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Evaluation of Anticipated Performance Index of Tree Species for Air Pollution Mitigation in Islamabad, Pakistan

ABSTRACT

There is ever increasing problem of air pollution in cities due to urbanization, industrialization, population growth and increased number of vehicles. Plants can play a vital role in mitigation of air pollution in urban areas. The present study was conducted to estimate the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) for 21 different plant species used for green belt development along the roadsides in Islamabad, the capital city of Pakistan. For APTI and API estimation, ascorbic acid, total chlorophyll content, relative water content and pH of leaf extract of selected plant species were measured using standard methods. The results showed that Syzygium cumini L. (jaman), Pterospermum acerifolium (kanak champa) and Alstonia scholaris (devil tree) were the excellent performers. According to API and APTI values, these species were found effective in reducing air pollution and could be effective for green belt development in urban areas. Albezia lebbeck, Melia azedarach, Eucliptus camaldulensis, Dalbergia sissoo, Tamarindus indica, Acacia nilotica L., Callistemon viminalis and Leucaena leucocephala are very poor performers regarding air and noise abatement. These plants are very poor performers and are very sensitive plants to air pollution. These plants can be used as bio-indicators of poor urban air quality.

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INTRODUCTION

For the past few decades, there has been more urbanization, construction of roads and tremendous increase in traffic in cities of developing countries. Road traffic is considered the major source of atmospheric pollution having unfavorable impacts on human health and crop yield (*Franchini 2018; Leghari et al. 2017*). The ambient environment of an urban area may be contaminated with several pollutants such as SO_2, NO_x, CO, particulate matter (PM) and heavy metals. Plants play an important role in minimizing pollution through absorption and accumulation of pollutants through their leaves. If the uptake of pollutants, gasses and particles by plants is improved, the quality of air can be enhanced in urban environment (*Su et al. 2018; Naeem et al. 2018*). Plants, especially trees, are most important for maintaining the ecological balance in environment because they are more vulnerable to toxic air pollutants than animals and human beings (*Swami and Chouhan. 2015; Achakzai et al. 2017*). Dust interception capacity of plants depends on their surface geometry, phyllotaxy, leaf external characteristics, and height and canopy of trees. Furthermore, urban air temperature is also reduced by trees through absorption and heat storage, wind speed, relative humidity, turbulence, surface albino, surface roughness and consequently the evolution of the mixing-layer height. These changes in local meteorology can alter pollution level in urban areas (*Nowak et al. 1998*). The response of trees to air pollutants varies depending on species. In urban areas, vegetation captures radiation and contributes in reducing urban heat (*Leghari et al. 2019*).

Air pollution control is more complex than other environmental challenges. No physical or chemical method is known for controlling air pollution. Suitable alternatives may be used to develop a biological method by growing green belts in and around urban areas (*Sen et al. 2017*). Air Pollution Tolerance Index (APTI) is a significant parameter for pollution mitigation and it is based on the biochemical parameters of plants such as pH, chlorophyll contents, relative water content and ascorbic acid. The APTI expresses the ability of plants to counter the adverse effects of air pollution (*Lohe et al. 2015; Manjunath 2019; Molnar al. 2020; Ogunkunle 2018*). Further, APTI also expresses the ability of tree species in the urban environment to counter the adverse effects of air pollution (*Girish et al. 2017*).

Several researchers have designed models for the development of green belt with different factors such as distance of green belt from the pollution source and density, width, height of green belt and air pollution tolerance index (APTI) (*Ogunkunle 2014*). There is ever increasing problem of air pollution in Islamabad city. Present study was conducted to estimate the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of 21 different plant species in Islamabad on the basis of different biochemical as well as socioeconomic parameters of the plants.

MATERIALS AND METHODS

Study Area

The recent study was conducted in Islamabad, capital city of Pakistan during the summer season of 2018. It is situated at 33°43′ North and 73°04′ East in the Pothohar Plateau in the north of the country (**Figure 1**). It has humid subtropical climate having five seasons (winter, spring, summer, monsoon and autumn) with annual rainfall of 100 mm. There is ever increasing traffic load within and around the whole city that causes air and noise pollutions. Four major roads cover the whole city, IJP Road, Kashmir Highway, G.T Road and Islamabad Expressway.

Plant Species and Sample Collection

In this study, 21 plant species were selected from the green belt along the roadside in the Islamabad city for calculation of APTI on the basis of density, canopy, and leaf structure and plant height (**Table 1**). Selected plant species were identified and their scientific names

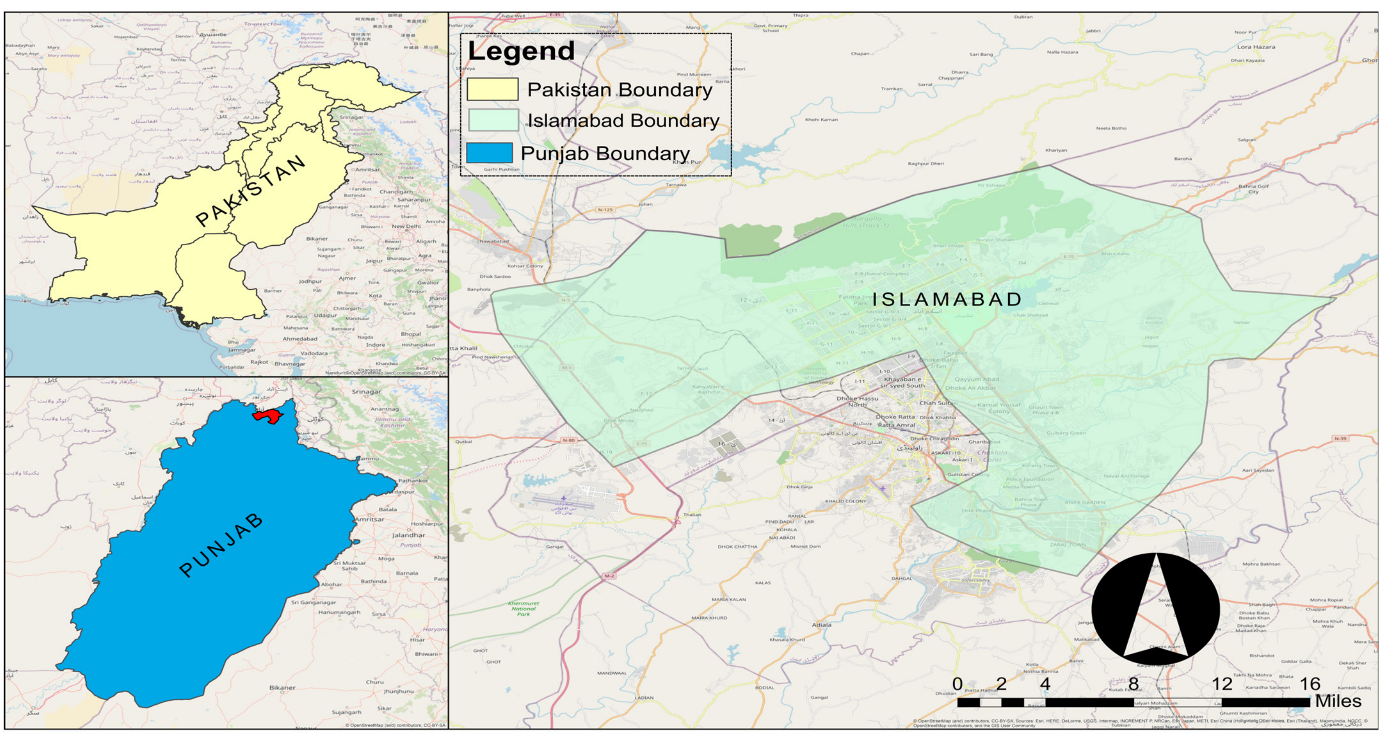

Figure 1. Map showing study area of Islamabad (Inset is map of Pakistan).

Table 1. List of selected plant species with common names.

Sr. No.	Name of Species	Common Name
1	*Tamarindus indica*	Imli
2	*Broussonetia papyrifera*	Paper mulberry
3	*Eucalyptus camaldulensis*	Sufaida
4	*Alstonia scholaris*	Devil tree
5	*Leucaena leucocephala*	Ipple Ipple
6	*Bauhinia purpurea*	Kachnar
7	*Morus alba*	Shehtoot
8	*Ziziphus mauritiana*	Beri
9	*Dalbergia sissoo*	Sheesham
10	*Acacia nilotica* L.	Keekar
11	*Acacia modesta*	Phulahi
12	*Albezia lebbeck*	Siris
13	*Callistemon viminalis*	Bottle brush
14	*Pterospermum acerifolium*	Kanak champa
15	*Melia azedarach*	Dhraik
16	*Sapium sebiferum*	Rubber plant
17	*Syzygium cumini* L.	Jaman
18	*Terminalia arjuna*	Arjun
19	*Populus caspica*	Popular
20	*Bombax ceiba*	Simbal
21	*Cassia fistula* L.	Amaltas

were confirmed by the experts from the Department of Horticulture, University of Arid Agriculture Rawalpindi. The plant samples of selected species were collected randomly from IJP Road, Kashmir Highway, Islamabad Expressway and GT Road. Leaf samples were stored in a container with ice during transport to laboratory. Fresh weights of all leaves were measured. All leaf samples were washed with distilled water before biochemical analysis (chlorophyll content, ascorbic acid, pH and relative water content of leaf extract).

Biochemical Analysis of Plant Leaves

Standard titration method was used for the determination of ascorbic acid (*Reiss 1993*). Total chlorophyll contents in plant samples were determined using Arnon equation (1949). Titration method was used to measure pH of leaf extract (*Kuddus et al. 2011*). The percentages of relative water contents were calculated by using the formula given by *Singh* (*1977*).

$$Relative\ Water\ Content\ (RWC) = \frac{\text{fresh leave weight} - \text{dry leave weight}}{\text{turgid leave weight} - \text{dry leave weight}} \times 100$$

Evaluation of Air Pollution Tolerance Index

The values of APTI of plants was calculated using total chlorophyll, ascorbic acid, relative water contentand leaf extract pH in the following formula (*Singh and Rao 1983*);

$$Air\ Pollution\ Tolerance\ Index\ (APTI) = \frac{A(T+P)+R}{10}$$

Where 'A' is ascorbic acid (mg g^{-1}), "T" is total chlorophyll (mg g^{-1}), 'P' is pH of leaf extract and "R" is the relative water contents of leaf (%).

On the basis of APTI, the plants were categorized into tolerant (30-300 APTI), intermediate (17-29 APTI), sensitive (1-16 APTI) and very sensitive (< 1 APTI) plant species (*Singh et al. 1991*).

Evaluation of Anticipated Performance Index

The API values of all tree species were calculated using different natural, social, economic as well as biochemical characteristics such as APTI, plant habit, canopy structures, economic values and laminar structure (**Table 2**). The target plants were categorized on the basis of their percent score (**Table 3**).

Table 2. Grading of plant species on the basis of Air Pollution Tolerance Index and other biological and socioeconomic characters.

Grading Character	Parameters	Pattern of Assessment	Grade
Tolerance	APTI	9.6-12.5	+
		12.6-15.5	++
		15.6-18.5	+++
		18.6-21.5	++++
		21.6-24.5	+++++
Biological and Socio-economic	Plant habit	Small	-
		Medium	+
		Large	++
	Canopy structure	Sparse/irregular/ globular	-
		Spreading crown/ open/semi-dense	+
		Spreading dense	++
	Type of plant	Deciduous	-
		Evergreen	+
Laminar structure	Size	Small	-
		Medium	+
		Large	++
	Texture	Smooth	-
		Coriaceous	+
	Hardiness	Delineate	-
		Hardy	+
Socio-economic	Economic value	Less than three uses	-
		Three or four uses	+
		Five or more uses	++

Table 3. Grading pattern of various tree species.

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

Source: *Prajapati and Tripathi* (*2008*); *Govindaraju et al.* (*2012*)

Statistical Analysis

Results of biochemical parameters (ascorbic acid, total chlorophyll content, pH, relative water content) and APTI of different tree species were statistically analyzed using SAS program (version 9.0). Analysis of variance (ANOVA) test was performed at P= 0.05, whereas Fisher Protected Least Significant Difference (LSD) test was conducted to compare and differentiate means of different parameters.

RESULTS AND DISCUSSION

Ascorbic acid

Ascorbic acid is a very important indicator to determine APTI. It provides resistance to adverse climatic conditions and hence is considered influential in the plants (*Keller and Schewager 1977*). Pollution in soil and air could result in decrease in concentration of ascorbic acid (*Klumpp et al. 2000*). Ascorbic acid plays an important role in decreasing reactive oxygen species in leaves. Higher contents of ascorbic acid of leaves could be effective tool to save thylakoid membrane from oxidative damage under worst condition and indicates tolerance of plant species against air pollutants such as SO_2. Higher ascorbic acid contents in plants reveal the high resistivity of air pollution (*Aghajanzadeh et al. 2016*). Ascorbic acid is an antioxidant; its concentration increases with auto exhaust and industrial pollution rates (*Gupta et al. 2016; Nadgórska-Socha et al. 2017*). Highest ascorbic acid content was measured in *Terminalia arjuna* (10.17 mg g^{-1}). *Syzygium cumini* L. (9.33 mg g^{-1}), *Populus caspica* (9.63 mg g^{-1}), and *Sapium sebiferum* (9.41 mg g^{-1}) also has very high ascorbic acid (**Figure 2**).

Total Chlorophyll

Highest total chlorophyll was recorded in *Alstonia scholaris* (13.59 mg g^{-1}), followed by *Pterospermum acerifolium* (12.51 mg g^{-1}) and *Syzygium cumini* L. (11.84 mg g^{-1}) (**Figure 3**). High chlorophyll content helps in creating hindrance in pollutants (*Shafiq et al. 2012*). Chlorophyll content reduces the production of reactive oxygen species (ROS) in the chloroplast under water stress (ROS is very low reactive molecule which may cause damage to cellular bodies during environmental stress). Higher chlorophyll contents are involved in the protection against ROS produced by the photosynthetic apparatus (*Smirnoff 1996*).

Average pH of Leaf Extract

Highest pH was recorded in *Leucaena leucocephala* (5.99) followed by *Bombax cieba* (5.56), *Acacia nilotica* L. (5.40), and *Pterospermum acerifolium* (5.39) (**Figure 4**). Samples of leaves extract had pH values in the range of 1.93-5.99 in all species. Acidic pH of leaves might be due to the presence of acidic pollutants in the air. The responsive species were more susceptible to acidic pollutants (*Scholz and Reck 1977*). Higher pH of leaf extract enhances plant tolerance to air pollutants

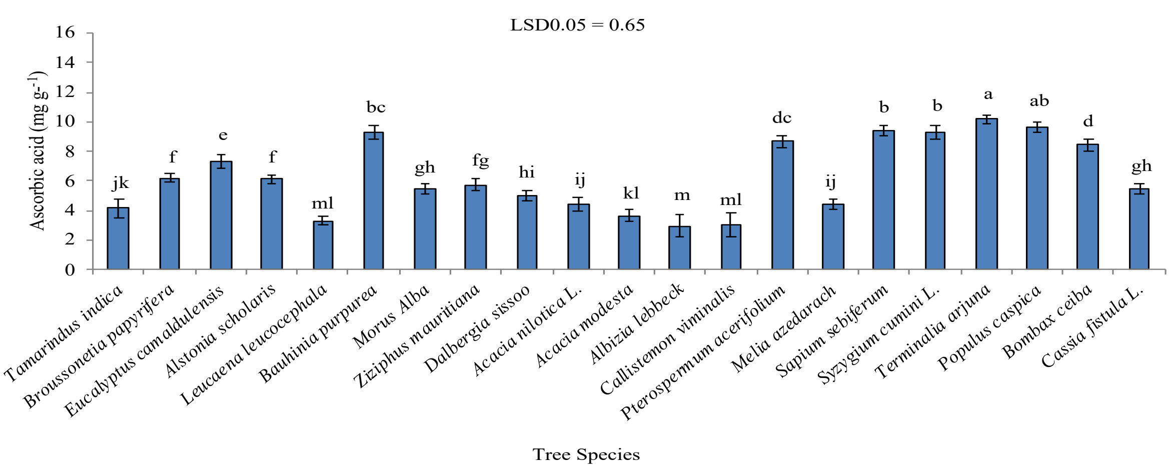

Figure 2. Variations in the mean values of ascorbic acid content of the leaf extract of sampled tree species. Error bars are standard error values.

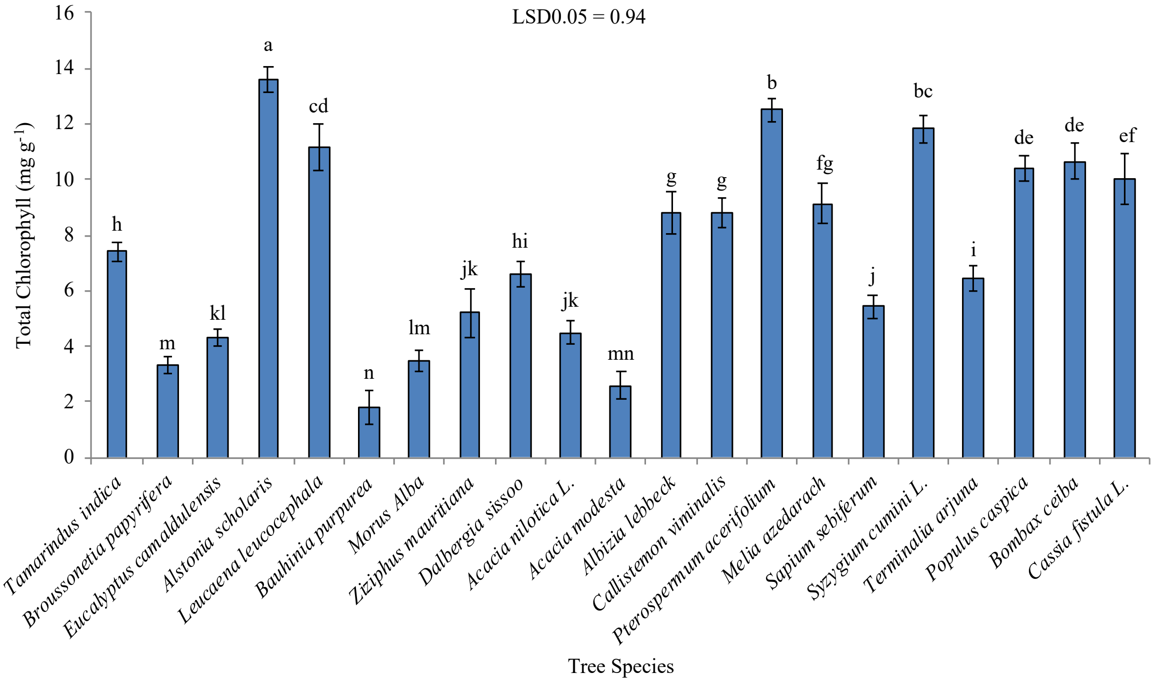

Figure 3. Variations in the mean values of total chlorophyll content of the leaf extract of sampled tree species. Error bars are standard error values.

(*Agarwal 1988*). Moreover, many physiological as well as biochemical processes of the plant depend on the pH because the enzymes require different ranges of pH for their proper functions. Level of pH also regulates the hexose sugar into ascorbic acid (*Achakzai et al. 2017*). It is reported by various researchers that photosynthetic efficiency of plants is strongly dependent on pH *i.e.,* low pH reduces the photosynthetic activities of plants (*Liu and Ding 2008*).

Average pH of Leaf Extract

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Relative Water Content

Maximum relative water content (%) was recorded in *Alstonia scholris* (95.32) followed by *Dalbergia sisso* (91.41), *Melia azedarach* (91.27) and *Syzygium cumini* L. (90.35), respectively (**Figure 5**). Higher water content is beneficial for drought resistance. Relative water content is also important parameter for pollution tolerance of the plant because water regulates many physiological processes under high stress of pollutants. Present study also indicated that the sensitive species had the low value of relative water content such as *Morus Alba* (67.62) and *Callistemon viminalis* (65.48). Furthermore, these species are very poor performers with reference to the pollution tolerance.

Air Pollution Tolerance Index (APTI)

All the target tree species were evaluated for biochemical and biological parameters such as APTI, plant habit, canopy structure, laminar structure and economic value. On the basis of such parameters, 21 tree species were graded for air pollution abatement. Greater APTI values were found for some tree species including *Syzygium cumini* L. (24.4), *Pterospermum acerifolium* (23.66), *Bombax ceiba* (22.33) and *Alstonia scholaris* (20.66). *Morus alba*, *Acacia modesta* and *Callistemon viminalis* had low APTI values (**Figure 6)**. *Morus alba* had average APTI value of 11.62. APTI of *Morus alba* of 22.66 (polluted site) and was also determined by

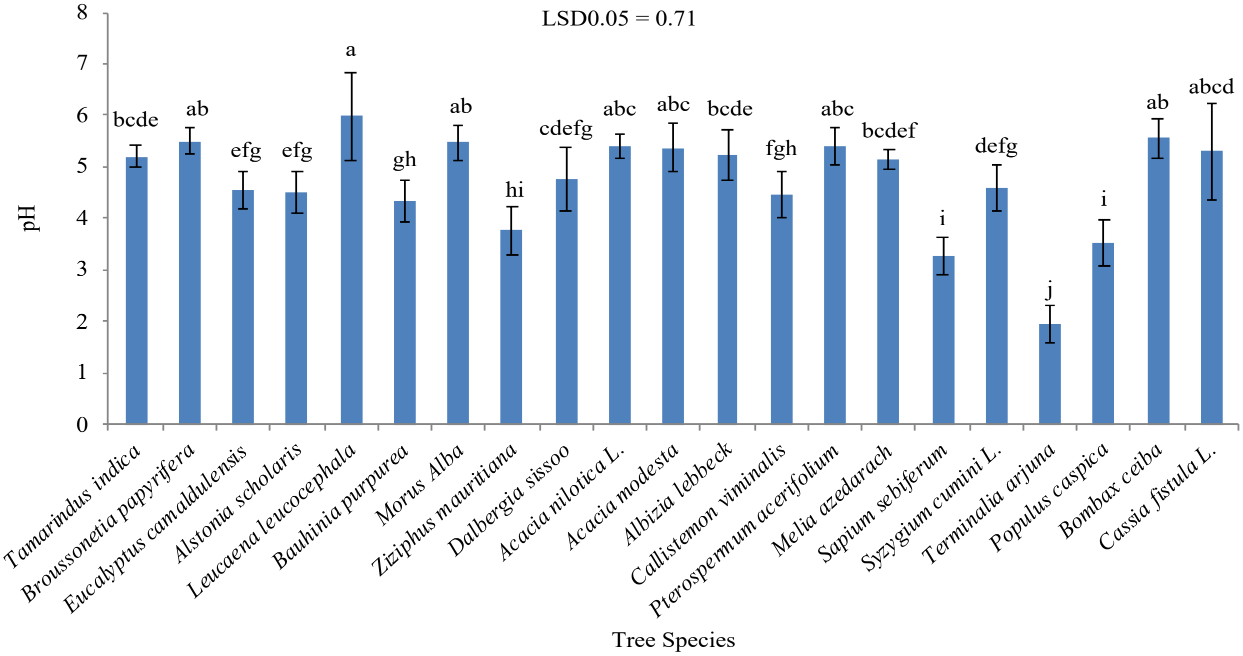

Figure 4. Variations in the mean values of pH of the leaf extract of sampled tree species. Error bars are standard error values.

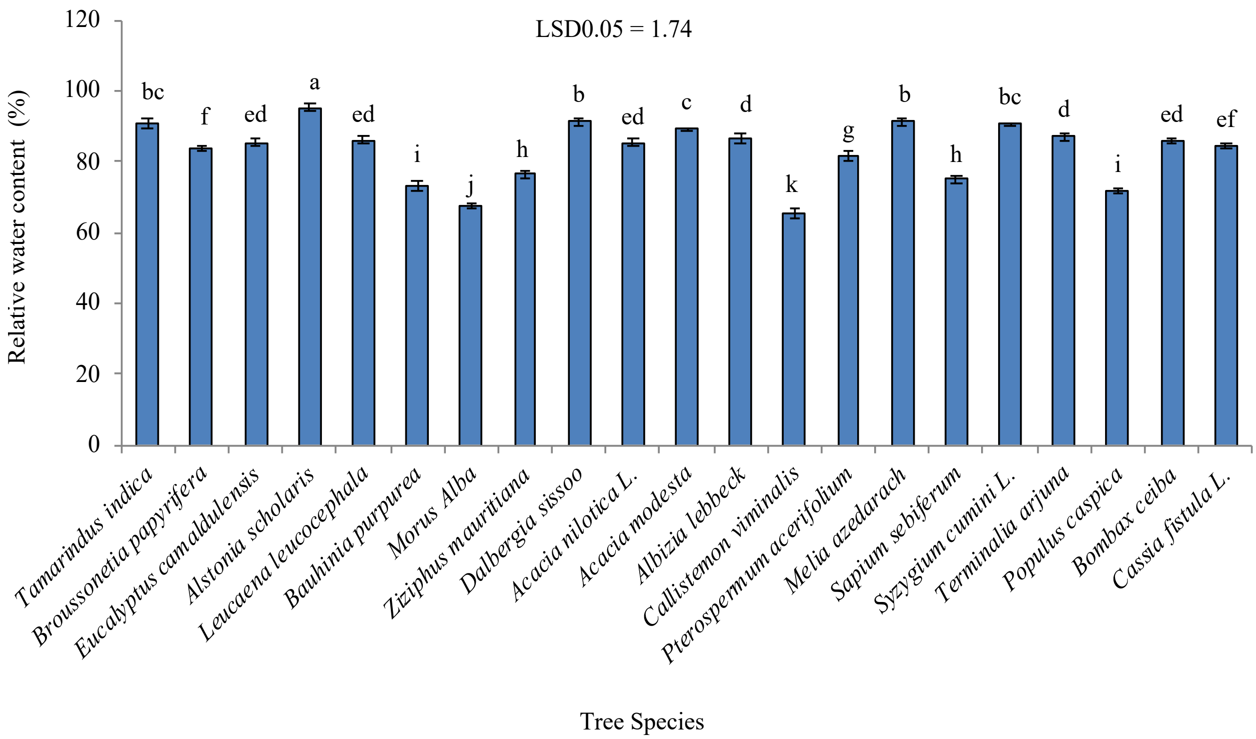

Figure 5. Variations in the mean values of relative water content of the leaf extract of sampled tree species. Error bars are standard error values.

Leghari et al. (*2019*) in Quetta, Pakistan. APTI values reflect suitability of tree species for the urban environment to reduce the air pollution and API values are utilized to estimate the fitness of plant species for green belt formation (*Chaudry et al. 2016*). Majority of the Asian countries use APTI for selection of tree species, where urban greenery is used to mitigate air pollution from industrial, vehicular and domestic emissions. Due to this reason, tree species having high APTI values are ideal, while sensitive species with low APTI values are usually used as bio indicators (*Molnár et al. 2018*).

Anticipated Performance Index (API)

It is clear that *Syzyium cumini* L., *Pterospermum acerifolium* and *Alstonia scholaris* have excellent performance (**Table 4**). *Ahmad et al.* (*2019*) also found *Alstonia scholaris* one of the most desirable tree species for planting around air polluted areas in neighboring city of Islamabad (Rawalpindi). *Bombax cieba* is very good performer. These species have globular canopies, large leaf size, tall height for the better absorption of dust and ambient air particles. *Albezia lebbeck*, *Melia azedarach*, *Eucaliptus camaldulensis*, *Dalbergia sissoo*, *Tamarindus indica*, *Acacia nilotica* L., *Callistemon viminalis* and *Leucaena leucocephala* are very poor

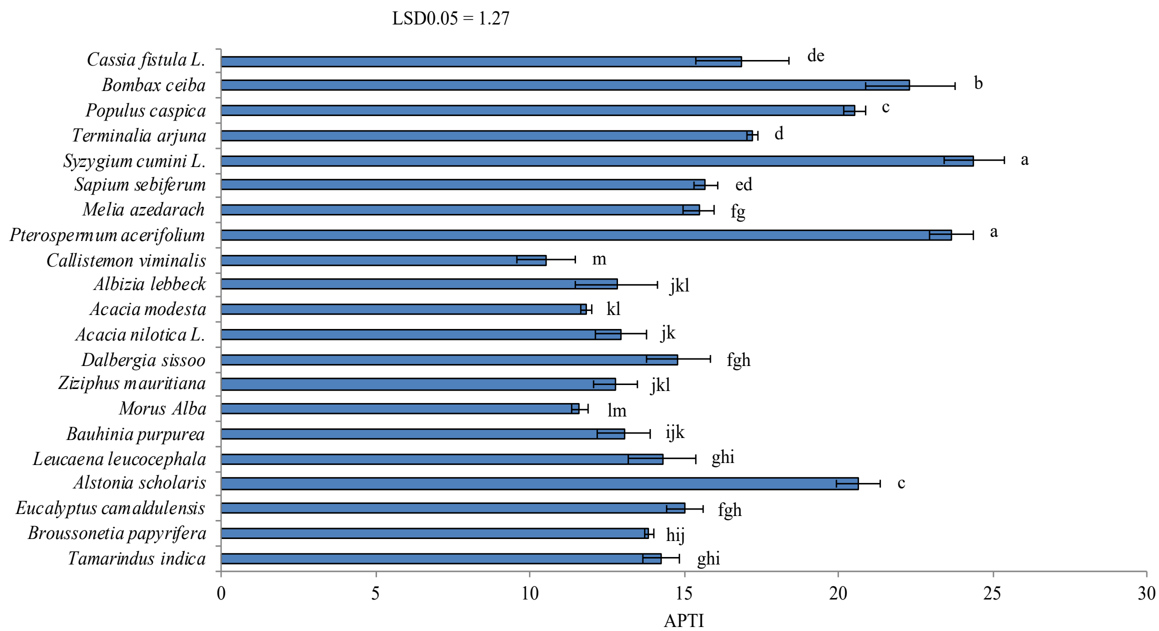

Figure 6. Variations in the mean values of APTI of sampled tree species. Error bars are standard error values.

Table 4. Anticipated Performance Index grades and socioeconomic values of species.

Common Names of Species	Botanical Names of Species	APTI	Habit of Tree	Canopy	Type of Tree	Laminar		Economic Value	Obtained Grades	Score (%)	API Grade
						Texture	Size				
Jaman	*Syzygium cumini* L.	+++++	++	++	+	-	+	+ +	13	81.00	6
Kanak champa	*Pterospermum acerifolium*	+++++	++	++	+	+	+	+	13	81.00	6
Devil tree	*Alstonia scholaris*	++++	++	++	+	+	+	++	13	81.00	6
Simbal	*Bombax cieba*	+++++	++	+	-	+	+	++	12	75.00	5
Popular	*Populus caspica*	++++	+	+	+	+	+	++	11	68.75	4
Arjun	*Termenalia Arjuna*	+++	++	++	+	+	+	+	11	68.75	4
Paper mulberry	*Broussonetia papyrifera*	++	++	++	+	+	+	+	10	62.50	4
Amaltas	*Cassia fistula* L.	+++	-	+	+	+	+	++	9	56.25	3
Rubber plant	*Sapium sebiferum*	+++	-	++	+	+	+	+	9	56.25	3
Shehtoot	*Morus alba*	+	+	++	-	+	+	++	8	50.00	2
Khachnar	*Bauhinia purpurea*	++	-	++	-	+	+	++	8	50.00	2
Beri	*Ziziphus mauritiana*	++	-	+	+	-	+	++	7	43.75	2
Pulahi	*Acacia modesta*	+	+	+	+	-	+	++	7	43.75	2
Siris	*Albezia lebbeck*	++	-	+	-	+	+	+	6	37.50	1
Dharaik	*Melia azedarach*	++	+	+	+	-	+	-	6	37.50	1
Sufaida	*Eucaliptus camaldulensis*	++	++	-	+	+	-	-	6	37.50	1
Sheesham	*Dalbergia sissoo*	++	+	++	-	-	-	+	6	37.50	1
Imli plant	*Tamarindus indica*	++	+	-	-	-	-	++	5	31.25	1
Keekar	*Acacia nilotica* L.	++	-	+	+	-	-	+	5	31.25	1
Bottle brush	*Callistemon viminalis*	+	+	+	+	+	-	+	6	31.25	1
Ipple ipple	*Leucaena leucocephala*	++	-	+	-	-	-	+	4	25.00	0

performers regarding air and noise abatement because of having open canopies, small height and small leaf area. *Dalbergia sissoo* was also found to sensitive towards air pollution (*Pandit 2016*). *Rawat and Banerjee* (*1996*) reported that there are tree mechanisms through which plants remove pollutants by absorption through leaves, deposition of pollutants and aerosol over leaf surface.

Analysis of variance (ANOVA) test was performed (**Table 6**). The summary of statistical analysis (ANOVA) included the source of variation, degrees of freedom and mean squares of ascorbic acid, chlorophyll content, pH, relative water content, and APTI in different tree species.

Table 5. Grading of various tree species.

Plant species	Grade (Total +)	Score (%)	Anticipated Performance Index Value	Assessment
Syzygium cumini L.	13	81.00	6	Excellent
Pterospermum acerifolium	13	81.00	6	Excellent
Alstonia scholaris	13	81.00	6	Excellent
Bombax cieba	12	75.00	5	Very good
Populus caspica	11	68.75	4	Good
Termenalia Arjuna	11	68.75	4	Good
Broussonetia papyrifera	10	62.50	4	Good
Cassia fistula L.	9	56.25	3	Moderate
Sapium sebiferum	9	56.25	3	Moderate
Morus alba	8	50.00	2	Poor
Bauhinia purpurea	8	50.00	2	Poor
Ziziphus mauritiana	7	43.75	2	Poor
Acacia modesta	7	43.75	2	Poor
Albezia lebbeck	6	37.50	1	Very Poor
Melia azedarach	6	37.50	1	Very Poor
Eucliptus camaldulensis	6	37.50	1	Very Poor
Dalbergia sissoo	6	37.50	1	Very Poor
Tamarindus indica	5	31.25	1	Very Poor
Acacia nilotica L.	5	31.25	1	Very poor
Callistemon viminalis	6	31.25	1	Very poor
Leucaena leucocephala	4	25.00	0	Not recommended

Table 6. Source of variation, degrees of freedom and mean squares of ascorbic acid, chlorophyll content, pH, relative water content, and Air Pollution Tolerance Index in different tree species.

Source of Variation	df	Mean Square				
		Ascorbic Acid	Total Chlorophyll	pH	Relative Water Content	APTI
Tree Species	20	17.728***1/	36.870***	2.745***	207.744***	49.877***
Replication	2	1.050***	0.094ns	0.753*	1.393n	2.699**
Error	40	0.159	0.329	0.1902	1.124	0.598
CV, %		6.33	7.62	9.23	1.27	4.85

*, **, *** and ns, as superscript indicate the levels of significance at probability (P) 0.05, 0.01, 0.001 and > 0.05 and are expressed as significant, highly significant, very highly significant and non-significant effect, respectively.

CONCLUSION AND RECOMMENDATIONS

Overall, *Syzygium cumini* L., *Pterospermum acerifolium* and *Alstonia scholaris* are ranked the best among all the target tree species. These species have better aesthetic, social and economic values and are strongly recommended for green belt development. Furthermore, these are dense canopied, tall and are very effective for urban forestry. *Albezia lebbeck*, *Melia azedarach*, *Eucliptus camaldulensis*, *Dalbergia sissoo*, *Tamarindus indica*, *Acacia nilotica* L., *Callistemon viminalis* and *Leucaena leucocephala* are very poor performers regarding air and noise abatement because of having open canopies, low height and small leaf area. These tree species are very sensitive to air pollution and can be used as bioindicators in polluted areas.

Further research should be conducted on other tree species in urban areas. Findings of this study will be useful for environmentalists, urban planners and policy makers in selecting tree species for green belt in urban areas of developing countries.

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