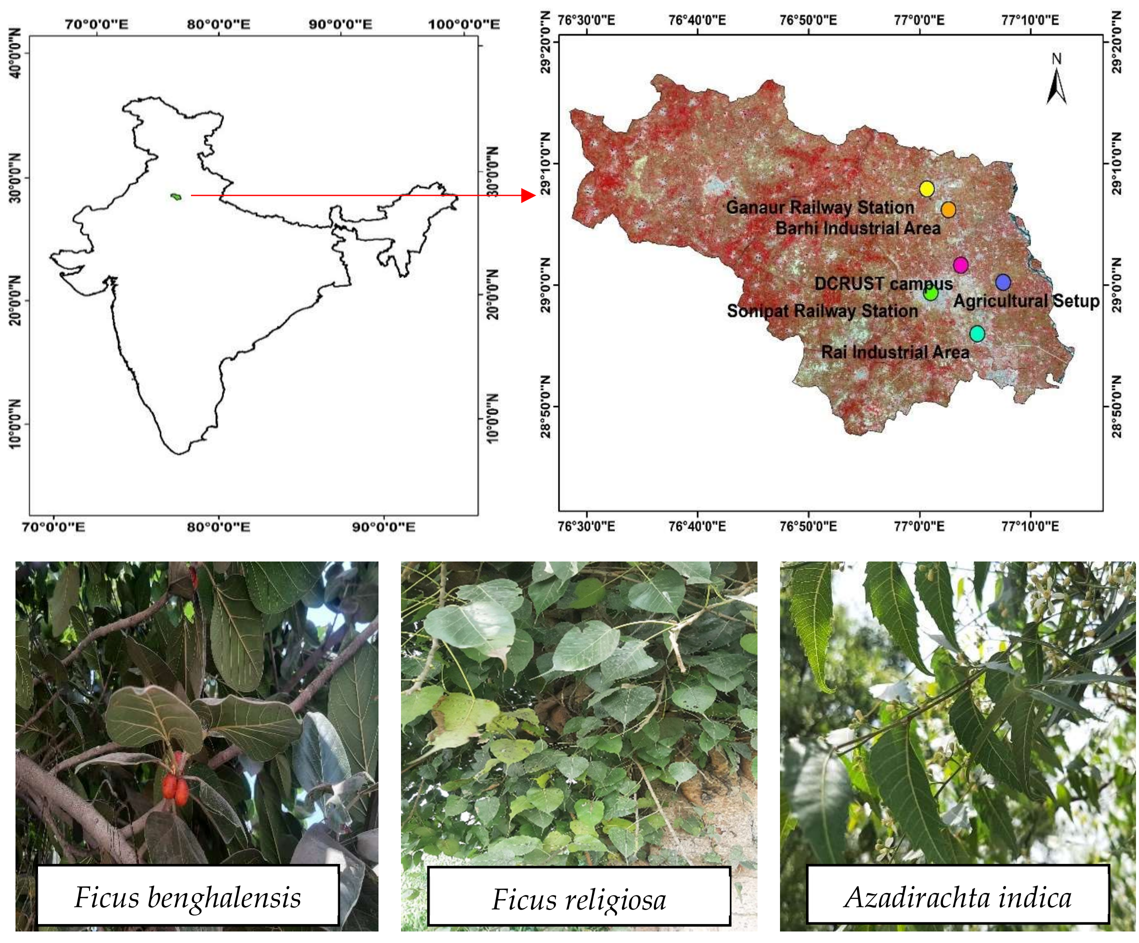

Fig. 1: Location of the sampling sites at district Sonipat, Haryana, India and photos of tree species studied.

The fresh weight (FW) of the leaves was determined by weighing the fresh leaves. The leaves were immersed in water overnight, blotted dry, and the turgid weight (TW) of the leaves was measured. The leaves were dried overnight in an oven at 70 °C, and the dry weight (DW) was measured. Leaf RWC was calculated using Eq. 1, given by Singh et al. 1983.

$$RWC = \frac{(Fresh\ Weight - Dry\ Weight)}{(Turgid\ Weight - Dry\ Weight)} \times 100 \qquad \ldots(1)$$

Leaf Extract pH

Fresh leaf samples (5 g) were crushed and homogenized in 50 mL of deionized water, and the mixture was centrifuged. The supernatant was collected, and the pH was measured using a pH meter (HQ 40d) (Rai et al. 2014).

Total Chlorophyll Content (TCh)

One gram of fresh leaves was ground and extracted with 10 mL of 80% acetone. The extract was left for 15 min and centrifuged at 2500 rpm for 3 min. The supernatant was collected, and the absorbance was measured at 645 and 663 nm using a spectrophotometer (Shimadzu UV-2600i). Calculations were performed using Eq. 2 (Jain et al. 2019).

$$Total\ Chlorophyll\ (mg.g) = 20.2A_{645} + 8.02A_{663} \times \frac{V}{1000W} \qquad \ldots(2)$$

Ascorbic Acid (AA)

The ascorbic acid content was determined using the modified calorimetric 2,6-dichlorophenol indophenol method described by Roy et al. (2020). 2.5 g sample was extracted in 4% oxalic acid, made up to a known volume (25 mL), and centrifuged at 2500 rpm for 5 min. Five milliliters of the supernatant was pipetted out, and 10 mL of oxalic acid was added and titrated against the dye. The calculations were performed using Eq. 3.

$$Ascorbic\ acid\ (mg/g) = \frac{0.5mg \times V_2 \times 25mL}{v_1\ ml \times 5\ ml \times wt\ of\ the\ sample} \qquad \ldots(3)$$

Where,

V1 = Volume of dye titrated against the working standard

V2 = Volume of dye titrated against the sample

Table 1: Standard of gradation level for APTI and response (Singh et al.1991, Bharti et al.2018).

Sr. No.	APTI	Category
1.	≤ 11	Sensitive
2.	12-16	Intermediate Tolerant
3.	≥ 17	Tolerant

APTI and API calculations

Based on the calculations of the above parameters, the APTI was calculated using the formula proposed by Singh et al. (1983).

Table 2: Gradation of plants based on APTI and Biological and Socioeconomic characters (Noor et al. 2015, Sahu et al. 2020).

Grading Character	Parameters	Pattern of Assessment	Grade Allotted
Tolerance	Air Pollution Tolerance Index	<7	-
		7-9	+
		9-11	++
		11-13	+++
		13-15	++++
		15-17	+++++
Biological and Socioeconomic	Plant Habit	Small	-
		Medium	+
		Large	++
	Canopy structure	Sparse/Irregular/Globular	-
		Spreading crown/Open/Semi-dense	+
		Spreading Dense	++
		Deciduous	-
	Type of Plant	Evergreen	+
		Small	-
	Laminar Structure	Medium	+
	-Size	Large	++
		Smooth	-
	-Texture	Coriaceous	+
		Delineate	-
	Hardness	Hardy	+
		Less than three uses	-
	Economic Value	Three or four uses	+
		Five or more uses	++

Table 3: Anticipated Performance Index (API) of plant species.

Grade	Score [%]	Assessment Category
0	Up to 30	Not Recommended
1	31-40	Very Poor
2	41-50	Poor
3	51-60	Moderate
4	61-70	Good
5	71-80	Very Good
6	81-90	Excellent
7	91-100	Best

$$APTI = \frac{A \times (T+P)+R}{10} \quad \ldots(4)$$

Where A is the ascorbic acid content (mg.g^{-1}), T- Total chlorophyll content (mg.g^{-1}), P is the leaf extract pH, and R-Relative water content (%). Furthermore, the APTI values of the trees were classified according to Singh et al. (1991) (Table 1).

API of plant species was calculated using a combination of APTI and socio-economic and biological characteristics. This method was proposed by Moore et al. (1986). Table 2 shows the gradation of plants based on APTI and their biological and socio-economic characteristics. Based on these characteristics, different grades (+/-) were assigned to the plant species, and the API score was calculated. The criteria used for the API calculation are listed in Table 3 (Mondal et al. 2011).

$$API = \frac{No.\,of\ '+'obtained}{Total\,No.\,of\ '+'} \times 100 \quad \ldots(5)$$

Statistical Analysis

The APTI values were statistically analyzed using a two-sample t-test (assuming equal variance) for all three species to identify whether there is a significant difference between the APTI values of the industrial setup (Barhi industrial area and Rai industrial area) and other setups, including the urban setup (Ganaur railway station and Sonipat railway station), institutional setup (DCRUST campus, Murthal), and agriculture-dominated regions. The statistical assessment showed a significant difference (p=0.0000) in APTI. The significant statistical difference between trees in industrial and other setups indicates that the trees in industrial areas show higher APTI values; therefore, these trees are preferred for greenbelt and urban planning. Green belts occur as a buffer between industrial zones and residential spaces; thus, significant differences in p-values lead planners to choose specific plant species.

RESULTS AND DISCUSSION

The current study focused on identifying tolerant species and assessing their tolerance potential in varying environmental setups, including urban (Ganaur railway station and Sonipat railway station), industrial (Barhi industrial area and Rai industrial area), institutional (DCRUST campus), and agricultural setups. The criteria used for the identification of tolerant species were the APTI and API. APTI uses four parameters, including AA, pH, TCh, and RWC, to assess trees. It has been observed that APTI alone is not adequate for the selection of tolerant species for the establishment of green belt development. Therefore, the API grade was calculated based on the APTI socio-economic and biological characteristics of trees (Noor et al. 2015). The four important parameters react differently for different environmental setups, even if they are assessed for the same species.

The variations in the RWC among all setups are listed in Table 4. RWC varied significantly from 76.03 ± 5.24% to 83.82 ± 4.72% for all setups. The maximum RWC was recorded at 83.82% in the agricultural setup for *F. religiosa,* and the minimum RWC was recorded at 76.03% in the urban setup (Ganaur Railway Station) for *A. indica*. The values recorded for *A. indica* were 76.03 ± 5.24 %, 76.59 ± 2.61%, 76.86 ± 2.58 %, 77.21 ± 1.65 %, 78.61 ± 4.60 %, and 78.23 ± 5.64 % at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area, and Agricultural setup, respectively. The values recorded for *F. benghalensis* were 80.76 ± 2.30, 80.06 ± 5.38, 82.45 ± 4.06, 81.01 agricultural, 81.46 ± 3.90 and 80.70 ± 12.21 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area, and Agricultural setup, respectively. The values recorded for *F. religiosa* were 82.64 ± 3.33, 83.06 ± 3.83, 83.55 ± 2.82, 83.01 ± 3.12,, 83.5agricultural 83.82 ± 4.72 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and agricultural setup respectively. Relative water content (RWC) helps maintain physiological balance in trees under stress. Plants with high RWC have higher transpiration rates and are more resilient to pollution (Jyothi et al. 2010). Trees with higher RWC have improved water retention capabilities and can support metabolic functions even when water loss is increased due to pollution (Kamal et al. 2024). A reduction in RWC might signal water stress, potentially resulting in drought-like conditions even when sufficient water is available (Zeeshan et al. 2024). A tree's capacity to sustain elevated RWC under pollution stress is frequently a crucial characteristic of its pollution tolerance (Li et al. 2024). In the present study, the RWC of *A. indica*, *F. benghalensis,* and *F. religiosa* at polluted sites was higher, indicating that these tree species have adapted effectively. High soil moisture content is also linked to high leaf RWC (Das et al. 2010, Sahu et al. 2020). A greater RWC indicates a plant's ability to withstand air pollution (Paulsamy et al. 2011). Under stress conditions,

Table 4: APTI of *Azadirachta indica*, *Ficus benghalensis* and *Ficus religiosa*.

Setup	Species	A [mg.g^{-1}]	T [mg.g^{-1}]	P	R [%]	APTI	Category
Ganaur Railway Station (Urban)	*Azadirachta indica*	9.00 ± 0.39	1.02 ± 0.63	6.41 ± 0.10	76.03 ± 5.24	14.29 ± 0.48	Intermediate Tolerant
	Ficus benghalensis	4.46 ± 0.64	1.20 ± 0.53	8.33 ± 0.12	80.76 ± 2.30	12.30 ± 0.56	Intermediate Tolerant
	Ficus religiosa	4.82 ± 0.63	1.08 ± 0.22	8.25 ± 0.12	82.64 ± 3.33	12.75 ± 0.67	Intermediate Tolerant
Sonipat Railway Station (Urban)	*Azadirachta indica*	8.16 ± 0.54	1.29 ± 0.30	7.73 ± 0.09	76.59 ± 2.61	15.02 ± 0.58	Intermediate Tolerant
	Ficus benghalensis	5.10 ± 0.60	1.55 ± 0.32	7.51 ± 0.08	80.06 ± 5.38	12.63 ± 0.75	Intermediate Tolerant
	Ficus religiosa	5.14 ± 0.62	1.18 ± 0.49	8.40 ± 0.17	83.06 ± 3.83	13.18 ± 0.93	Intermediate Tolerant
DCRUST Campus (Institutional)	*Azadirachta indica*	11.73 ± 0.76	0.86 ± 0.42	6.80 ± 0.09	76.86 ± 2.58	16.67 ± 0.74	Intermediate Tolerant
	Ficus benghalensis	5.77 ± 0.74	1.04 ± 0.37	7.39 ± 0.13	82.45 ± 4.06	13.13 ± 0.67	Intermediate Tolerant
	Ficus religiosa	4.78 ± 0.48	0.83 ± 0.21	8.57 ± 0.15	83.55 ± 2.82	12.85 ± 0.57	Intermediate Tolerant
Barhi Industrial Area	*Azadirachta indica*	14.08 ± 0.80	1.42 ± 0.27	6.66 ± 0.16	77.21 ± 1.65	19.13 ± 0.93	Tolerant
	Ficus benghalensis	6.81 ± 0.51	1.46 ± 0.27	8.22 ± 0.49	81.01 ± 4.04	14.67 ± 0.3	Intermediate Tolerant
	Ficus religiosa	4.73 ± 0.56	1.17 ± 0.26	7.76 ± 0.42	83.01 ± 3.12	12.52 ± 0.37	Intermediate Tolerant
Rai Industrial Area	*Azadirachta indica*	15.75 ± 0.92	1.40 ± 0.37	7.39 ± 0.12	78.61 ± 4.60	21.70 ± 1.08	Tolerant
	Ficus benghalensis	7.23 ± 0.41	1.14 ± 0.74	7.68 ± 0.07	81.46 ± 3.90	14.85 ± 0.75	Intermediate Tolerant
	Ficus religiosa	6.05 ± 0.77	1.42 ± 0.68	8.50 ± 0.15	83.57 ± 2.69	14.50 ± 0.60	Intermediate Tolerant
Agricultural	*Azadirachta indica*	12.46 ± 0.77	1.26 ± 0.50	7.61 ± 0.13	78.23 ± 5.64	18.89 ± 0.80	Tolerant
	Ficus benghalensis	4.60 ± 0.67	1.18 ± 0.50	7.79 ± 0.12	80.70 ± 3.67	12.21 ± 0.55	Intermediate Tolerant
	Ficus religiosa	4.29 ± 0.64	1.21 ± 0.27	7.86 ± 0.21	83.82 ± 4.72	12.09 ± 0.57	Intermediate Tolerant

(A= Ascorbic acid content, T = Total Chlorophyll content, P = pH, R = Relative Water content).

RWC plays an important role in regulating physiological balance (Tsega et al. 2014). The high RWC in the agricultural setup was probably due to the high soil moisture content (Huang et al. 2020).

pH varied significantly from 6.41 ± 0.10 to 8.57 ± 0.15 in all setups. The maximum pH was recorded as 8.57 at the institutional setup (DCRUST Campus) for *F. religiosa,* and the minimum pH was recorded as 6.41 at the urban setup (Ganaur Railway Station) for *A. indica*. The values recorded for *A. indica* were 6.41± 0.10, 7.73 ± 0.09, 6.80 ± 0.09, 6.66 ± 0.16, 7.39 ± 0.12 and 7.61 ± 0.13 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively. The values recorded for *F. benghalensis* were 8.33 ± 0.12, 7.51 ± 0.08, 7.39 ± 0.13, 8.22 ± 0.49, 7.68 ± 0.07 and 7.79 ± 0.12 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively. The values recorded for *F. religiosa* were 8.25 ± 0.12, 8.40 ± 0.17, 8.57 ± 0.154, 7.76 ± 0.42, 8.50 ± 0.15 and 7.86 ± 0.21 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively. The variations in pH among all setups are listed in Table 4. Variability in leaf pH was observed across all sites. A change in pH can impact the chemical composition of tree tissues, affecting the availability of nutrients, water absorption, and enzyme function (Weintraub et al. 2007). Trees that can withstand fluctuations in pH or maintain their tissues at an ideal pH are more resilient to pollution (Gopamma et al. 2024). For instance, certain trees may adjust their root exudates to change the soil pH or sustain nutrient absorption during stressful conditions (Sun et al. 2024). The difference in leaf pH is due to variations in species and other environmental conditions, including air pollutants (Sahu et al. 2020). *A. indica* exhibited both acidic (< 7) and basic (>7) pH. An acidic pH was found at the Ganaur railway station, DCRUST Campus, and Barhi industrial area, whereas a basic pH was found at the Sonipat railway station, Rai industrial area, and agricultural setup. Both *F. benghalensis* and *F. religiosa* exhibited a basic pH (> 7) at all sites/setups. Leaf pH affects AA synthesis in trees. Dubey et al. (2023) reported that areas with high pollution show low pH. At higher pH, the AA content is also higher in trees, which increases their tolerance to air pollution (Sahu et al. 2020, Paulsamy et al. 2009). However, *F. benghalensis* and *F. religiosa* exhibited a contradictory response, with higher pH values in highly polluted areas. The basic pH in the Industrial setup for *F. benghalensis* and *F. religiosa* has been reported in the current study, and the same results were also reported by Bharti et al. (2018) at the Industrial site in Lucknow for *F. religiosa* and *F. benghalensis*. The low pH (for all the target species) in the Barhi industrial area is due to the high pollution load, as reported by CSE INDIA. (2020) and contributed approximately 37% of the total pollution loading compared to the Rai industrial area, which contributed only 1% and showed a high (basic) pH value.

Variations in TCh among all setups for *A. indica*, *F. benghalensis,* and *F. religiosa* are presented in Table 4. The TCh content varied significantly from 0.83 ± 0.21 $mg.g^{-1}$ to 1.55 ± 0.32 $mg.g^{-1}$ across all setups. The maximum TCh was recorded at 1.55 $mg.g^{-1}$ at the urban setup (Sonipat Railway Station) for *F. benghalensis,* and the minimum TCh was recorded at 0.83 $mg.g^{-1}$ at the institutional setup (DCRUST Campus) for *F. religiosa*. The values recorded for *A. indica* were 1.02± 0.63 $mg.g^{-1}$, 1.29 ± 0.30 $mg.g^{-1}$, 0.86 ± 0.42 $mg.g^{-1}$, 1.42 ± 0.27 $mg.g^{-1}$, 1.40 ± 0.37 $mg.g^{-1}$, and 1.26 ± 0.50 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area, and Agricultural setup, respectively. The values recorded for *F. benghalensis* were 1.20 ± 0.53 $mg.g^{-1}$, 1.55 ± 0.32 $mg.g^{-1}$, 1.04 ± 0.32 $mg.g^{-1}$, 1.04 ± 0.37 $mg.g^{-1}$, 1.46 ± 0.27 $mg.g^{-1}$ and 1.18 ± 0.50 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup respectively. The values recorded for *F. religiosa* were 1.08 ± 0.22 $mg.g^{-1}$, 1.18 ± 0.49 $mg.g^{-1}$, 0.83 ± 0.21 $mg.g^{-1}$, 1.17 ± 0.26 $mg.g^{-1}$, 1.42 ± 0.68 $mg.g^{-1}$ and 1.21 ± 0.27 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup respectively.

An increase in TCh with an increase in pollution indicates plant tolerance and resistance to pollution (Singh et al. 2007). In the present study, species in the industrial setup exhibited more chlorophyll than those in the other setups, indicating that these species were pollution-resistant. Similar results for an increase in chlorophyll content in polluted sites in *A. indica*, *F. benghalensis* and *F. religiosa* were observed by Zahid et al. (2023), Sahu et al. (2020), and Bharti et al. (2018). Kammerbauer et al. 2000 showed that the synthesis of photosynthetically active pigments was increased by 15% due to gaseous exhaust. High values of chlorophyll content in polluted setups might be the reason for the higher ascorbic acid content in trees at polluted setups. This is due to the close relationship with ascorbic acid content, which is mostly concentrated in chloroplasts (Liu et al. 2008). Higher chlorophyll content at the polluted sites is due to the mechanism that favors tolerance towards pollution (Ogunkunle et al. 2015). Elevated chlorophyll concentrations assist trees in sustaining photosynthesis, even when faced with stress. In environments impacted by pollution, trees may produce extra chlorophyll to offset diminished light absorption or harm caused by pollutants (Cessna et al. 2010). However, a drop in chlorophyll might be a sign of stress and a diminished ability to photosynthesize, which could restrict the tree's ability to grow and reproduce (Sembada et al. 2024).

Photosynthesis is strongly related to the pH of leaves and decreases with a decrease in leaf pH (Türk et al. 1975). Because both pH and TCh are highly correlated and differently affected by AA, the pH of the leaf extract (P) and TCh (T) were combined and multiplied by the AA content in the suggested APTI formula (Liu et al. 2008).

AA varied significantly from 4.29 ± 0.64 $mg.g^{-1}$ to 15.75 ± 0.92 $mg.g^{-1}$ in all setups. The maximum AA was recorded as 15.75 $mg.g^{-1}$ at Rai Industrial area for *A. indica,* and the minimum AA was recorded as 4.29 $mg.g^{-1}$ at Agricultural Setup in *F. religiosa*. The values recorded for *A. indica* were 9 ± 0.39 $mg.g^{-1}$, 8.16 ± 0.54 $mg.g^{-1}$, 11.73 ± 0.76 $mg.g^{-1}$, 14.08 ± 0.80 $mg.g^{-1}$, 15.75 ± 0.92 $mg.g^{-1}$ and 12.46 ± 0.77 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup respectively. The values recorded for *F. benghalensis* were 4.46 ± 0.64 $mg.g^{-1}$, 5.10 ± 0.60 $mg.g^{-1}$, 5.77 ± 0.74 $mg.g^{-1}$, 6.81 ± 0.51 $mg.g^{-1}$, 7.23 ±

Table 5: API of different tree species in different environmental setups at the district Sonipat.

Setup	APTI	Habitat	Canopy	Type	Size	Texture	Hardness	Economic value	Total "+"	% score	API grade	Assessment category
Azadirachta indica												
Ganaur Railway Station (Urban)	++++	++	++	-	-	-	+	++	11	68.75	4	Good
Sonipat Railway Station (Urban)	+++++	++	++	-	-	-	+	++	12	75	5	Very Good
DCRUST Campus (Institutional)	+++++	++	++	-	-	-	+	++	12	75	5	Very Good
Barhi Industrial Area	+++++	++	++	-	-	-	+	++	12	75	5	Very Good
Rai Industrial Area	+++++	++	++	-	-	-	+	++	12	75	5	Very Good
Agricultural	+++++	++	++	-	-	-	+	++	12	72	5	Very Good
Ficus benghalensis												
Ganaur Railway Station (Urban)	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
Sonipat Railway Station (Urban)	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
DCRUST Campus (Institutional)	++++	++	++	+	+	+	+	++	14	87.5	6	Excellent
Barhi Industrial Area	++++	++	++	+	+	+	+	++	14	87.5	6	Excellent
Rai Industrial Area	++++	++	++	+	+	+	+	++	14	87.5	6	Excellent
Agricultural	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
Ficus religiosa												
Ganaur Railway Station (Urban)	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
Sonipat Railway Station (Urban)	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
DCRUST Campus (Institutional)	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
Barhi Industrial Area	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent
Rai Industrial Area	++++	++	++	+	+	+	+	++	14	87.5	6	Excellent
Agricultural	+++	++	++	+	+	+	+	++	13	81.25	6	Excellent

0.41 $mg.g^{-1}$ and 4.60 ± 0.67 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup respectively. The values recorded for *F. religiosa* were 4.82 ± 0.63 $mg.g^{-1}$, 5.14 ± 0.62 $mg.g^{-1}$, 4.78 ± 0.48 $mg.g^{-1}$, 4.73 ± 0.56 $mg.g^{-1}$, 6.05 ± 0.77 $mg.g^{-1}$ and 4.29 ± 0.64 $mg.g^{-1}$ at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup respectively. The variations in the AA among all setups are listed in Table 4. Ascorbic acid content is higher in industrial setups, as AA shows a positive relationship with SO2 and NOx. Under pollution stress, the production of reactive oxygen species increases the production of AA, which in turn scavenges ROS and prevents the tree from oxidative stress (Bhattacharya et al.2013). Elevated ascorbic acid levels protect essential cellular processes by reducing oxidative damage caused by contaminants in trees (Wang et al. 2012). A tree's ability to prevent or repair damage to its photosynthetic apparatus and other cellular components increases with its antioxidant concentration. Conversely, lower levels of ascorbic acid indicate a diminished ability to fight oxidative stress, making one more vulnerable to harm brought on by pollution (Sharma et al. 2012).

Among all three species *A. indica* has the highest AA content. Our results were in agreement with studies conducted by Jain et al. (2019), Sahu et al. (2020), and Prajapati et al. (2008). They found higher values of AA content in *A. indica*. The findings by Gupta et al. (2016), Ogunkunle et al. (2015), Pandey et al. (2015), and Rai et al. (2014) suggested that AA content increases with an increase in pollution level.

Variations in APTI among all setups for *A. indica*, *F. benghalensis* and *F. religiosa* are given in Table 4. APTI varied significantly from 21.70 ± 1.08 to 12.09 ± 0.57 at all setups. Maximum APTI was recorded 21.70 at Rai Industrial Area for *A. indica,* and minimum APTI was recorded 12.09 at the Agricultural setup in *F. religiosa*. The values recorded for *A. indica* were 14.29 ± 0.48, 15.02 ± 0.58, 16.67 ± 0.74, 19.13 ± 0.93, 21.70 ± 1.08 and 18.89 ± 0.80 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively. The values recorded for *F. benghalensis* were 12.30 ± 0.56, 12.63 ± 0.75, 13.13 ± 0.67, 14.67 ± 0.3, 14.85 ± 0.75 and 12.21 ± 0.55 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively. The values recorded for *F. religiosa* were 12.75 ± 0.67, 13.18 ± 0.93, 12.85 ± 0.57, 12.52 ± 0.37, 14.50 ± 0.60 and 12.09 ± 0.57 at Ganaur Railway station, Sonipat Railway station, DCRUST campus, Barhi Industrial area, Rai Industrial area and Agricultural setup, respectively.

The APTI values were increased in polluted setups. A high APTI value indicates a great defense mechanism against air pollution. Various researchers used the APTI to categorize trees into three categories, i.e., sensitive, intermediate and tolerant. Trees with APTI values $\leq$ 11 are categorized as sensitive, 12-16 are considered intermediate, and $\geq$17 are termed as tolerant (Singh et al. 1991). Present findings suggested that *A. indica* is tolerant, and *F. benghalensis* and *F. religiosa* are considered intermediately tolerant. The present study showed that *A. indica* was a very good performer, and *F. benghalensis* and *F. religiosa* were excellent performers in all setups. Table 5 shows the percentage scores and API values of the selected trees in the different setups.

API accounts for both socioeconomic and biochemical parameters. Various parameters, including plant type, leaf size, canopy structure, plant height, plant habit, laminar texture, and economic value, also contribute to the capacity of plants to reduce pollution (Prajapati et al. 2008). The API was calculated based on these factors and the APTI. Different tree species have different API grades based on these factors. Trees with the highest API scores are highly recommended for the development of green belts. The current study showed that *F. benghalensis* and *F. religiosa* are excellent species, and *A. Indica* falls under the very good category based on the API score. Species with high API grades are recommended for plantation in urban areas because of their high socio-economic and aesthetic value. These species have dense canopies and are evergreen, and are known for their economic, medicinal, and aesthetic values. (Enitan et al. 2022).

Green belts with tolerant tree species act as a natural air filter (Tomson et al. 2021). Greenbelts also serve as cycling and pedestrian corridors, promoting active transport while mitigating pollution. (Thompson et al. 2024). In urban planning, vegetative barriers reduce air pollution and contribute to temperature regulation in the context of urban heat islands (Karimi et al. 2023). These large-canopy, low-maintenance, evergreen, and semi-evergreen trees contribute to the aesthetic value of urban areas and play a vital role in ecosystem services (Liang et al. 2023).

CONCLUSIONS

This study clearly revealed that the single biochemical parameter criterion was important in predicting how different tree species responded to air pollution, but it might not be the best option for assessing how plants respond to different contaminants. Our research indicates that choosing a tolerant tree species may be greatly aided by evaluating the API along with the APTI. Species with the highest API scores can be recommended for plantation. Among all three species in the six different setups, *F. benghalensis* and *F. religiosa* were found to be excellent species for plantation based on the API. These species can be included in the layout of greenbelts and urban planning to support industrial regions and urban air pollution control measures. Ground-based studies are limited and laborious; therefore, there is a need for a satellite-based approach for estimating APTI using surrogate variables. Indices should be developed to assess the parameters used in the APTI so that it is easy to monitor a large number of species in a short period of time.

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