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Research paper

Seasonal and Site-Specific Variation in Plant Tolerance to Air Pollution: An APTI and API Assessment

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ABSTRACT

Urban vegetation serves as an important natural barrier against atmospheric pollution by capturing, absorbing and filtering airborne contaminants, thereby improving air quality. The Air Pollution Tolerance Index (APTI), which is derived from key biochemical parameters of plants, is widely used to evaluate their tolerance to polluted conditions. In the present investigation, seasonal and site-specific variations in biochemical parameters and APTI were assessed in six common tree species: *Ficus benghalensis, Syzygium cumini, Azadirachta indica, Ficus religiosa, Saraca asoca and Psidium guajava*, growing across five distinct urban sites (Control, Residential, Commercial, Traffic and Industrial areas) in Rohtak during winter and summer seasons. Biochemical parameters including leaf extract pH, relative water content, total chlorophyll content and ascorbic acid concentration were analysed and subsequently used to compute APTI values. Considerable variation was observed among species, sites and seasons in all measured biochemical attributes and APTI values. Differences among sampling sites indicated that APTI values did not always decline with increasing pollution intensity, suggesting that certain species may sustain or strengthen their physiological defence mechanisms under prolonged environmental stress. Variations in biochemical parameters collectively influenced the pollution tolerance capacity of the studied species. In addition, the Anticipated Performance Index (API), which integrates APTI with biological, ecological and socioeconomic attributes, was applied to assess the suitability of species for urban plantation and green-belt development. The study highlights that plant tolerance is not static but is governed by species characteristics, environmental conditions and seasonal climatic changes. The combined application of biochemical indicators, APTI and API provides a robust framework for identifying pollution-tolerant species and supports informed decision-making for urban greening, environmental management and biomonitoring programs.

1. Introduction

Rapid urban expansion, industrial growth and increased vehicular emissions have led to a substantial rise in both gaseous and particulate air pollutants within urban ecosystems (Grover et al., 2025) . Sulphur oxides (SO_x), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), polyaromatic hydrocarbons (PAHs) and heavy metals are among the worst air pollutants released by automobiles and industrial processes has significantly degraded air quality, posing serious risks to human health and adversely affecting plant growth and performance (Kumar et al., 2023; Sheoran et al., 2022). Urban vegetation is persistently exposed to these contaminants, which can affect various physiological processes, including photosynthesis, water balance, membrane integrity and antioxidant defence systems. Nevertheless, the extent of these effects differs among plant species due to inherent variations in their physiological and biochemical attributes (Anand et al., 2024).

Plants are increasingly recognized as effective natural agents for mitigating air pollution. Their ability to capture and retain atmospheric contaminants contribute significantly to improve air quality, particularly in urban environments. Plant leaf act as sink for air pollutants because their large surface area facilitates the interception and accumulation of contaminants (Mondal & Singh, 2021; Sternberg et al., 2010).Vegetation can effectively remove particulate matter (PM) from the atmosphere through adsorption and absorption process, including PM_{10} and $PM_{2.5}$, which are particles with aerodynamic diameter of less than 10 µm and 2.5 µm, respectively (WHO, 2021). Numerous studies have reported that concentrations of airborne particles decline when wind-transported particles become deposited on surfaces of the plant's leaf and stem (Currie & Bass, 2008; Mondal & Singh, 2021). In addition to particulate matter removal, plants can absorb gaseous pollutants through their stomata, with carbona dioxide (CO_2) being one of the most significant gases sequestered by vegetation (Baraldi et al., 2019; Nowak & Dwyer, 2007). The pollution mitigation potential of plants is substantial, for example, it has been estimated that approximately 2000m^2 of unmanaged rooftop grass can remove nearly 4000kg of PM annually through deposition on its and stems and leaf (Arbid, 2021; Currie & Bass, 2008).

Plants mitigate air pollution through several mechanisms, including adsorption, absorption, detoxification, metabolism and accumulation of pollutants, often without exhibiting visible foliar injury (Guo et al., 2023; M. Kaur & Nagpal, 2017; Li et al., 2023; Molina & Segura, 2021). Nevertheless, certain atmospheric contaminants, particularly nitrogen dioxides (No_x) and Ozone (O_3), can adversely affect plant growth and physiology by altering seed germination, photosynthesis efficiency, pedicel development, stomatal functioning (Oksanen & Kontunen-Soppela, 2021; Savita, 2021). In response to such environmental stressors, many plant species adjust their biochemical and physiological attributes, including leaf extract pH, ascorbic acid content, relative water content (RWC), and total chlorophyll concentration, thereby enhancing their tolerance to polluted environments. The combined assessment of these biochemical parameters forms the basis of the air pollution tolerance index (APTI), a widely used indicator for evaluating the response of plants to air pollution. APTI is calculated using total chlorophyll content (TCh), ascorbic acid (AA) concentration, leaf pH and RWC and provides a quantitative measure of tolerance and sensitivity of plant to atmospheric pollutants (Mukhopadhyay et al., 2021). Plant species can be classified as sensitive, intermediate, tolerant based on APTI values(Nayak et al., n.d.). Species exhibiting low values of APTI are generally considered sensitive and they are serving as effective bioindicators of environmental pollution (Anake et al., 2022; Rai & Panda, 2013; Roy et al., 2020). Whereas species with higher APTI values are more resistant to pollutant stress and are therefore recommended for urban greenbelt development and pollution mitigation programs. In addition to physiological adaptations, plants possess both enzymatic and non-enzymatic antioxidant defence systems that help maintain cellular homeostasis and neutralize reactive oxygen species generated under pollutant induced stress. Exposure to atmospheric contaminants can induce oxidative damage, which is often assessed through changes in malondialdehyde (MDA) levels, a widely recognized indicator of lipid peroxidation and oxidative stress (Giannakoula et al., 2021; Zhang et al., 2020).

Numerous studies have employed APTI to evaluate plant tolerance to environmental pollution in several Indian cities, including Delhi, Varanasi, Tamilnadu, Haridwar, Mizoram and Jammu (Balasubramanian et al., 2018; N. Kaur et al., 2016; Kour & Raina, 2014; A. K. Pandey et al., 2015). Similar studies have also been conducted in other countries such as China, Indonesia, Hungary, Iran which are highlighting the global applicability of APTI as a biomonitoring tool. They demonstrated that both APTI and the biochemical parameters differ significantly across different environmental conditions and pollution levels (Molnár et al., 2020). Seasonal variability has also been shown to influence plant tolerance to air pollution. Several studies reported significant seasonal variation in APTI values, reflecting changes in plant physiological status under differing climatic conditions (Bui et al., 2023; Gholami et al., 2016). Seasonal changes in biochemical characteristics indicate the adaptive capacity of plants to varying climatic and environmental stresses. Elevated ascorbic acid concentrations during the pre-monsoon season, compared with the post-monsoon period have been associated with enhanced tolerance to air pollution (M. Kaur & Nagpal, 2017). However environmental factors such as temperature, moisture availability and heat stress may also contribute to seasonal variations in ascorbic acid and other biochemical responses (Liu et al., 2022) .

A recent Delhi study demonstrated significant site and seasonal variations in biochemical parameters and APTI across selected plant species and found that chlorophyll and ascorbic acid are major contributors to APTI variation(D. P. Tripathi & Nema, 2023). However, urban environments are characterized by diverse pollution regimes such as residential, commercial, transportation and industrial which may influence plant responses differently. Additionally, plant physiological stress, biochemical defence systems and pollutant uptake can all be impacted by seasonal variations in temperature, humidity and atmospheric conditions (Wu et al., 2024). Although

APTI is frequently used to evaluate the resistance of plants to air pollution, it mainly captures physiological reactions and could not accurately reflect the overall potential of plant species for urban greening initiatives. Consequently, a more thorough method for assessing species for greenbelt development is the API which integrates APTI with morphological, biological and socioeconomic traits. It is crucial to incorporate physiological tolerance with other plant characteristics in urban plantation planning, as recent research has demonstrated that APTI and API may produce distinct rankings of plant performance (Rasool et al., 2025; Sapkota & Shrestha, 2024).

Rohtak, one of the rapidly expanding urban centre of Haryana, has experienced increasing environmental pressure due to urbanization, vehicular emissions, industrial activities and infrastructure development. A recent GIS-based spatio-temporal assessment of air quality in the city reported considerable spatial and seasonal variation in AQI across different sites, with vehicular and industrial areas exhibiting relatively higher pollution levels than residential and control sites (Jakhar et al., 2026). The study further highlighted the persistent influence of particulate pollutants on urban air quality, indicating continuous exposure of roadside and urban vegetation to atmospheric contaminants. Despite the documented air pollution scenario, information on the tolerance and adaptive responses of common urban plant species in Rohtak remains limited. Therefore, evaluating the biochemical parameters, APTI and API of the selected plant species is essential for identifying appropriate plant species for urban biomonitoring and greenbelt development. Accordingly, the specific objectives of the study were as follows: (1) to evaluate the seasonal changes in biochemical parameters (2) to determine the Air Pollution Tolerance Index (APTI) (3) to assess species, site and season specific variation in plant tolerance (4) to integrate APTI with biological and socioeconomics characteristic through the API.

2. Material and Methods

2.1 Study Area

The present study was conducted in Rohtak city, Haryana, India (28°89′0″ N, 76°58′0″ E), located in the National Capital Region (NCR) approx. 70km northwest of Delhi. Rohtak is one of the major urban centres of Haryana and has undergone rapid urban expansion due to increasing population, transportation activities, industrial growth and infrastructure development (Deswal et al., 2019). The city lies on the Indo-Gangetic Plain at an elevation of around 220m above mean sea level and experiences a subtropical monsoon climate characterized by hot summers, mild winters and a distinct monsoon season (Jakhar et al., 2026).

Five sampling sites representing major land-use categories of Rohtak city were selected to capture the variability in urban environmental conditions. The geographical distribution of these sites is represented in Fig. 1. The selected locations enabling assessment of seasonal changes in biochemical parameters and evaluation of APTI and API among the studied plant species.

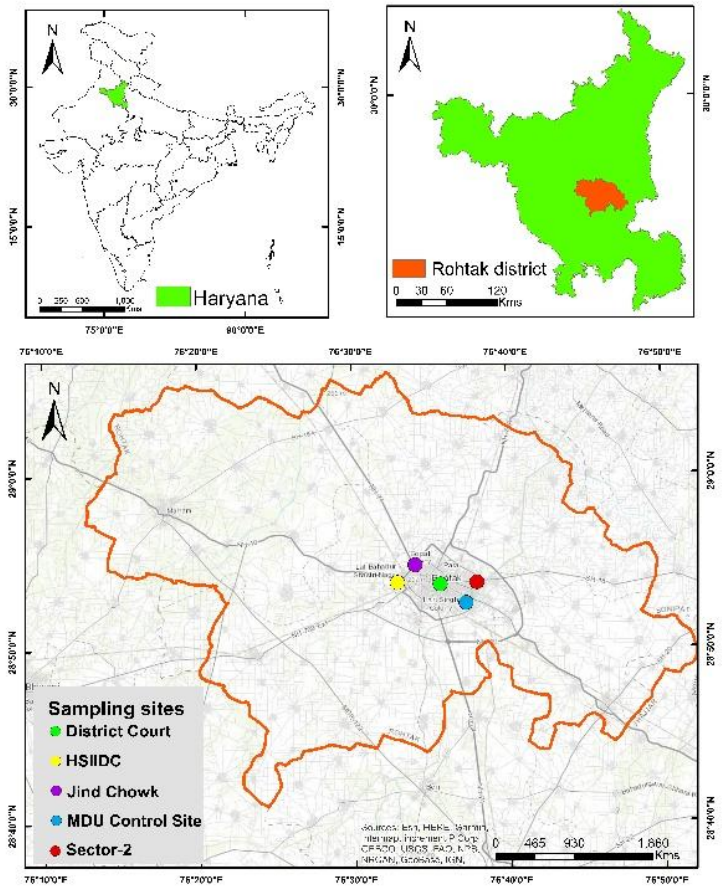


Fig. 1 Location Map of the Rohtak City showing selected Sampling Sites representing Control, Residential, Commercial, Traffic and Industrial land-use zones

2.2 Sampling and Analysis

Sampling of the plant leaves for biochemical analyses was carried out during the winter and summer seasons at the selected sites. The six study plant species (Table 1) were chosen based on their widespread occurrence, abundance, accessibility for sampling, ecological and socioeconomic significance across all sampling sites. Healthy, mature and fully expanded leaves were collected during morning hours from each plant species and transported to the laboratory in zip-lock polyethylene bags. All collections were performed in triplicate. Fresh leaf weight was measured immediately after collection while the remaining samples were preserved under refrigerated conditions for further analysis.

Table 1 Description of the Selected Plant Species

Scientific name	Family	Common name
Ficus benghalensis	Moraceae	Banyan tree
Ficus religiosa	Moraceae	Peepal
Azadirachta indica	Meliaceae	Neem
Syzygium cumini	Myrtaceae	Jamun
Saraca asoca	Fabaceae	Ashoka
Psidium guajava	Myrtaceae	Guava

The biochemical parameters of required for the calculation of APTI such as RWC, TCh, AA and pH of the leaf extract, were determined using standard methods. RWC was determined by using modified method of (Henson et al., 1981) by taking leaf's fresh weight, turgid weight and dry weight and calculated using the formula;

$$RWC\ (\%) = \frac{Fresh\ wt. - Dry\ wt.}{Turgid\ wt. - Dry\ wt.} \times 100$$

Total chlorophyll content was determined by using the method (Arnon, 1949) spectrophotometrically after extraction of 100mg leaf with 10 ml of 80% acetone and chlorophyll a and chlorophyll b were calculated from absorbance values recorded at 663nm and 645nm, respectively. The TCh concentration was calculated using formula;

Chl 'a'= [(12.7× A663) -(2.69×A645)] ×V/mg
Chl 'b'=[(22.9×A645) -(4.69×A663)] ×V/mg

where, V= volume of filtrate
total chlorophyll content = chl 'a'+ chl 'b'

The method explained by (Mukherjee & Choudhuri, 1983) was used to determine the AA concentration. 0.2g leaf samples were extracted with 10ml of 6% trichloroacetic acid (TCA). Then the supernatant was reacted with 2ml of 2,4-dinitrophenyl hydrazine and a drop of ethanol, boiled and cooled and mix with 5ml of 80% Sulphuric Acid. The concentration of AA was calculated from standard calibration curve of ascorbic acid solution and expressed as mg/g fresh weight. The pH of the leaf extract was measured by homogenizing fresh leaf in 10ml of deionized water, followed by centrifugation and determine the pH in supernatant using a pH meter (Deswal et al., 2019).

2.3 Determination of APTI and API

The APTI of the selected plant species was evaluated using biochemical and physiological parameters following the method by (Singh & Rao, 1983). This approach is widely employed to assess the tolerance and sensitivity of plants to air pollution and their suitability for biomonitoring and green-belt development. Based on the APTI values, the plant species were categorized into different tolerance classification (Table 2). APTI was calculated using the formula;

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

where, A is ascorbic acid, T is total chlorophyll, P is pH of leaf extract, R is relative water content.

Table 2 Plant species tolerance category based on APTI values

APTI values	Tolerance category
30-100	Pollution-tolerant
17-29	Moderately tolerant
1-16	Pollution-sensitive
>1	Highly sensitive

The API provides a more comprehensive assessment of plant suitability for pollution mitigation than APTI, as it considers not only the pollution tolerance capacity of plant species but also ecological, biological and socioeconomics properties. In addition to APTI values, the API evaluation considers such as plant habit, plant type, laminar structure, canopy structure and economic value, all of which influence the effectiveness of a species in reducing air pollution and enhancing environmental quality (Govindaraju et al., 2012). By integrating these parameters with APTI, the API serves as a more evaluation approach for identifying suitable plant species for biomonitoring, pollution control and greenbelt development (Ogunkunle et al., 2015). The score of API was evaluated using equation;

$$API = \frac{\text{Number of(+)obtained}}{16} \times 100$$

The API was determined by assigning (+/-) grades to the selected attributes of the plants mentioned in Table 3 and Table 4 (Govindaraju et al., 2012; Prajapati & Tripathi, 2008).

Table 3 Grading allotment of plant species on basis of APTI and Socio-economic importance

Grading character	Assessment pattern	Grades
a) Tolerance (APTI)	9.0-12.0	+
	12.1-15.0	++
	15.1-18.0	+++
	18.1-21.0	++++
	21.1-24.0	+++++
	24.1-27.0	++++++
	27.1-30.0	+++++++
b) Biological and Socio-Economic		
i. Plant habit	Small	-
ii. Canopy Structure	Medium	+
iii. Plant types	Large	++
iv. Laminar structure	Sparse/Irregular/globular	-
a. Size	Spreading	+
b. Texture	crown/open/semi dense	
c. Hardiness	Spreading dense	++
v. Economic value	Deciduous	-
	Evergreen	+
	Small	-
	Medium	+
	Large	++
	Smooth	-
	Coriaceous	+
	Delineate	-
	Hardy	+
	Less than three uses	-
	Three or four uses	+
	Five or more uses	++

Maximum grade that can be scored by a plant is 16

Table 4 API-based Categorization of Plant species

Grade	Score (%)	Category
0	< 30	Not recommended
1	31to40	Very poor
2	41to50	Poor
3	51to60	Moderate
4	61to70	Good
5	71to80	Very good
6	81to90	Excellent
7	91to100	Best

3. Result and Discussion

3.1 Environmental exposure conditions

The plant physiological assessment was conducted during the same monitoring period (October 2021-July 2022) for which the ambient air quality and meteorological conditions were previously monitored (Jakhar et al., 2026). The study period represented contrasting winter and summer environmental regimes with differences in temperature, relative humidity and concentration of air pollutants across the selected sites. In the present study, these environmental conditions are considered as the exposure context for evaluating plant biochemical responses, APTI and API. The selected sites represented contrasting urban exposure environments as relatively less disturbed or control conditions at residential, traffic influenced and industrial environments.

3.2 Biochemical parameters

3.2.1 Chlorophyll concentration

Chlorophyll is an important biochemical indicator associated with photosynthetic activity and the physiological condition of plants. Air pollution interferes with photosynthetic processes and chloroplast functioning which results in change in chlorophyll concentration. In the study, the total chlorophyll showed clear season and site-wise differences among the studied plant (Table 5 and 6).

TChl ranged from 7.06-10.72mg/g in winter with the highest value recorded in *S. cumini* (10.72) at commercial site, followed by F. benghalensis (10.54mg/g) at control site, whereas the lowest value was observed in *S. asoca* (7.06mg/g) at traffic site. During summer, it is ranged from 6.04-10.84mg/g, highest value was found in A. indica (10.84mg/g) at control site and the lowest in P. guajava (6.04mg/g) at the industrial site. The comparatively higher TChl content at control site suggests that the species maintained relatively high chorophyll levels under the conditions prevailing at control site. The lower chlorophyll content at traffic and industrial sites corresponds with the higher concentration of PM2.5, PM10, So_x and No_x recorded at these locations during winter and summer (Jakhar et al., 2026). Similar reduction in chlorophyll at polluted sites have been reported previously, including studies on roadside plants and A. indica, where increased vehicular pollution associated with reduction in chlorophyll content and photosynthetic activity (Sinquin et al., 2024; Tyagi & Singh, 2022). The lower chlorophyll concentration observed at more polluted site, indicates the adverse effect of air pollution on plants (Grover et al., 2025).

Seasonal comparison further revealed that TChl content was generally higher during winter than summer. The decline from winter to summer was observed at all five sites, with the greatest reduction occurring at industrial site, where the mean TChl increased from approximately 9.23mg/g in winter to 10.00mg/g in summer, while the residential site increased from 9.09mg/g-9.60mg/g. in contrast, the commercial site decreased from 9.45-8.87mg/g, traffic site reduced 8.06-8.45mg/g and highest reduction at industrial site from 8.13-7.25mg/g. This indicates that seasonal variation in chlorophyll was particularly pronounced at the industrial site. At the species level, the winter to summer comparison also demonstrated substantial variation. F. benghalensis decreased from a mean TChl of approx. 9.66mg/g in winter to 9.50mg/g in summer, while *S. cumini* increased from 8.93-9.27mg/g, A. indica showed an increment from 8.40-8.67mg/g, *F. religiosa* decreased slightly from 9.46-9.32mg/g, *S. asoca* decreased from 8.22-7.64mg/g and P. guajava increased from 8.07 to 8.61mg/g. The reduction in TChl observed particularly at industrial sites may be associated with greater exposure to atmospheric pollutants and particulate matter deposition (Tripathi & Gautam, 2007). PM can interfere with light interception by leaves and affect chloroplast and photosynthetic functioning while gaseous pollutants can also contribute to chlorophyll degradation and physiological stress (Kalaji et al., 2017). The observed interspecific differences further indicate species specific responses to seasonal and site related air pollution, highlighting their potential as bioindicators of environmental quality (Gautam & Shukla, 2020a). The observed reduction in chlorophyll content indicates increased sensitivity of the plant species to air pollution, highlighting their potential as bioindicators of environmental quality.

3.2.2 Ascorbic Acid (AA)

AA serves as a key component of plant's antioxidant defence system and plays a significant role in protecting plant tissues against oxidative stress (Alotaibi et al., 2020; Mandal & Dhal, 2022). In the present study, spatial seasonal variation in AA was observed among the studies plant species (Table 5 and 6). During winter season, the highest AA concentration was found in *F. benghalensis*

(8.26mg/g) at control site followed by *A. indica* (7.71mg/g) and *F. religiosa* (7.81mg/g) at control site, whereas the minimum value was found in *S. asoca* (3.18mg/g) at industrial site, followed by 3.24mg/g at traffic site. During summer, the maximum value was observed in *A. indica* (7.80mg/g) at control site followed by *A. indica* (6.86mg/g) and *F. benghalensis* (6.29mg/g) at commercial site. The minimum AA was recorded in *P. guajava* and *S. asoca* (3.14mg/g) at industrial site and traffic site respectively, *S. asoca* also showed comparatively low values ranging from 3.18-5.18mg/g during winter and 3.14-5.37mg/g during summer.

A clear site wise variation in each season was observed. The mean AA concentration across all sites follow a pattern Control (6.89-5.89mg/g)> Residential (6.33-5.14mg/g)> Commercial (5.58-5.45mg/g)> Traffic (5.32-4.69mg/g)> Industrial (4.63-4.34mg/g) during winter and summer respectively. The lower values at traffic and industrial sites indicate that plant biochemical responses varied according to environmental pollution at sampling sites. Seasonal comparison revealed that AA content was generally higher during winter than summer at all sites. At species level, F. benghalensis maintained the highest mean AA concentration of 6.57mg/g in winter and 5.45mg/g in summer, while *S. cumini* showed 6.02 and 5.24mg/g mean values, respectively. *A. indica* maintained relatively high mean values of 6.45mg/g in winter and 6.32mg/g in summer, whereas *S. asoca* had comparatively lower mean values 4.17mg/g in winter and 4.38mg/g in summer. *P. guajava* exhibited a particularly pronounced seasonal reduction from 5.68mg/g in winter and 4.28mg/g in summer. The higher AA observed in species during winter may indicate differences in antioxidant metabolism and physiological response between seasons. Ascorbate participates in ROS scavenging and helps maintain cellular redox balance under environmental stress, consequently variation in AA can reflect changes in plant physiological status (Rao et al., 2020). The lower AA concentrations observed particularly at more polluted sites may therefore reflect differences in oxidative stress and antioxidant responses. The occurrence of this relationship across different seasonal conditions implies that plants exhibit a stable physiological response to air pollution despite variations in environmental factors (Bharti et al., 2018).

3.2.3 Leaf pH

The site and inter-specific differences in leaf pH of the selected plant species is shown in Table 5 and 6. During winter, leaf pH ranged from 4.14-7.95, with the highest value found in F. religiosa (7.95) at the residential site followed by F. benghalensis (7.79) at control site and the lowest value was observed in P. guajava (4.14) at the commercial site.

Among the other species, *P. guajava* maintained relatively high pH at control (6.72) and residential (5.85) sites, whereas *S. cumini* showed comparatively lower values particularly at traffic (4.47) and industrial (4.51) sites. In summer, maximum value found in *S. cumini* (6.64) followed by *F. benghalensis* (6.42) at control site. The minimum pH was found in S. asoca (4.03) at traffic site. *A. indica* and *S. asoca* showed relatively pronounced reductions in pH at more polluted sites, particularly during summer. A general decline was observed from control to industrial sites in both seasons. The lower values found at more polluted sites, particularly during summer may indicate changes in leaf cellular chemistry under pollution stress. Gaseous pollutants can enter leaf through stomata and may contribute to acidification of leaf tissues, similar results were observed by (Gautam & Shukla, 2020b). A clear site wise and seasonal variation was also observed in leaf pH. During winter mean leaf pH across the plant species followed the order Residential (6.37)> Control (6.29)> Commercial (5.78)> Traffic (5.16)> industrial (5.06), whereas during summer control (6.06)> Residential (5.67)> Commercial (5.35)> Traffic (5.06)> Industrial (4.84). Thus, the lowest mean pH was consistently observed at industrial site. Seasonal variation also showed that leaf pH was higher during winter than summer across all sites. Some of the species maintained high pH at all sites and some species marked reduction at polluted sites during summer. At the species level, F. benghalensis decreased from a mean pH of 6.15 in winter to 5.17 in summer, while *S. cumini* slight increased from 5.13-5.45, *A. indica* (5.54-5.25), F. religiosa (7.02-5.78), S. asoca (5.16-4.91) and *P. guajava* (5.52-5.14). The maintenance of high pH may reflect greater buffering capacity and the ability of plants to maintain cellular homeostasis under pollution conditions, suggested in some studies by Parmar et al. (2013) and Shah et al. (2019).

3.2.4 Relative Water Content (RWC)

RWC is an important parameter of the water status and physiological condition of plants. Changes in RWC reflect alterations in cell membrane permeability, which may result in water and nutrients loss, making it a sensitive indicator of pollution induced stress. (Dhankhar et al., 2015; Lohe et al., 2015). RWC of the leaves exhibited considerable interspecific and site-specific variation during both season (Table 5 and 6).

In winter, P. guajava (82.45%) was found with highest RWC at control site followed by *F. religiosa* (81.53%) and *F. benghalensis* (80.15%) at the residential site. The lowest RWC was observed in *S. asoca* (66.42%) at the industrial site. At commercial

site value ranged from 67.31 (*S. asoca*)- 78.80 (A. indica), while at the traffic site, RWC varied from 68% (*F. religiosa*) to 76.84% (*F. benghalensis*). During summer, RWC ranged from 66.57% (*S. cumini*) at industrial site to 78.52% (*P. guajava*) at the control site. At the residential site, RWC ranged from 71.94% (*S. asoca*) to 78.52% (*P. guajava*), at commercial site, 70% (*S. cumini*) to 77.48% (*P. guajava*), at traffic site from 68.16% (*S. cumini*) to 75% (*P. guajava*) and at the industrial site 67.57 (*S. cumini*)-74.72 (*P. guajava*). The higher RWC of P. guajava across all sites indicates its ability to maintain leaf hydration under different environmental conditions, whereas the comparatively lower values found in *S. cumini* and *S. asoca* at some polluted sites reveals greater variation in their water status response. Plants with higher RWC are generally better able to maintain physiological functions, tolerate environmental stress and withstand drought conditions (Rai et al., 2013). A clear site wise variation in RWC was observed in both seasons. During winter, the mean RWC of all species followed order Control (78.59)> Residential (77.71)> Commercial (74.05)> Traffic (72.24)> Industrial (70.36) and during summer, the order was Residential (75.51)> Control (74.71)> Commercial (73.51)> Traffic (71.81)> Industrial (70.90). Thus, the industrial site consistently showed the lowest mean RWC while at control and residential sites it is maintained with higher RWC. Seasonal comparison showed that RWC declined during summer, although the magnitude of change differed among sites and species.

The seasonal decline in RWC was observed in all species across all sites. Such as *F. benghalensis* declined from 79.21 to 76.24 at the control site and 75.60 to 73.17 at industrial site, while *S. cumini* decreased from 76 – 74 at control site and 71.64-67.57 at industrial site. Similarly, *A. indica* decreased from 78.16-75 at control site and from 65.32- 68.16 at industrial site, whereas *F. religiosa* decreased from 81.53-72.86 at control site and 71.05-72.27 at industrial site. *S. asoca* showed a reduction from 74.19-71.64 at control site and 66.42-69.53 at industrial site while *P. guajava* declined from 82.45-78.52 at control site and 72.15-74.72 at industrial site. These observations are consistent with earlier findings that environmental and air pollution stress can alter leaf water relations and species differ in their ability to maintain water status under stressful conditions (Malav et al., 2022). The relatively higher RWC maintained by *P. guajava* across the polluted sites indicate a greater capacity to leaf hydration, whereas the lower values observed in *S. cumini* and *S. asoca* at some polluted sites indicate greater variation in their water status response.

Table 5 Variation in biochemical parameters of the plant species at different sites in winter

Plant species	Winter season																			
	Control site				Residential site				Commercial site				Traffic site				Industrial site			
	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC
Ficus benghalensis	7.79	10.54	8.26	80.21	6.52	10.17	7.75	80.15	7.26	9.72	6.65	78.7	5.12	9.21	6.73	76.84	5.87	8.67	4.44	75.6
Syzygium cumini	5.16	8.42	6.99	76	5.65	9.67	5.91	72.49	5.85	10.72	5.95	74	4.47	8.11	5.8	73	4.51	7.75	4.75	71.64
Azadiracta indica	5.71	8.62	7.71	78.16	6.89	8.29	7.12	77.02	5.91	8.62	5.75	78.8	4.62	7.42	5.69	69.5	4.58	9.04	5.58	65.32
Ficus religiosa	6.82	9.81	7.81	81.53	7.95	9.01	6.07	80.61	6.84	9.68	6.14	71.23	5.58	8.89	4.54	68	5.63	9.92	4.89	71.05
Saraca asoca	5.51	9.74	4.52	74.19	5.37	8.26	5.18	75	4.68	8.8	3.41	67.31	5.42	7.06	3.24	69.45	5.45	7.25	3.18	66.42
Psidium guajava	6.72	8.27	6.02	82.45	5.85	9.16	5.97	81	4.14	9.14	5.59	74.28	5.74	7.67	5.93	76.65	4.31	6.12	4.91	72.15

Units, Chl=mg/g, AA=mg/g, RWC=%

Table 6 Variation in biochemical parameters of the plant species at different sites in Summer

Plant species	Summer season																			
	Control site				Residential site				Commercial site				Traffic site				Industrial site			
	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC	pH	Chl	AA	RWC
Ficus benghalensis	6.42	10.42	5.86	76.24	6.37	10.14	5.52	76.89	5.92	9.58	6.29	75.23	5.53	9.17	5.48	73.6	5.31	8.18	5.09	73.17
Syzygium cumini	6.64	9.96	6.2	74	5.48	9.79	5.84	72.78	5.87	9.42	4.53	70	4.47	8.84	4.81	68.16	4.85	8.32	4.84	67.57
Azadiracta indica	5.28	10.84	7.8	75	5.59	9.57	6.4	77.7	5.31	8.26	6.86	73	5.83	7.74	5.73	72.85	4.25	6.95	4.79	68.16
Ficus religiosa	6.39	10.38	5.24	72.86	6.21	10.26	4.08	75.52	5.47	9.38	5.59	74.58	5.68	8.96	4.46	71.58	5.17	7.64	4.37	72.27
Saraca asoca	5.92	8.74	4.86	71.64	4.94	8.28	4.73	71.94	4.81	7.46	5.37	70.74	4.03	7.37	3.14	70	4.87	6.35	3.82	69.53
Psidium guajava	5.72	9.68	5.38	78.52	5.94	9.56	4.27	78.25	4.73	9.14	4.06	77.48	4.79	8.64	4.53	75	4.57	6.04	3.14	74.72

Units, Chl=mg/g, AA=mg/g, RWC=%

3.2.5 APTI and API

The APTI was determined using four biochemical parameters and it showed considerable variation among all the six plant species across all the monitoring sites during both seasons (Table 7). The highest APTI (23.16) was found in *F. benghalensis* followed by *F. religiosa* (21.14) at control site and *F. benghalensis* (20.95) at residential site during winter. Whereas the lowest APTI was found in *S. asoca* (10.58) at traffic site followed by *P. guajava* (10.80) at the industrial site during summer. The highest values at control site were observed in *F. benghalensis* (23.16) in winter and *A. indica* (20.07) in summer. At Residential site, *F. benghalensis* again had the highest value (20.95) in winter and lowest value was found in *S. ascoca* (13.45) in summer. At the commercial site, APTI ranged from 11.33 (*S. asoca*) to 19.16 (*F. benghlensis*) during winter. At the traffic site, the APTI values were ranged between 10.58 (*S. asoca*) in summer to 17.33 (*F. benghalensis*) during winter. At the industrial site, *F. benghalensis* (14.18), highest APTI and *S. asoca* (11.24) had the lowest APTI during summer. These variations indicate differences among plant species in their biochemical response to the environmental conditions prevailing at different sites. Site-wise variation showed that APTI values were generally maximum at control and residential sites, lower at Commercial, Traffic and Industrial sites.

Seasonal variation also differed among the plant species and sites. F. benghalensis showed a higher APTI during winter at control, residential, commercial and traffic sites, while its value increased slightly from 14.02 in winter to 14.18 in summer at industrial site. *S. cumini* showed a slight increase during summer at control and industrial site whereas lower summer values were observed at residential, commercial and traffic site. *A. indica* recorded higher APTI in summer at control, commercial and traffic sites but lower values at Residential and industrial sites. F. religiosa, winter APTI values were higher at control, residential, commercial and industrial sites while a slight increase was observed at traffic site during summer. *S. asoca* showed relatively similar values at control during both seasons, whereas its APTI decreased at residential and traffic sites in summer and increased at commercial sites. *P. guajava* generally had lower APTI values during summer with the most pronounced decrease occurring at industrial site, 15.43 in winter to 10.80 in summer.

Overall, the higher APTI values were predominantly found in F. benghalensis, A. indica and F. religiosa showed moderately tolerant particularly at control and residential sites, *S. cumini* showed moderate to sensitive whereas lower values were frequently observed in *S. asoca* and *P. guajava* at more polluted sites and considered sensitive species. The occurrence of relatively high APTI values in some species considered greater tolerance to pollution and species with lower APTI can be considered more sensitive and potentially useful as bioindicators of environmental stress. Thus, the observed differences in tolerance categories demonstrate clear interspecific, site-specific and seasonal variation in the response of the selected plant species to air pollution. These reductions suggest that the physiological parameters contributing to APTI were more adversely affected during summer, particularly at the polluted sites. The pattern is consistent with the study that seasonal changes in the environmental conditions can modify chlorophyll, pH, RWC and AA, thereby influencing APTI (Pandey et al., 2015; Roy et al., 2020).

Table 7 Seasonal and Site-Specific variation in APTI of selected plant species

Plant species	Control		Residential		Commercial		Traffic		Industrial	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Ficus benghalensis	23.16	17.49	20.95	16.80	19.16	17.27	17.33	15.42	14.02	14.18
Syzygium cumini	17.09	17.69	16.30	16.20	17.26	13.93	14.60	13.22	12.99	13.13
Azadiracta indica	18.86	20.07	18.51	17.47	16.23	16.61	13.80	15.06	14.13	12.18
Ficus religiosa	21.14	16.07	18.36	14.27	17.27	15.76	13.37	13.69	14.71	12.82
Saraca asoca	14.31	14.29	14.56	13.45	11.33	13.66	10.99	10.58	12.37	11.24
Psidium guajava	17.27	16.14	17.06	14.44	14.85	13.38	15.62	13.58	15.43	10.80

In the present study, the API results showed distinct differences among species and between seasons. *F. religiosa* comes under excellent performance category, *S. cumini* and A. indica were under very good category, F. benghalensis and P. guajava under good category whereas *S. asoca* was categorized as poor

during winter. The highest API score for F. religiosa was 81.25 indicating its comparatively high anticipated performance during winter. The occurrence of F. religiosa in excellent category agrees with the findings, who also classified F. religiosa in excellent category and identified it as suitable for greenbelt development(Pathak et al., 2011). During summer, A. indica and F. religiosa were categorized as very good while S. cumini remained in good category. F. benghalensis and P. guajava were under moderate category whereas S. asoca still to show poor performance. The relatively high API performance of A. indica and F. religiosa suggests that these species retained comparatively favourable characteristics under summer conditions. However, the seasonal shift in the category of F. religiosa from excellent in winter to very good in summer and the reduction observed for F. benghalensis and P. guajava, indicate that API can vary with seasonal environmental conditions. The present findings also show both agreement and differences with earlier studies reported F. benghalensis under excellent category in the industrial area and F. religiosa was under very good category (Patel et al., 2018) . In the present study, F. benghalensis under good category during winter and moderate during summer, while F. religiosa reached the excellent category during winter and very good during summer. A review also demonstrate that the same species can have different API score across studies supporting the importance of site-specific assessment (Enitan et al., 2022). Overall, after the API assessment F. religiosa and A. indica are identified as species with high API, while S. asoca with low API. *S. cumini*, *F. benghalensis* and *P. guajva* show intermediate tolerance that vary between seasons. (Pathak et al., 2011) similarly reported that incorporating plant species through API evaluation into urban greening and corridor planning can contribute to sustainable urban development, particularly in rapidly urbanizing areas.

Table 8 Mean APTI and API grading of the plant species for both season

Plant species	Winter					Summer				
	Mean APTI	APTI Category	API Score	Grade	Performance	Mean APTI	APTI Category	API Score	Grade	Performance
Ficus benghalensis	18.92	MT	62.5	4	Good	16.23	MT	56.25	3	Moderate
Syzygium cumini	15.65	S	75	5	Very good	14.83	S	68.75	4	Good
Azadiracta indica	16.31	MT	75	5	Very good	16.28	MT	75	5	Very good
Ficus religiosa	16.97	MT	81.25	6	Excellent	14.52	S	75	5	Very good
Saraca asoca	12.37	S	50	2	Poor	12.64	S	50	2	Poor
Psidium guajava	15.43	S	62.5	4	Good	13.67	S	56.25	3	Moderate

where, MT= Moderately tolerant, S= Sensitive

4. Conclusion

The current study showed a distinct species, site and season specific differences in the biochemical parameters, APTI and API of the selected plant species at different locations in Rohtak. In general *S. asoca* and *P. guajava* had lower air pollution tolerance index in more polluted sites, but *F. religiosa*, *A. indica* and *F. benghalensis* show greater pollution tolerance. The API assessment further identified *F. religiosa* and A. indica as better performing species for urban planation and greenbelt development consideration. The finding demonstrate that plant tolerance is influenced by specie characteristics, environmental conditions and seasonal changes. Additionally, the combined use of biochemical parameters, APTI and API provides a useful approach for identifying suitable plant species for urban greening, pollution management and biomonitoring in Rohtak city.

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References

1. Alotaibi, M. D., Alharbi, B. H., Al-Shamsi, M. A., Alshahrani, T. S., Al-Namazi, A. A., Alharbi, S. F., Alotaibi, F. S., & Qian, Y. (2020). Assessing the response of five tree species to air pollution in Riyadh City, Saudi Arabia, for potential green belt application. *Environmental Science and Pollution Research International*, *27*(23), 29156–29170. https://doi.org/10.1007/S11356-020-09226-W
2. Anake, W. U., Bayode, F. O., Jonathan, H. O., Omonhinmin, C. A., Odetunmibi, O. A., & Anake, T. A. (2022). Screening of Plant Species Response and Performance for Green Belt Development: Implications for Semi-Urban Ecosystem Restoration. *Sustainability (Switzerland)*, *14*(7), 3968. https://doi.org/10.3390/SU14073968/S1
3. Anand, P., Kota, S. H., & Mina, U. (2024). Effects of Elevated Ozone Concentrations on Evergreen Shrubs in Delhi, India. *EGU24*. https://doi.org/10.5194/EGUSPHERE-EGU24-398
4. Arbid, Y. (2021). *Impact of green roof plants on the removal of air pollutants (NO_2/O_3) and on the photochemical fate of pesticides*. https://doi.org/10.70675/3BE2C33DZC520Z4E24Z8B64Z955449F5DD4E
5. Arnon, D. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. *Plant Physiology*, *24*(1), 1–15.
6. Balasubramanian, A., Prasath, C. N. H., Gobalakrishnan, K., & Radhakrishnan, S. (2018). Previously known as British Journal of Environment & Climate Change Air Pollution Tolerance Index (APTI) Assessment in Tree Species of Coimbatore Urban City, Tamil Nadu, India. *International Journal of Environment and Climate Change*, *8*(1), 27–38. https://doi.org/10.9734/IJECC/2018/v8i127106
7. Baraldi, R., Chieco, C., Neri, L., Facini, O., Rapparini, F., Morrone, L., Rotondi, A., & Carriero, G. (2019). An integrated study on air mitigation potential of urban vegetation: From a multi-trait approach to modeling. *ElsevierR Baraldi, C Chieco, L Neri, O Facini, F Rapparini, L Morrone, A Rotondi, G CarrieroUrban Forestry & Urban Greening, 2019•Elsevier*, *41*, 127–138. https://doi.org/10.1016/J.UFUG.2019.03.020
8. Bharti, S. K., Trivedi, A., & Kumar, N. (2018). Air pollution tolerance index of plants growing near an industrial site. *Urban Climate*, *24*, 820–829. https://doi.org/10.1016/J.UCLIM.2017.10.007
9. Bui, H. T., Jeong, N. R., & Park, B. J. (2023). Seasonal Variations of Particulate Matter Capture and the Air Pollution Tolerance Index of Five Roadside Plant Species. *Atmosphere 2023, Vol. 14, Page 138*, *14*(1), 138. https://doi.org/10.3390/ATMOS14010138
10. Currie, B. A., & Bass, B. (2008). Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *SpringerBA Currie, B BassUrban Ecosystems, 2008•Springer*, *11*(4), 409–422. https://doi.org/10.1007/S11252-008-0054-Y
11. Deswal, M., Deswal, P., & Duhan, S. (2019). An assessment of anticipated pollution index of some common plants and trees of Rohtak city of Haryana (India). *Rasāyan Journal of Chemistry*, *12*(3), 1627–1640. https://doi.org/10.31788/RJC.2019.1235214
12. Dhankhar, R., Mor, V., & Narwal, S. (2015). (PDF) Anticipated performance index of selected plant species in University campus area, Rohtak, Haryana, India. *International Journal of Advanced Multidisciplinary Research (IJAMR)*, *2*(2), 32–41. https://www.researchgate.net/publication/315112292_Anticipated_performance_index_of_selected_plant_species_in_University_campus_area_Rohtak_Haryana_India
13. Enitan, I. T., Durowoju, O. S., Edokpayi, J. N., & Odiyo, J. O. (2022). A Review of Air Pollution Mitigation Approach Using Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API). *Atmosphere 2022, Vol. 13, Page 374*, *13*(3), 374. https://doi.org/10.3390/ATMOS13030374
14. Gautam, P., & Shukla, A. K. (2020a). Identification of Air Pollution Index of certain local available plants at industrial area on the basis of Air Pollution Tolerance index. *IOP Conference Series: Materials Science and Engineering*, *955*(1). https://doi.org/10.1088/1757-899X/955/1/012081
15. Gautam, P., & Shukla, A. K. (2020b). Identification of Air Pollution Index of certain local available plants at industrial area on the basis of Air Pollution Tolerance index. *IOP Conference Series: Materials Science and Engineering*, *955*. https://doi.org/10.1088/1757-899X/955/1/012081/META
16. Gholami, A., Mojiri, A., & Amini, H. (2016). Investigation Of The Air Pollution Tolerance Index (Apti) Using Some Plant Species In Ahvaz Region. *The Journal of Animal and Plant Sciences*, *26*(2), 475–480. http://science.time.com/2013/10/18/the-10-
17. Giannakoula, A., Therios, I., & Chatzissavvidis, C. (2021). Effect of Lead and Copper on Photosynthetic Apparatus in Citrus (Citrus aurantium L.) Plants. The Role of Antioxidants in Oxidative Damage as a Response to Heavy Metal Stress. *Plants 2021, Vol. 10, Page 155*, *10*(1), 155. https://doi.org/10.3390/PLANTS10010155
18. Govindaraju, M., Ganeshkumar, R. S., Muthukumaran, V. R., & Visvanathan, P. (2012). Identification and evaluation of air-pollution-tolerant plants around lignite-based thermal power station for greenbelt development. *SpringerM Govindaraju, RS GaneshEnvironmental Science and Pollution Research*, *19*(4), 1210–1223. https://doi.org/10.1007/S11356-011-0637-7
19. Grover, D., Dahiya, B., Garg, S., & Sharma, A. (2025). Evaluation of nature-based solutions for biomonitoring of air quality and identification of air pollution-tolerant species. *International Journal of Environmental Science and Technology 2025 22:12*, *22*(12), 11655–11672. https://doi.org/10.1007/S13762-024-06313-0
20. Guo, K., Yan, L., He, Y., Li, H., Lam, S. S., Peng, W., & Sonne, C. (2023). Phytoremediation as a potential technique for vehicle hazardous pollutants around highways. *Environmental Pollution*, *322*, 121130. https://doi.org/10.1016/J.ENVPOL.2023.121130
21. Henson, I. E., Mahalakshmi, V., Bidinger, F. R., & Alagarswamy, G. (1981). Genotypic variation in pearl millet (Pennisetum americanum (L.) Leeke), in the ability to accumulate abscisic acid in response to water stress. *Journal of Experimental Botany*, *32*, 899–910. https://www.jstor.org/stable/23690235

22. Jakhar, M., Laura, J. S., & Nandal, M. (2026). A GIS Based Spatio-Temporal Analysis of Air Quality Index Across Diverse Land-Use Zones in Rohtak City, India. *Current World Environment*, *21*(01). In press.
23. Jakhar, M., Nandal, M., & Laura, J. S. (2026). A GIS Based Spatio-Temporal Analysis of Air Quality Index Across Diverse Land-Use Zones in Rohtak City, India. *Current World Environment*, *1*(21), 194–210. https://doi.org/10.12944/CWE.21.1.15
24. Kalaji, H. M., Bąba, W., Gediga, K., Goltsev, V., Samborska, I. A., Cetner, M. D., Dimitrova, S., Piszcz, U., Bielecki, K., Karmowska, K., Dankov, K., & Kompała-Bąba, A. (2017). Chlorophyll fluorescence as a tool for nutrient status identification in rapeseed plants. *Photosynthesis Research 2017 136:3*, *136*(3), 329–343. https://doi.org/10.1007/S11120-017-0467-7
25. Kaur, M., & Nagpal, A. K. (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. *Environmental Science and Pollution Research 2017 24:23*, *24*(23), 18881–18895. https://doi.org/10.1007/S11356-017-9500-9
26. Kaur, N., Singh, S., & Gupta, N. C. (2016). Study of pollution tolerance index for plant species exposed to vehicular traffic on urban streets. *INT J CURR SCI*, *19*(4), 181–192. www.currentsciencejournal.info
27. Kour, B., & Raina, A. K. (2014). Assessment of air pollution tolerance levels of some plant species of Jammu. *Environment Conservation Journal*, *15*(1 & 2), 89–93. https://doi.org/10.36953/ECJ.2014.151212
28. Kumar, P., Singh, A. B., Arora, T., Singh, S., & Singh, R. (2023). Critical review on emerging health effects associated with the indoor air quality and its sustainable management. *Science of The Total Environment*, *872*, 162163. https://doi.org/10.1016/J.SCITOTENV.2023.162163
29. Li, Y., Chen, X., Sonne, C., Lam, S. S., Yang, Y., Ma, N. L., & Peng, W. (2023). Reduction and control of air pollution: based on plant-microbe interactions. *Environmental Pollutants and Bioavailability*, *35*(1). https://doi.org/10.1080/26395940.2023.2173657
30. Liu, Y. H., Wang, H., Liu, J. X., Shu, S., Tan, G. F., Li, M. Y., Duan, A. Q., Liu, H., & Xiong, A. S. (2022). AgGMP encoding GDP-D-mannose pyrophosphorylase from celery enhanced the accumulation of ascorbic acid and resistance to drought stress in Arabidopsis. *PeerJ*, *10*, e12976. https://doi.org/10.7717/PEERJ.12976/SUPP-1
31. Lohe, R. N., Tyagi, B., Singh, V., Kumar Tyagi, P., Khanna, D. R., & Bhutiani, R. (2015). A comparative study for air pollution tolerance index of some terrestrial plant species. *Global Journal of Environmental Science and Management*, *1*(4), 315–324. https://doi.org/10.7508/GJESM.2015.04.006
32. Malav, L. C., Kumar, S., Islam, S., Chaudhary, P., & Khan, S. A. (2022). Assessing the environmental impact of air pollution on crops by monitoring air pollution tolerance index (APTI) and anticipated performance index (API). *Environmental Science and Pollution Research 2022 29:33*, *29*(33), 50427–50442. https://doi.org/10.1007/S11356-022-19505-3
33. Mandal, K., & Dhal, N. K. (2022). Pollution resistance assessment of plants around chromite mine based on anticipated performance index, dust capturing capacity and metal accumulation index. *Environmental Science and Pollution Research International*, *29*(42), 63357–63368. https://doi.org/10.1007/S11356-022-20246-6
34. Molina, L., & Segura, A. (2021). Biochemical and Metabolic Plant Responses toward Polycyclic Aromatic Hydrocarbons and Heavy Metals Present in Atmospheric Pollution. *Plants 2021, Vol. 10, Page 2305*, *10*(11), 2305. https://doi.org/10.3390/PLANTS10112305
35. Molnár, V. É., Simon, E., Tóthmérész, B., Ninsawat, S., & Szabó, S. (2020). Air pollution induced vegetation stress – The Air Pollution Tolerance Index as a quick tool for city health evaluation. *Ecological Indicators*, *113*, 106234. https://doi.org/10.1016/J.ECOLIND.2020.106234
36. Mondal, S., & Singh, G. (2021). Air pollution tolerance, anticipated performance, and metal accumulation capacity of common plant species for green belt development. *Environmental Science and Pollution Research 2021 29:17*, *29*(17), 25507–25518. https://doi.org/10.1007/S11356-021-17716-8
37. Mukherjee, S., & Choudhuri, M. (1983). Implications of water stress-induced changes in the levels of endogenous ascorbic acid and hydrogen peroxide in Vigna seedlings. *Wiley Online Physiologia Plantarum.*, *58*(2), 166–170. https://doi.org/10.1111/J.1399-3054.1983.TB04162.X
38. Mukhopadhyay, S., Dutta, R., & Dhara, A. (2021). Assessment of air pollution tolerance index of Murraya paniculata (L.) Jack in Kolkata metro city, West Bengal, India. *Urban Climate*, *39*, 100977. https://doi.org/10.1016/J.UCLIM.2021.100977
39. Nayak, D., Patel, D. P., Thakare, H. S., Satasiya, K., & Shrivastava, P. K. (n.d.). *Assessm Ent Of Air Pollution Tolerance Index Of Selected Plants*.
40. Nowak, D. J., & Dwyer, J. F. (2007). Understanding the Benefits and Costs of Urban Forest Ecosystems. *Urban and Community Forestry in the Northeast*, 25–46. https://doi.org/10.1007/978-1-4020-4289-8_2
41. Ogunkunle, C. O., Suleiman, L. B., Oyedeji, S., Awotoye, O. O., & Fatoba, P. O. (2015). Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. *Agroforestry Systems 2015 89:3*, *89*(3), 447–454. https://doi.org/10.1007/S10457-014-9781-7
42. Oksanen, E., & Kontunen-Soppela, S. (2021). Plants have different strategies to defend against air pollutants. *Current Opinion in Environmental Science & Health*, *19*, 100222. https://doi.org/10.1016/J.COESH.2020.10.010
43. Pandey, A. K., Pandey, M., Mishra, A., Tiwary, S. M., & Tripathi, B. D. (2015). Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. *Urban Forestry & Urban Greening*, *14*(4), 866–871. https://doi.org/10.1016/J.UFUG.2015.08.001
44. Pandey, A., Pandey, M., & Tripathi, B. (2015). Air Pollution Tolerance Index of climber plant species to develop Vertical Greenery Systems in a polluted tropical city. *Landscape and Urban Planning*, *144*, 119–127. https://doi.org/https://doi.org/10.1016/j.landurbplan.2015.08.014

45. Parmar, P., Kumari, N., & Sharma, V. (2013). Structural and functional alterations in photosynthetic apparatus of plants under cadmium stress. *Botanical Studies 2013 54:1*, *54*(1), 45-. https://doi.org/10.1186/1999-3110-54-45
46. Patel, D., Kumar, J. I. N., Patel, D., & Kumar, J. I. N. (2018). An Evaluation of Air Pollution Tolerance Index and Anticipated Performance Index of Some Tree Species Considered for Green Belt Development: A Case Study of Nandesari Industrial Area, Vadodara, Gujarat, India. *Open Journal of Air Pollution*, *7*(1), 1–13. https://doi.org/10.4236/OJAP.2018.71001
47. Pathak, V., Tripathi, B. D., & Mishra, V. K. (2011). Evaluation of Anticipated Performance Index of some tree species for green belt development to mitigate traffic generated noise. *Urban Forestry & Urban Greening*, *10*(1), 61–66. https://doi.org/10.1016/J.UFUG.2010.06.008
48. Prajapati, S., & Tripathi, B. (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. *Journal of Environmental Management*, (4), 1343–1349. https://doi.org/10.1016/j.jenvman.2007.07.002
49. Rai, P. K., & Panda, L. L. S. (2013). Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region. *Air Quality, Atmosphere & Health 2013 7:1*, *7*(1), 93–101. https://doi.org/10.1007/S11869-013-0217-8
50. Rai, P. K., Panda, L. L. S., Chutia, B. M., & Singh, M. M. (2013). *Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non industrial area (Aizawl) of India: An eco-management approach*. *7*(10), 944–948. https://doi.org/10.5897/AJEST2013.1532
51. Rao, D. S., Raghavendra, M., Madan, S., Munjal, R., & Gill, P. (2020). Effect of oxidative stress on chlorophyll fluorescence, canopy temperature and total leaf protein content in Wheat (*Triticum aestivum* L.) under drought during. *International Journal of Chemistry Studies*, *8*(6). https://doi.org/10.22271/chemi.2020.v8.i6s.10941
52. Rasool, A., Muhammad, S., Tayyab, M., Bajwa, A. A., Majeed, M., Munam, B., Faisal, S., Khairdin, A., Khalid, S., Hanif, H. K., Malik, S. M., & Bilal, M. (2025). Ecological evaluation of dominant roadside plants through APTI and API for sustainable green belt development in cosmopolitan city (Lahore) of Pakistan. *Scientific Reports 2024 15:1*, *15*(1), 10496-. https://doi.org/10.1038/s41598-024-76882-0
53. Roy, A., Bhattacharya, T., & Kumari, M. (2020). Air pollution tolerance, metal accumulation and dust capturing capacity of common tropical trees in commercial and industrial sites. *Science of The Total Environment*, *722*, 137622. https://doi.org/10.1016/J.SCITOTENV.2020.137622
54. Sapkota, S., & Shrestha, S. M. (2024). Assessment of air pollution tolerance index and anticipated performance index of roadside plants used for greenbelt development in the Kathmandu Valley, Nepal. *Environmental Challenges*, *14*, 100818. https://doi.org/10.1016/J.ENVC.2023.100818
55. Savita. (2021). Impacts of Air Pollutants on Forest Ecosystem and Role in Ecological Imbalance. In *Air Pollution and Its Complications* (pp. 129–142). Springer Nature. https://doi.org/10.1007/978-3-030-70509-1_8
56. Shah, K., Amin, N. ul, Ahmad, I., Ara, G., Ren, X., & Xing, L. (2019). Effects of Chronic Dust Load On Leaf Pigments of the Landscape Plant Murraya Paniculata. *Gesunde Pflanzen*, *71*(4), 249–258. https://doi.org/10.1007/S10343-019-00469-3
57. Sheoran, K., Siwal, S. S., Kapoor, D., Singh, N., Saini, A. K., Alsanie, W. F., & Thakur, V. K. (2022). Air Pollutants Removal Using Biofiltration Technique: A Challenge at the Frontiers of Sustainable Environment. *ACS Engineering Au*, *2*(5), 378. https://doi.org/10.1021/ACSENGINEERINGAU.2C00020
58. Singh, S. K., & Rao, D. N. (1983). Evaluation of plants for their tolerance to air pollution. *Symposium on Air Pollution Control*, *1*(1), 218–224.
59. Sinquin, B., Loas, G., Bouhier, S., Frein, L., Vallet, M., Alouini, M., & Romanelli, M. (2024). Influence of Vehicular Pollution on Chlorophyll Content of Roadside Plants. *Optique*, 106–113. https://doi.org/10.34894/VQ1DJA
60. Sternberg, T., Viles, H., Cathersides, A., & Edwards, M. (2010). Dust particulate absorption by ivy (Hedera helix L) on historic walls in urban environments. *Science of The Total Environment*, *409*(1), 162–168. https://doi.org/10.1016/J.SCITOTENV.2010.09.022
61. Tripathi, A., & Gautam, M. (2007). Biochemical parameters of plants as indicators of air pollution. *Journal of Environmental Biology*, *28*(1), 127–132. https://www.academia.edu/download/32863646/5._Journal_of_Env_Biology.pdf
62. Tripathi, D. P., & Nema, A. K. (2023). Seasonal variation of biochemical parameters and air pollution tolerance index (APTI) of selected plant species in Delhi city, and detailed meta-analysis from Indian metropolitan cities. *Atmospheric Environment*, *309*, 119862. https://doi.org/10.1016/J.ATMOSENV.2023.119862
63. Tyagi, N., & Singh, R. (2022). A comparative study on the chlorophyll content of Azadirachta indica plantation suffering from automobile pollution from the Meerut city, India. *Bulletin of Pure & Applied Sciences- Botany*, *41b*(1), 75–78. https://doi.org/10.5958/2320-3196.2022.00008.8
64. WHO. (2021). *WHO global air quality guidelines: particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide: executive summary*. https://iris.who.int/bitstreams/b729bbc4-7032-4799-898e-d112faa16f22/download
65. Wu, Q., Huang, Y., Irga, P., Kumar, P., Li, W., Wei, W., Shon, H. K., Lei, C., & Zhou, J. L. (2024). Synergistic control of urban heat island and urban pollution island effects using green infrastructure. *Journal of Environmental Management*, *370*, 122985. https://doi.org/10.1016/J.JENVMAN.2024.122985
66. Zhang, W., Zhang, Y., Gong, J., Yang, B., Zhang, Z., Wang, B., Zhu, C., Shi, J., & Yue, K. (2020). Comparison of the suitability of plant species for greenbelt construction based on particulate matter capture capacity, air pollution tolerance index, and antioxidant system. *Environmental Pollution*, *263*, 114615. https://doi.org/10.1016/J.ENVPOL.2020.114615