International Journal of Geography, Geology and Environment 2022; 4(2): 122-134

International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2022; 4(2): 122-134
Received: 11-08-2022
Accepted: 12-09-2022

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Suitability assessment of some tree species in traffic-area verges of Delhi, India for air pollution tolerance-cum-performance for green urban planning

Babita Singh and Anubha Kaushik

Abstract
Roadside verges have great role in improving ecology, aesthetics and air quality of urban areas. Capacity of various species to tolerate air pollution and their overall socio-economic importance are crucial for assessing their suitability in green urban planning, an aspect that has largely been overlooked. The present study was undertaken in highly polluted metropolitan city of Delhi, India, assessing five tree species of roadside verges *Bauhinia variegata*, *Ficus benghalensis*, *Ficus religiosa*, *Mangifera indica* and *Polyalthia longifolia* found consistently in high, medium, and low traffic areas in Delhi for their tolerance and performance based on Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API). These indices varied with species, but all responded to increasing air pollution through changed contents of ascorbic acid, relative water, total chlorophyll and pH in leaf extract. For all the species APTI followed the order: S1 (high traffic) > S2 (medium traffic) > S3 (low traffic area), the magnitude of variations was however, species dependent. All species were good performers based on holistic API parameters. *Ficus religiosa* and *Mangifera indica* were found to be excellent performers in highly polluted site S1 (API > 80%), while others were very good /good performers indicating their potential role in scientific urban landscaping of polluted sites.

Keywords: Air Pollution Tolerance Index (APTI), Anticipated Performance Index (API), pollution abatement, roadside verges, traffic density

1. Introduction

On-road emissions from vehicles in urban areas as mobile sources have been recognised as one of the larger contributors to poor air quality in many metropolitan cities of the world (Zhang *et al*., 2016) [68] posing risk to ecosystem and human health (Thimmegowda *et al*., 2020) [57]. Concentration of air borne pollutants along the roadside areas where a wide variety of vehicular traffic operates are of great concern, since these are not subjected to any kind of regular monitoring or maintenance, and air pollutants discharged into the atmosphere in large amounts include both exhaust and non-exhaust sources resulting from resuspension of road dust, mechanical wear and tear of clutches brake wear and tyres (Alshetty *et al*., 2020; Singh *et al*., 2020) [2, 55]. The uneven movement of traffic freight within the city and from outside the city leads to spatial variations of air pollution levels and often creates air pollution hotspots in areas such as traffic intersections, roundabouts and congested narrow roads etc. Air pollutants in cities are routinely being monitored using ground based fixed monitoring stations focussing on some criteria air pollutants and often lack extensive monitoring being confined to specified locations. In this scenario, it is important to aim for pollution abatement in potential air pollution hotspots in the cities which focusses on comprehensive management of air pollution addressing spatial heterogeneity of air pollutants. Trees present in Urban green spaces have the capacity to reduce atmospheric pollution, and provide multiple benefits by mitigating the potential hazards associated with air pollutants, providing great ecosystem service values, and enhancing the aesthetic beauty of the area (Millenium Ecosystem Assessment, 2005; Salmond *et al*., 2016; WHO, 2017; Frumkin et el., 2017; Wang *et al*., 2019; Philips *et al*., 2020) [28, 46, 63, 10, 60, 39].

Leaves of plants growing along the roadside act as a natural sink for many atmospheric pollutants. They act as natural filters to all kind of air pollutant emissions. Also they can provide data about the occurrence, concentration, chemical nature and intensity and morphology of a specific pollutant or of a broad range of pollutants and hence can be successfully incorporated as a simple, cost-effective mitigation strategy, for long-term and large-scale monitoring and revealing the spatio-temporal trends of pollution in different environmental regimes and development of green infrastructure in urban areas (Tong *et al*., 2016; Deshmukh *et al*., 2019; Chen *et al*., 2020) [58, 9, 5]. Every plant possesses some unique natural capacity to act as biological filters to mitigate polluted air, but the response is species specific and pollutant dependent. Resistance to air pollutants by plants is governed by type, concentration level of air pollutants and interaction between plant system and the pollutants (Sæbø *et al*., 2012; Chen *et al*., 2017) [43, 71]. While some plants have got greater adaptability and suitability to a particular type and magnitude of pollutants, there are others that are less tolerant or susceptible to the pollutant. Tolerance, resistance, or sensitivity of plant systems to air pollutants can be successfully used to monitor and mitigate environmental pollution (Oksanen., 2021) [36]. Plant species showing high tolerance can be planted to moderate the air pollution in an area, the resistant species can be considered for future plantations, while sensitive species can be used as natural monitoring systems as biomonitors (Mukherjee *et al*., 2020) [33].

Elevated pollution levels have been reported to have marked effects on micromorphology physiology and biochemical components of plants growing along polluted areas (Sharma *et al*., 2019; Skrynetska *et al*., 2019) [49, 56]. Changes in biochemical attributes of leaves are indicative adaptive strategy to the external abiotic stress in the environment. Ascorbic acid (AA), the strongest plant antioxidant system is known to impart tolerance to the plants under various stress conditions. It not only plays a key role in important cellular functioning of plant like cell wall synthesis, cell division, photosynthesis and the processes that are associated with cell detoxification (Ogunkunle *et al*. 2015) [35] but also helps in withstanding different abiotic stresses like UV radiation, high light intensity, low or high temperature, salinity, deficient or excess water, xenobiotics, heavy metals and air pollution (Singh *et al*., 2021) [52, 53]. Measurement of ascorbic acid gives important information about a plant' s defensive mechanism in terms of its tolerance and sensitivity to pollution load and stress (Gupta *et al*., 2015; Sen *et al*., 2017; Skrynetska *et al*., 2019) [14, 48, 56]. pH of plant shows significant influence on physiological functioning of plants as, all enzymes mediated metabolic pathways are pH specific also plant response to various external stresses are dependent on cell pH (Hussan *et al*., 2018) [17]. Relative water content of leaves is another important parameter representing overall hydration conditions inside the leaf matrix. It is important for physiological functioning of the plant leaves and for withstanding adverse conditions such as air pollution, drought and others (Ogunkunle *et al*., 2015) [35]. Since protoplasmic permeability is directly associated with relative water content, higher percentage of water indicates more tolerant behaviour under stress conditions like air pollution (Singh *et al*., 2019) [72]. Chlorophyll content in plants is essential component of energy production in green plants. Changes in Total chlorophyll content of leaves can be used as a criterion for plant health status and assessment of external environmental condition (Kaur and Nag pal, 2017) [20]. It is seen that a single physiological/ biochemical parameter is not enough to calculate tolerance/sensitivity and sometimes results into conflicting interpretations about the same species (Ogunkunle *et al*., 2015) [35] therefore composite response in the form of Air Pollution Tolerance Index (APTI) gives a holistic tolerance response of a species to the pollutants. This index has been successfully used by many researchers for screening pollution abatement potential of plants exposed to air pollution (Tiwary *et al*., 2015; Alotaibi *et al*., 2019; Roy *et al*., 2020; Yadav *et al*., 2020; Karmakar and Padhy 2019; Molnár *et al*., 2020; Sahu *et al*. 2020) [37, 1, 42, 73, 19, 31, 44]. However, in addition to APTI, which is based on biochemical and physiological responses, another composite index, the Anticipated Performance Index, (API) based on socio-economical and biological parameters helps in providing a more rational decision on adaptability and suitability of particular tree species for monitoring of air pollutants together with ecological restoration and green belt development (Ogunkunle *et al*., 2015; Kaur and Nagpal., 2017; Sahu *et al*., 2020) [35, 20, 44].

Delhi, the capital of India, in the recent years, has witnessed skyrocketing levels of air pollutants such as particulate matter (PM), nitrogen oxides (NO_X), sulphur oxides (SO_X), ground level ozone (O_3) much exceeding the permissible levels recommended by the World Health Organization (WHO, 2006) and National Ambient Air Quality Standards NAAQS (Sahu *et al*. 2010) [45]. Studies report consistently high levels of atmospheric particulates PM_{10} and $PM_{2.5}$ concentrations in the ambient air of Delhi, irrespective of the type of locations. Delhi bears a daily load of about 147 tonnes of atmospheric particulates with varied sources, road dust 52.5%, industries 22.1% and residential sources 18.8% (Kumar *et al*., 2017). Source apportionment studies indicate that 40 per cent Delhi' s bad air quality is contributed by vehicular exhausts (Sahu *et el*., 2010) [45]. Attempts have been made from time to time to improve deteriorating air quality in Delhi by introduction of unleaded petrol, mandatory conversion of all gasoline and diesel based public transport systems to compressed natural gas (CNG), closure and migration of major air polluting industries and Power plants (Guttikunda *et al*., 2014) [15]. But despite these interventions Delhi' s air quality continued dipping and emergency government plans like Graded Response Action Plan (GRAP) have come into place (CPCB, 2017) [6].

Urban landscaping with suitable pollution tolerating and multi-performing plant species is pivotal in effective management and eco-restoration of sites with high air pollution, which till now has been overlooked. Despite a good urban green cover, various constraints of increasing population, and high level of pollution, planning of urban greening in Delhi is gaining attention and scientific planning is crucial for this. The present study is therefore, aimed at assessing the tolerance or sensitivity of six commonly present native trees of roadside verges present in three air pollution hotspots of Delhi currently under the influence of Continuous Ambient Air Quality Monitoring Stations established by Central Pollution Control Board of India, based on two well-known air pollution indices APTI and API for the identification of suitable plant species for successful air pollution mitigation and green infrastructure planning of urban areas with varying magnitudes of air pollution. Novelty of the study is to explore the range of adaptability of these species to increasing exposure of air pollution.

2. Materials and Methods

2.1 Study area

This study was carried out in Delhi, India by selecting three zones S1, S2, S3 (Fig 1) with varying vehicular density (high, moderate, and low) and proximity to an existing air pollution monitoring station, which made air pollution data of the site readily available. Sampling site Table 1 provides details about biomonitoring zones, nearest Continuous air quality monitoring stations (CAAQMS), station type, location and, physical condition of roads with traffic conditions during peak traffic hours. Anand Vihar traffic intersection (S1) is a high traffic density area surrounded by largest interstate bus terminus (ISBT), a metro station, and industrial areas Sahibabad and Patparganj. The nearest air pollution monitoring station to this site is Anand Vihar, which is located inside the ISBT parking lot. Sampling site (S2) is located near Wazirpur industrial area which has moderate traffic density. The area is mostly surrounded by steel pickling industries. The nearest air pollution monitoring station to this site is Wazirpur (≈ 1 Km distance). Sampling site Punjabi Bagh (S3) is a residential area with low traffic density. The nearest air pollution monitoring station near to this site is Punjabi Bagh (30 m away).

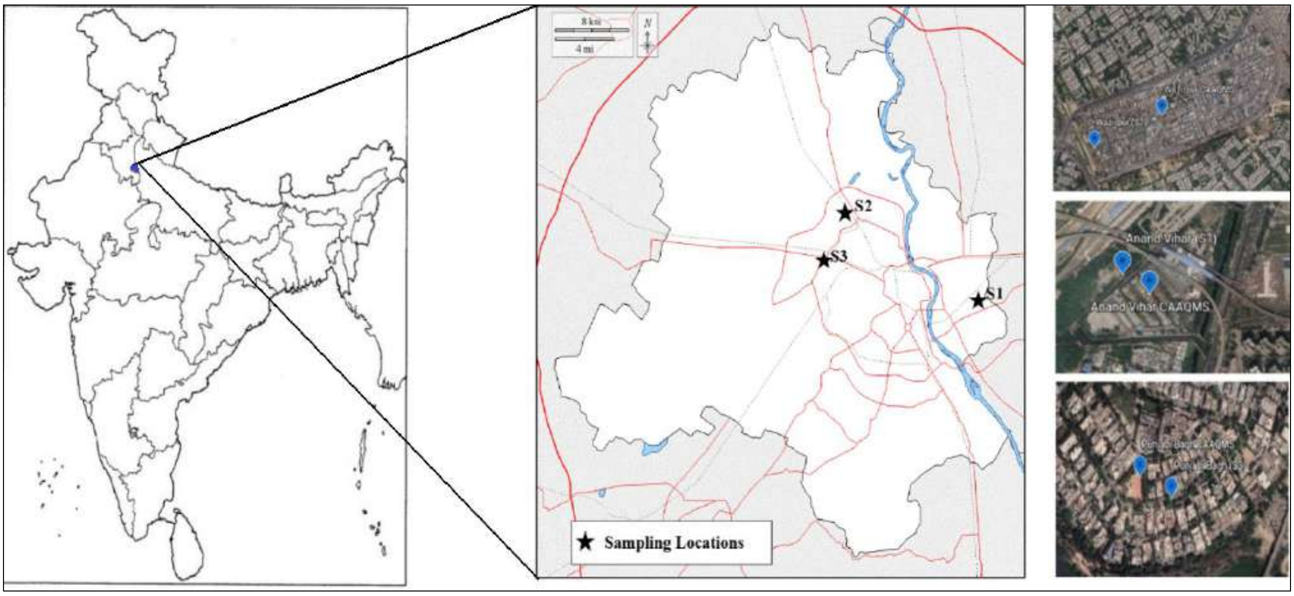


Fig 1: Map of Delhi showing biomonitoring sites (S1, Anand Vihar, S2, Wazirpur; S3, Punjabi Bagh) and nearest continuous air quality monitoring stations (CAAQMS)

Table 1: Details of Biomonitoring zones, nearest Continuous air quality monitoring stations (CAAQMS), station type, and location and, physical condition of roads with traffic conditions during peak traffic hours

Biomonitoring zones	Nearest CAAQMS	Monitoring Station type	Location	Physical condition of road and traffic conditions during peak traffic hours
Anand Vihar (S1)	Anand Vihar	Residential, industrial and commercial	28.646835, 77.316032	Dusty roads, high traffic density
Wazirpur (S2)	Wazirpur	Industrial	28.422523, 77.103292	Dusty roads, medium traffic density
Punjabi Bagh (S3)	Punjabi Bagh	Residential, industrial and commercial	28.563262, 77.186937	Comparatively cleaner roads, low traffic density

2.2 Selection of tree species, sample collection and preparation

The road verges comprising a strip of vegetation located between a roadway (carriageway) and a sidewalk (pavement) were considered in the study for selection and sampling of the trees. Five Tree species *viz*. *Ficus religiosa* (Moraceae), *Ficus benghalensis* (Moraceae), *Bauhinia variegata* (Fabaceae), *Mangifera indica* (Anacardiaceae) and *Polyalthia longifolia* (Annonaceae) were selected. Micro-morphological characteristics of the selected tree species are provided in Table 2.

Sampling was done in March- April 2018 with frequency of sampling once in a week. The trees were marked in first sampling, mature trees with a girth at breast height (GBH) higher than 30 cm were sampled ensuring their commonness to all biomonitoring zones and presence within (2 Km radius) so that they were under the maximum zone of influence of respective Continuous air quality monitoring stations (CAAQMS). About 10-15 healthy leaves were sampled from each individual tree at a height of 1.3 to 1.7 m from ground level to simulate adult human inhalation height conditions. Sampled leaves were washed and stored in ziplock bags and before chemical analysis samples from different trees of each individual species collected from a specific biomonitoring zone were mixed to make a composite sample for that particular zone. All the experiments were performed in triplicates. Altogether a total of 61 trees were sampled from all biomonitoring zones. Details of Tree species and number of individual trees selected for sampling in each zone are given in Table 3.

Table 2: Leaf micromorphological properties and nature of the tree species used in the study

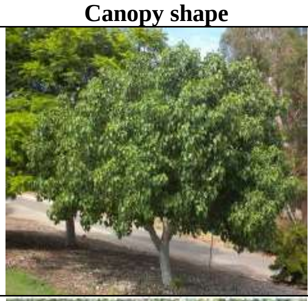
Tree species (Family)	Leaf properties, Nature of the tree	Leaf image	Canopy shape
Ficus religiosa (Moraceae)	Cordate, wavy, smooth adaxial, slightly rough abaxial surface, non-glandular trichomes present; stomata on abaxial surface only deciduous, hardy.		
Ficus benghalensis (Moraceae)	Elliptical, entire, epi-cuticular wax, leathery, unicellular glandular trichomes on abaxial surface, stomata abaxial, deciduous, hardy.		
Bauhinia variegata (Fabaceae)	Simple lobed, entire, smooth glabrous, stomata abaxial, pubescent, trichomes present, deciduous, hardy.		
Mangifera indica (Anacardiaceae)	Lanceolate, entire, fibrous, trichomes present on both abaxial and adaxial surfaces, stomata abaxial, Semi - evergreen, hardy.		
Polyalthia longifolia (Annonaceae)	Linear lanceolate, wavy, glossy smooth. trichomes absent, stomata abaxial, evergreen.		

Table 3: Tree species and number of individual trees selected for sampling in each zone

Tree species	Common name	Number of individual trees per zone		
		Anand Vihar (S1)	Wazirpur (S2)	Punjabi Bagh (S3)
Ficus religiosa	Peepal	5	7	8
Ficus benghalensis	Bargad	3	4	3
Bauhinia variegate	Kachnar	2	2	3
Mangifera indica	Mango	4	3	4
Polyalthia longifolia	Ashoka	4	5	4
Sub total		18	21	22
Total		61		

2.3 Determination of leaf biochemical parameters

Ascorbic acid content was determined spectrophotometrically following the method described by Bajaj and Kaur (1981) [74]. 1 gm of the crushed leaf sample was taken in a test tube. 4 ml of oxalic acid-EDTA extracting solution was added to the contents of test tube followed by 1ml of orthophosphoric acid, 1ml of 5% sulphuric acid and 2 ml of 5% ammonium molybdate and 3 ml of distilled water. The solution was kept for 15 minutes, and the absorbance was taken at 760 nm using UV Visible Spectrophotometer (Hach DR- 4000). Concentration of ascorbic acid in mg/ml was obtained from the standard ascorbic acid curve and was converted to ascorbic acid content per gram dry weight.

Total chlorophyll content (mg/g) was determined using methodology proposed by Arnon (1949) [3]. For this 5 g of the leaf sample was homogenised using 80% acetone and the contents were centrifuged at 2500 rpm for 15 minutes. The supernatant was separated, and absorbance was taken spectrophotometrically at 645 nm for chlorophyll a, and 663 nm for chlorophyll b, using UV Visible Spectrophotometer (Hach DR- 4000). Total chlorophyll content was calculated using Eq. (1):

$$\text{Total CHL (mg g}^{-1}) = 20.2\,(A_{645}) + 8.02\,(A_{663}) * V/m * 1000 \quad (1)$$

Where A_{645}, A_{663} are absorbance at 645 nm, 663 nm, V= Total volume of the extract (ml), m = weight of leaf sample (g).

Leaf-extract pH was determined following the method described by Singh and Rao (1983). 5g of the leaf sample was taken crushed and homogenised in 50 ml of deionised water. The homogenised sample was filtered, and pH was measured using digital pH meter.

Relative water content of leaf samples was determined gravimetrically using the Eq.2 (Singh 1977) [51]:

$$\text{Relative water content (\%)} = (W_f - W_d) * 100 / (W_t - W_d) \quad (2)$$

Where W_f is fresh weight of individual leaves immediately taken after collection of leaves, W_d is oven dried weight of leaves subjected to overnight drying at 70˚C in hot air oven. W_t is turgid weight of leaves obtained after overnight immersion of leaves in deionised water.

2.5 Determination of Air pollution Tolerance Index (APTI) and Anticipated Performance Index (API)

Air pollution Tolerance Index (APTI) was calculated as per Eq.3 (Singh *et al*. 1983):

$$APTI = [AA (TCh + pH) + RWC] / 10 \quad (3)$$

Where AA = ascorbic acid content, TCh= Total chlorophyll, pH represents pH of leaf-extract, RWC= relative water content of leaf

Anticipated performance index (API) was calculated as a composite score based upon the pollution tolerance, biological characteristics like tree height, canopy structure, leaf structure, deciduous/ perennial nature, and socio-economic significance and uses of the species. Grading scheme of plant species, % score and assessment categories were adopted from Prajapati and Tripathi (2008) [40], Pandey *et al*. (2015) [37]. Based on APTI and API, the plant species were evaluated for assessing their suitability

Table 4: Grading scheme based on APTI and biological and socio-economic importance

Grading criteria	Parameter	Pattern of assessment	Grades allotted
Air pollution Tolerance	APTI	12.0-16.0	+
		16.1-20.0	++
		20.1-24.0	+++
		24.1-28.0	++++
		28.1-32.0	+++++
		> 36.0	++++++
Biological characteristics	Tree height	Small	-
		Medium	+
		Large	++
	Canopy Structure	Sparse/irregular/globular	-
		Spreading crown	+
		Spreading dense	++
	Nature of plant	Deciduous	-
		Evergreen	+
	Laminar structure	Small	-
		Medium	+
		Large	+++
	Texture	Smooth	-
		Coriaceous	+
	Hardiness	Delineate	-
		Hardy	+
Socio- economic value	Economic value	Less than three uses	-
		Three to four uses	+
		Five or more uses	++

Table 5: Anticipated Performance Index scores and assessment categories

Grade	% Score	Assessment category
0	< 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

2.6 Collection of Air pollution data

Daily 24 Hrs mean concentration data of $PM_{2.5}$ and PM_{10} were obtained from the nearest Continuous air quality monitoring system (CAAQMS) station as mentioned above for all the three study sites. The data was downloaded from ENVIS Centre on Control of Pollution of Water, Air and Noise website hosted by Central Pollution Control Board (CPCB) and sponsored by Ministry of Environment, Forest and Climate change, Government of India (http://www.cpcbenvis.nic.in). The data follows quality assurance and quality control protocols (QA/QC) which is done by CPCB using standardised rigorous protocols for the calibration and maintenance of instruments. Since accumulation of air pollutants is a gradual process data from the nearest air pollution monitoring to the study sites was obtained for 45 days prior to carrying out sampling.

3. Results and discussion

3.1 Air pollution data from nearest CAAQMS to study sites

The air quality data obtained from the nearest CAAQMS at each site showed different air pollutant concentrations (daily 24 Hrs mean) in the study sites. Study site S1 represented highest concentration of $PM_{2.5}$ and PM_{10}. Overall trend of $PM_{2.5}$ in the three sites was in the order S1 (115.72 µg/m^3) >

S2 (112.60 μg/m^3) > S3 (92.75 μg/m^3). Overall trend of PM_{10} in the three sites was in the order S1 (307.88 μg/m^3) > S2 (301.16 μg/m^3) > S3 (215.66 μg/m^3).

3.2 Ascorbic acid content of plant leaves in different sites

Ascorbic acid (AA) concentrations varied significantly between species across different sites (Fig.2). Interestingly, all the five species showed highest ascorbic acid content (5.08-21.34 mg/g) at S1, with high traffic emission exposure. This was followed by that at S2 (10.32-13.73mg/g) with medium traffic emissions, while at site S3 with low traffic density, the plant species had the lowest AA content (5.03- 8.9 mg/g). The differences in average AA content in the leaves of the trees at these three sites were statistically significant ($p > 0.05$) indicating strong impact of existing pollution load in the atmosphere on the plant' s accumulation of ascorbic acid (Mukherjee and Agrawal., 2016) [32]. Overall, for the AA content we observed the trend S1 > S2 > S3 indicating that higher the anthropogenic/ technogenic pollution load higher is the AA content. The high traffic site S1 has much higher load of air pollutants (PM_{10} and $PM_{2.5}$) as compared to S2 and S3. The plants tend to synthesize more AA as a defence to the stress conditions. The medium traffic area S2, shows significantly greater ($p > 0.05$) AA accumulation in the plant leaves than that in low traffic density site S3.

Amongst various species, the trend of average AA accumulation followed the order:

Ficus benghalensis > *Polyalthia longifolia* > *Bauhinia variegata* > *Mangifera indica* > *Ficus religiosa*

Thus, there are significant inter-specific differences in AA accumulation, but the variations are found to get further influenced by the prevailing air pollution in the site, as may be seen in Fig.2.

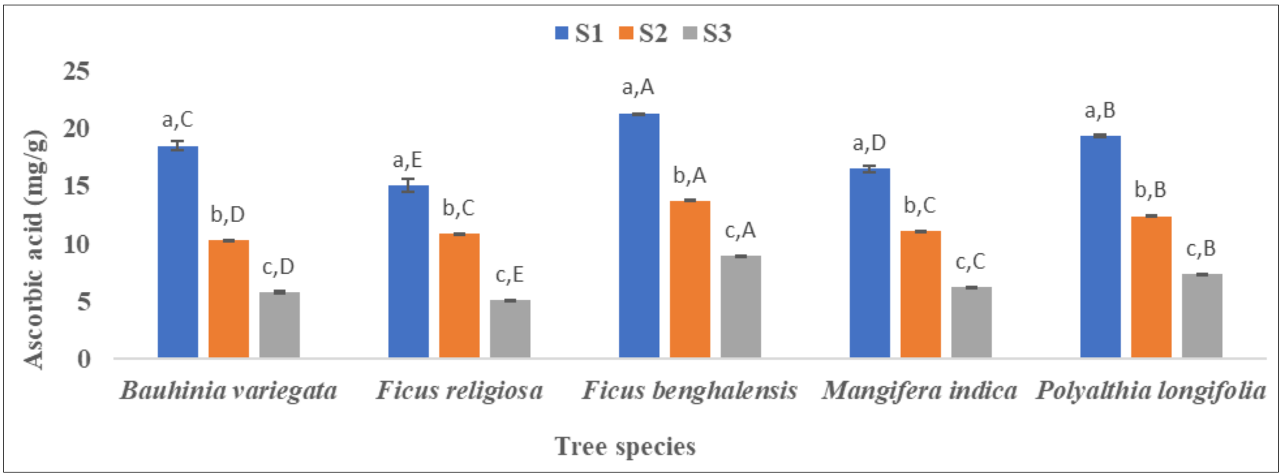


Fig 2: Ascorbic acid content (AA) in various species from different sampling sites S1 (Anand Vihar Traffic intersection), S2 (Wazirpur industrial area), S3 (Punjabi Bagh). Values are mean ± S.D (n =3). Small letters indicate significant differences between different sampling sites for each considered species. Capital letters indicate significant differences between the tree species within each sampling site. Same letters are not statistically significant at ($p \leq 0.05$) [ANOVA Tukey HSD]. Error bars are standard deviation.

3.3 Leaf extract pH

The pH values of leaf extract exhibited inter-species as well as inter-site variations (Fig.3). The low traffic density site S3, in general, showed slightly acidic to neutral pH of leaf extracts (pH 6.1-7.3) with the following order of average pH: *Ficus religiosa* (7.33) > *Polyalthia longifolia* (7.16) > *Bauhinia variegata* (6.88) > *Mangifera indica* (6.35) > *Ficus benghalensis.* The average pH of leaf extrats tended to be low in the medium traffic site S2 also. Except *Bauhinia variegata* and *Mangifera indica*, in all the other species, the leaf extract showed significant decline ($P < 0.05$) in pH in S2, in comparison to that in S3. Maximum fall in pH was observed in case of *Polyalthia longifolia* (from 7.16±0.13 in S3 to 4.14±0.07 in S1). This indicates that *Polyalthia longifolia* leaves have low buffering capacity and therefore, on exposure to acidic pollutant gases, the pH falls. The variations between species as well as between sites were found to be statistically significant in most of the cases as may be seen in Fig.3.

The variations are indicative of species-dependent response to the pollution stress as has often been reported (Kaur and Nagpal, 2017) [20]. The results show that pH of leaf extract tends to fall in response to the acidic atmospheric pollutants like SO_2 and NO_x, which is a mechanism of the plants to deal with abiotic stress in the form of atmospheric pollutants. Presence of pollutants in the ambient environment causes stress in plant and in response plant releases massive H+ ions to react with acidic gases which enter from the stomata and intercellular spaces from the atmosphere to form acids thereby reducing pH (Zhen., 2000) [70]. Reduction in leaf pH value indicates sensitivity to air pollutants while a higher pH value indicates tolerance (Govindaraju *et al*., 2012) [12]. In this study the pH values of species in site S1 were observed to be lower than other two sites (S2 and S3). The mean pH values of leaf extracts in the sites S2 (5.83) and S1 (5.41) indicates prevalence of acidic gases like SO_2 and NO_x in these areas (Sharma *et al*., 2019) [49]. Overall, the mean pH value across all the sites followed the sequence S3 > S2 > S1. Interestingly the pH values of all the species were > 6 indicating that these species are not affected adversely by high pollution stress and seem have devised adaptability and tolerance to elevated levels of air pollutants by good buffering capacity (Roy *et al*., 2020) [42].

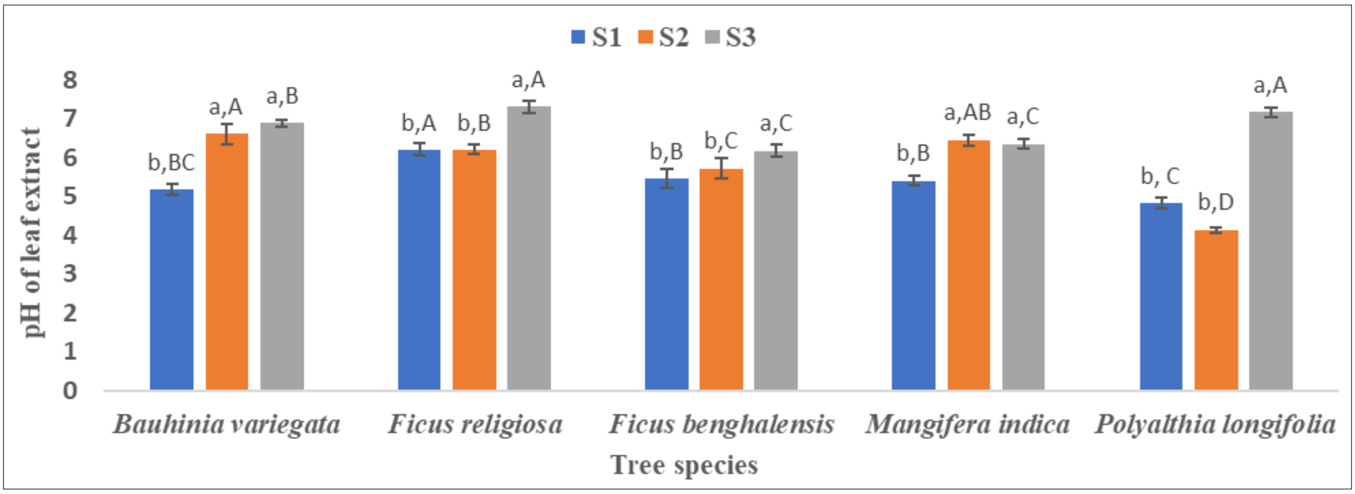


Fig 3: pH variation as observed for species *Bauhinia variegata*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica* and *Polyalthia longifolia* as observed in considered sampling sites S1 (Anand Vihar Traffic intersection), S2 (Wazirpur industrial area), S3 (Punjabi Bagh). (Values are mean ± S.D (n =3). Small letters indicate significant differences between different sampling sites for each considered species. Capital letters indicate significant differences between the tree species within each sampling site. Same letters are not statistically significant at ($p \leq 0.05$) [ANOVA Tukey HSD]. Error bars are standard deviation)

3.4 Relative water content (RWC %)

In the present study, RWC (%) in leaves of the species varied from 71.46±2.41 to 95.22±0.17 across different sites (Fig.4). RWC (%) in leaves were found to be in quite high (90.1- 95.22) in different species, in site S3 with low traffic exposure. At site S1 with high traffic density, the RWC of leaves in all the species was found to decline (Fig.4). The RWC (%) ranged from 73.43±4.38 in *Mangifera indica* to 76.44±1.03 in *Bauhinia variegate*, with a site average of 74.67. At S2 site, the lowest RWC (%) was observed in *Bauhinia variegata* (85.05±0.58) and highest in *Polyalthia longifolia* (93.76±0.56) with an average value of 90.05. Species *Ficus religiosa*, *Ficus benghalensis* and *Polyalthia longifolia and Mangifera indica* had values > 90% indicating that these species are more tolerant and are able to maintain hydration conditions under medium pollution stress. High RWC (%) is found in species that can tolerate or effectively remove pollutants (Paulsamy *et al.*, 2000; Karmakar and Padhy., 2019; Treesubsuntorn *et al.*, 2021) [38, 19, 59]. Species *Bauhinia variegata* and *Mangifera indica* showed statistically significant variation in RWC ($p < 0.05$) across the sites and followed the sequence S3 > S2 > S1.

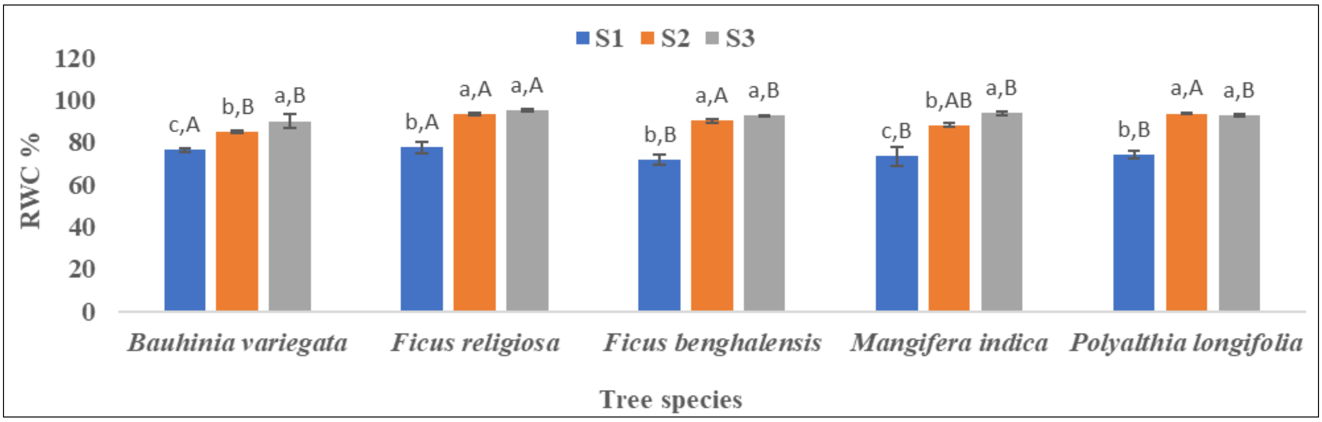


Fig 4: RWC variation as observed for species *Bauhinia variegata*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica* and *Polyalthia longifolia* as observed in considered sampling sites S1 (Anand Vihar Traffic intersection), S1 (Wazirpur industrial area), S3 (Punjabi Bagh). Values are mean ± S.D (n =3). Small letters indicate significant differences between different sampling sites for each considered species. Capital letters indicate significant differences between the tree species within each sampling site. Same letters indicate that the differences are statistically not significant ($p \leq 0.05$) [ANOVA Tukey HSD] Error bars indicate standard deviation.

3.5 Total chlorophyll content (TCh)

Total chlorophyll in leaves of various species varied from 2.55±0.02 mg/g (*Ficus benghalensis*) to 7.91±0.05 mg/g (*Bauhinia variegata*) across different sites as shown in Fig 5. The average TCh values at different sites followed the sequence S3 (6.84 mg/g) > S2 (4.93 mg/g) > S1 (3.53 mg/g), which indicates that as the exposure of the plants to traffic emissions increase, there is a decline in TCh. During stress conditions plant chlorophyll undergoes photochemical reactions like oxidation, reduction, phaeophytinization and reversible bleaching as it is highly organised pigment in the plant system (Karmakar and Padhy, 2019) [19]. At the low traffic site S3, leaf TCh values ranged from 6.22±0.01 mg/g in *Mangifera indica* to 7.91± 0.05 mg/g in *Bauhinia variegata*, which was closely followed by *Ficus religiosa* (7.61). In site S2 with moderate traffic exposure, the concentration of TCh was found to decline in all the species. However, the decline was less marked in the case of *Polyalthia longifolia* (5.71±0.01 mg/g), which shows that this species has more resistance to TCh degradation on exposure to medium pollution stress. At high traffic site S1, all the species showed a distinct decline in TCh concentration, which varied from 2.55±0.02 mg/g in *Ficus benghalensis* to 4.02± 0.05 mg/g in *Polyalthia longifolia*. Thus, the TCh concentration was affected less in the case of *Polyalthia longifolia* even in S1 site indicating its tolerance. Exposure to pollutants such as SO_2, NO_2 and O_3 damage the stomatal membrane and chlorophyll pigments (Ramakrishnaiah and Somashanker, 2013) [41]. Presence of acidic gases in the ambient environment leads to the increase in H+ ions in the leaf tissue thereby affecting the pH of plant leaf, and subsequent loss of magnesium ion from the tetrapyrol ring of chlorophyll molecule which causes structural damage to chlorophyll molecule and converts it into a brown coloured pigment phaeophytin (Kaur and Nagpal., 2017; Karmakar and Padhy., 2019) [20, 19]. In polluted environments generally there is decrease in chlorophyll content (Kaur and Nagpal 2017; Milkailova *et al*., 2017; Molnár 2018; Sahu *et al*., 2020) [20, 30, 44] due to chlorophyll degradation as we also observed in case of the five tree species studied in response to differential pollution exposure.

The leaf TCh values were affected adversely by the pollutant and therefore showed the trend S3 (6.84 mg/g) > S2 (4.93 mg/g) > S1 (3.53 mg/g). As traffic exposure increases, the damage to chlorophyll biosynthetic pathway of the species increases. Species that develop some adaptation to the pollutants show relatively higher TCh (De Nicola *et al*., 2011), as in case of *Polyalthia longifolia* in the present study. High O_3 concentrations in ambient environment also has profound effects on the plant TCh levels. Studies have indicated that O_3 causes oxidative stress in plants leading to impairment of photosynthetic activity and loss of chlorophyll pigment (Yan *et al*., 2010; Wang *et al*., 2015; Zhang *et al*., 2016) [65, 61, 68] and decrease in TCh contents can be attributed to the synergistic effect air pollutants present in the polluted areas rather than single air pollutant (Kapoor *et al*., 2013; Mir *et al*., 2021) [18, 29].

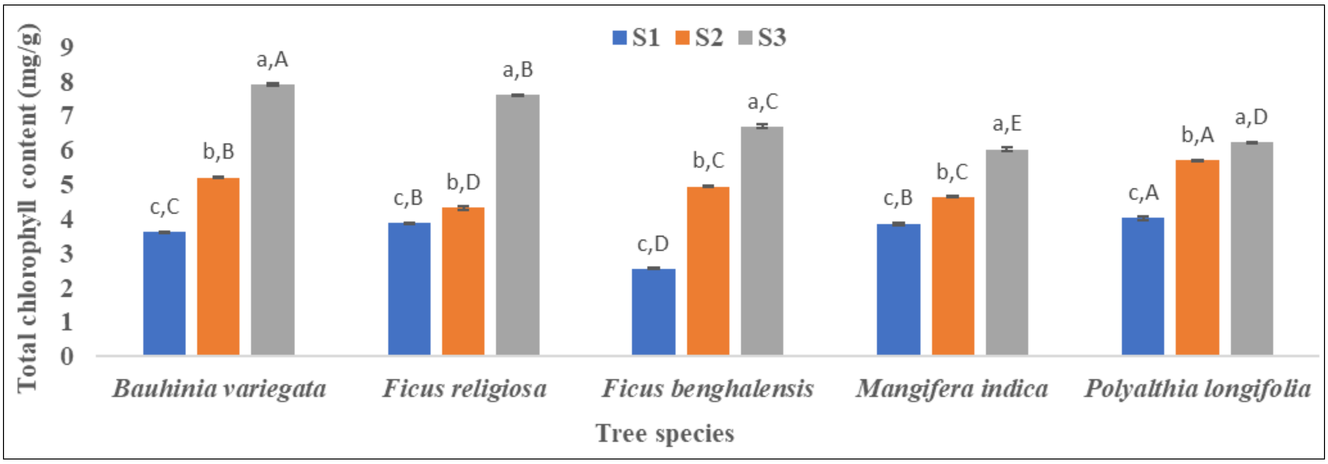


Fig 5: Total chlorophyll content (TCh) as observed for species *Bauhinia variegata*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica* and *Polyalthia longifolia* as observed in considered sampling sites S1 (Anand Vihar Traffic intersection), S2 (Wazirpur industrial area), S3 (Punjabi Bagh). (Values are mean ± S.D (n =3). Small letters indicate significant differences between different sampling sites for each considered species. Capital letters indicate significant differences between the tree species within each sampling site. Same letters are not statistically significant at ($p \leq 0.05$) [ANOVA Tukey HSD]. Error bars are standard deviation).

3.6 Air Pollution Tolerance Index (APTI) of the tree species

APTI of the five species in the three sites are shown in Table 6 The highest APTI was shown by *Ficus religiosa* across the three sites, in low traffic site S3, its APTI was 22.80, which increased to 24.62 on medium traffic site S2, and was still higher (29.26) when exposed to high traffic. This shows that a species tends to adapt itself to the pollution stress by multiple adjustments in its biochemical-physiological functions, which is revealed by increasing APTI values in *Ficus religiosa* in response to increasing load of pollutants in the atmosphere. All the species showed the following trend of APTI: S1 >S2 > S3. However, *Mangifera indica* showed relatively more pronounced increase in APTI values with increasing exposure to emissions. In this species the values were 22.63 (S1), 21.07 (S2) and 17.08 (S3), which shows that this species adapts itself very well to the pollution by modifying its biochemical and physiological responses.

Table 6: Air pollution tolerance index of the studied species

Tree species	Area	AA (mg/g)	pH	TCH (mg/g)	RWC (%)	APTI
Bauhinia variegata	S1	18.52	5.18	3.62	76.44	23.94
Ficus benghalensis		15.08	5.46	2.55	71.76	19.25
Ficus religiosa		21.34	6.20	3.87	77.72	29.26
Mangifera indica		16.51	5.40	3.86	73.43	22.63
Polyalthia longifolia		19.39	4.81	4.02	74.16	24.53
Bauhinia variegata	S2	10.32	6.61	5.20	85.05	20.69
Ficus benghalensis		10.87	5.72	4.32	90.32	19.94
Ficus religiosa		13.73	6.20	4.94	93.26	24.62
Mangifera indica		11.05	6.45	4.64	88.16	21.07
Polyalthia longifolia		12.39	4.14	5.71	93.76	21.58
Bauhinia variegata	S3	17.52	6.88	7.91	90.10	17.52

Ficus benghalensis		15.74	6.17	6.69	92.81	15.74
Ficus religiosa		22.80	7.31	7.61	95.22	22.80
Mangifera indica		17.08	6.35	6.02	93.92	17.08
Polyalthia longifolia		19.07	7.16	6.22	92.99	19.07

Increased APTI values in response to higher pollution load were reported earlier also (Alotaibi *et al*., 2020) [1]. Tolerance of the present species when assessed on a generalized grading scale (Table 4) indicated that all the species except *Ficus benghalensis* had APTI more than 20, indicating good tolerance to air pollution. *Mangifera indica*, which has relatively lower APTI in site S3 having low pollution, shows remarkable increase in its APTI in polluted sites S1 and S2.

Thus, these species in the roadside verges are well adapted to the high pollution levels. Species with high APTI can be used as a sink to mitigate environmental pollution, while sensitive species can be used as biomonitors of atmospheric pollution (Zhang *et al*., 2016; Sahu *et al*., 2020) [68, 44]. Species *Ficus religiosa* showed highest tolerance (APTI) in all the areas indicating its excellent suitability in replantation drives for landscaping and as greenbelt in polluted urban environments.

3.7 Anticipated Performance Index (API) of the tree species

API is a composite score indicating the air pollution tolerance of the plant species as well as its overall utility from socio-economic point of view to indicate its suitability as an effective greenbelt species and urban landscape species, which will mitigate pollution and assist in Eco-restoration. The API values computed for all the five tree species, based on APTI and relevant biological and socioeconomic characteristics, are shown in Table 7. The anticipated performance category was assigned to each species across the three sites according to Prajapati and Tripathi (2008) [40]. Besides Air pollution tolerance index, tree height, canopy structure, laminar structure, laminar texture, economic value and hardiness of the species together reflect its overall performance under the polluted environment. The API values of the tree species under study showed the same trend as that for AA and APTI, as: S1 > S2 > S3.

Table 7: Evaluation of Anticipated Performance Index of selected tree species

Site	Tree species	APTI	TH	CS	LS	TOP	LT	EV	H	Grades Total plus (+)	Score %	API category
S1	*Bauhinia variegata*	+++	+	+	+	+	+	++	+	11	68.75	Good
	Ficus benghalensis	++	++	+	++	++	+	+	+	12	75	Very good
	Ficus religiosa	+++++	++	+	+	+	+	++	+	14	87.5	Excellent
	Mangifera indica	+++	++	++	+	+	+	++	+	13	81.25	Excellent
	Polyalthia longifolia	++++	++	+	+	+	+	+	+	12	75	Very good
S2	*Bauhinia variegata*	+++	+	+	+	+	+	++	+	11	68.75	Good
	Ficus benghalensis	++	++	+	++	++	+	+	+	12	75	Very good
	Ficus religiosa	++++	++	+	+	+	+	++	+	13	81.25	Excellent
	Mangifera indica	+++	++	++	+	+	+	++	+	13	81.25	Excellent
	Polyalthia longifolia	+++	++	+	+	+	+	+	+	11	68.75	Good
S3	*Bauhinia variegata*	++	+	+	+	+	+	++	+	10	62.5	Good
	Ficus benghalensis	+	++	+	++	++	+	+	+	11	68.75	Good
	Ficus religiosa	+++	++	+	+	+	+	++	+	12	75	Very good
	Mangifera indica	++	++	++	+	+	+	++	+	12	75	Very good
	Polyalthia longifolia	++	++	+	+	+	+	+	+	10	62.5	Good

APTI- Air pollution tolerance index; TH- Tree height; CS- Canopy structure; LS- Laminar structure; LT- Laminar texture; EV-Economic value; H- Hardiness

When the trees are exposed to increasingly higher traffic pollution, there is more and more accumulation of AA, which results in higher APTI values, and API values. Thus, under low pollution, the API values were relatively less, but all the species were found to have API in good (62.5% score) and very good (*Ficus religiosa*, *Mangifera indica* - 75% score) categories. In the moderate traffic area S2, these two species *Ficus religiosa* and *Mangifera indica* were found to be excellent performers with API score value of 81.25% each, and in high traffic area S1, the API score of *Ficus religiosa* improved further to 87.5%. Though Ficus *benghalensis* had a relatively lower APTI score, but its grading was good in terms of other parameters, which improve its API score (75%), making it a very good performer. *Bauhinia variegata* and *Polyalthia longifolia* which had relatively lower API scores (62.5-68.75%) were still anticipated as good performers. *Polyalthia longifolia* exhibited improved API score (75%) in the highly polluted S1 site, upgrading it to the category of very good performer.

Thus, none of the species represented poor anticipated performance index indicating that these existing roadside verge tree species are well adapted to high pollution stress due to fixed area sources such as industries as well as point mobile sources of automobile exhausts, and also to local air pollution sources in residential areas. High tolerance to pollution levels as revealed by APTI and API indicate that these species, particularly *Ficus religiosa* and *Mangifera indica* are very suitable for greenbelt development and replantation drives along the roadside areas. The results of present study suggested that tree species having higher APTI and API are more appropriate species in terms of pollution abatement which is similar to as reported many researchers (Ogunkunle *et al*., 2015; Alatoibi *et al*., 2020; Sahu *et al*., 2020) [35, 44].

4. Conclusion

Development of urban green infrastructure is being given prime importance in the recent times as health issues arising from growing air pollution in big cities have become alarming. While trees have been given importance since ages mainly because of the shade, flowers, fruits, nesting places for birds, and aesthetic beauty, the ecological services provided by them have been appreciated only in the last few decades. With role of trees as bio-trap and mitigators of atmospheric pollutants becoming evident, scientific selection of tree species with high pollution tolerance and superior performance potential has become important for urban green planning. *Ficus religiosa* and *Mangifera indica* show very high tolerance to the high traffic pollution exposure, with high APTI values (21-29), and excellent performance indices (API 81.5-87.5%) show great promise for their use in urban landscaping in highly polluted areas. Such species can be grown to moderate the air pollution and simultaneously provide socio-economic as well as ecological benefits. The tree species thriving in the polluted environments were found to have devised various physiological and biochemical transformations to cope up with the stress conditions. The other three species also showed very good to good performance in medium and high traffic areas.

A major finding of the study was that even though some species had relatively lower tolerance (APTI) under normal conditions but have an ability to improve their tolerance to atmospheric pollution by accumulating higher concentrations of ascorbic acid (Vitamin C), which is a powerful agent to fight oxidative stress caused by pollutants, thus increasing the APTI. This property of acquiring increased tolerance on being exposed to stress conditions is species-specific, and amongst the five species, it was manifested most in case of *Mangifera indica.* Results showing superior tolerance and anticipated performance of *Ficus religiosa*, *Mangifera indica* suggest their excellent suitability in urban greening programs across various ranges of polluted air environments. Further, the study shows that even those species (*Bauhinia variegata* and *Polyalthia longifolia*) that have relatively much lower air pollution tolerance in less polluted areas, have the potential to improve their APTI by accumulating more ascorbic acid content and relative water content, resisting fall in leaf pH, and maintaining the integrity of total chlorophyll in leaves on exposure to high air pollution. The potential of such species for improvement in APTI and API values with increased air pollution exposure suggests that these can also be used for future planning and management of urban landscaping and scientific planting.

5. Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work presented in this paper.

6. Acknowledgements

Authors thank GGS Indraprastha University, New Delhi for research grant under Faculty Research Grant Scheme and fellowship (STRF) to BS.

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