Research Paper

Assessment of Tolerance of Some Tree Species to Air Contamination Using Air Pollution Tolerance and Anticipated Performance Indices in Isfahan City, Iran

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ABSTRACT

Background: In the present study, the tolerance of plantain tree species (Platanus orientalis, Morus nigra and Ailanthus altissima) to air pollution was evaluated using Air Pollution Tolerance Index (ATPI) and Anticipated Performance Index (API) index in Isfahan city (Iran).

Methods: For this purpose, three dominant trees growing at six stations in Isfahan was selected and then sampling of the tree leaves was performed, after being transferred to the laboratory, the ATPI and API index were calculated.

Results: The results of calculating the ATPI in the leaves of M. nigra, P. orientalis and A. altissima species showed that the highest values of ATPI index was obtained in M. nigra at 20.77 and then detected in P. orientalis and A. altissima with the values 14.90 and 14.33 respectively. According to API values Morus nigra had the best performance (Score = 6 so it classified as the Excellent) while P. orientalis and A. altissima had very good and intermediate performance, respectively.

Conclusion: According to ATPI and API index most tolerant tree species was Morus nigra, so it would be the most suitable species for plantation programme in urban and pollutant areas followed by Platanus orientalis and Ailanthus altissima. As well as our results suggest that Platanus orientalis and Ailanthus altissima can be used as bio-indicators of air pollution due to their low ATPI scores (lower than 16). The present study suggests that the combination of both the ATPI and API indices for identifying and selection of plant species is very useful for plantation in urban areas.

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1. Introduction

Today primary and secondary air pollutants are a serious threat in almost all urban areas and have a detrimental effect on living organisms, ecosystem health, air quality, plant vitality, and environment [1]. Air pollutants are emitted to the ambient air by natural and anthropogenic origin [2]. These pollutants are increasing due to rapid urbanization, uncontrolled industrialization, heavy traffic load, inadequate emission control, and lack of strict environmental regulations [3]. The consequences of pollution include an increase in human diseases such as cardiovascular diseases, frequency, and severity of respiratory symptoms, infections, lung cancer, and premature death [4]. Thus, air pollution is the leading risk factor for human and living organisms' health [5].

Concerning the different effects of air pollution on human health, it is an essential task to mitigate, remove, and monitor air pollutants in different areas to protect the ecosystem and living creatures [6]. In this regard, urban vegetation can be used as good natural tools to absorb and remove air pollutants and improve air quality and human health [4]. Hence, it is wise to assess plants' tolerance and performance toward air pollution using different parameters and indices. These indices are Relative Water Content (RWC), total chlorophyll content, leaf extract pH, and ascorbic acid (biochemical parameters), Air Pollution Tolerance Index (APTI), and Anticipated Performance Index (API) (as multi-parameter indices). This study is necessary for the selection of suitable plants and categorizing them as being tolerant or sensitive to air pollution and the development of a greenspace [1, 7].

The use of plants to absorb and remove air pollution or develop a green belt has been applied since a long time ago. This approach is a suitable and cost-effective tool. It is a renewable and reliable alternative method for the mitigation and purification of air pollutants [3, 8]. Therefore, during recent years, there is growing interest in using plants as a bio-approach to capture, absorb, and accumulate air pollutants [9]. Plants act as a natural tool for improving air quality and preventing ecological risks and detrimental effects of toxic air pollutants [10, 11]. They absorb, uptake (by root, bark, and leaves), transfer and accumulate different pollutants from the air to soil environment, and concentrate, detoxify, or immobilize them in their tissues [3, 12, 13]. The absorption and concentration of various pollutions such as airborne metals in plants depend on different factors. These factors include air and soil conditions, climate and environmental factors, foliar and root pathway uptake, the bioavailability of pollutions in the soil, sources and amount of pollutants in the environment, and plant characteristics (such as age, foliage and branch configuration, physiological, morphological and anatomical characteristics of leaf, phyllosphere conditions) [14-16]. In previous studies, the ability of various trees to remove toxic and detrimental pollutants from the air has been investigated in many urban and industrial zones [11]. This research revealed that plant leaves act as an effective passive and active environmental sink for air pollutants. They provide broad surface area for trapping and accumulation of airborne pollutants such as gases, organic, inorganic, and particulate matter [3, 17]. Thus, air pollution removal by trees is suggested as a suitable and eco-friendly tool, particularly in polluted urban environments [1, 18]. The experimental evidence showed that the response, ability, and resistance of plants to air pollutants are very different from one species to another.

Hence to optimize the advantages of trees in plantation programs for selection of the best species, the identification, evaluation, and planting of highly air-pollution resistance plant species are advisable for the development of urban green space at vulnerable areas such as industrial, roadsides, and polluted areas [3, 7, 19]. The exposure, uptake, absorption, and accumulation of specific pollutants in various species can cause damage, physiological changes, or disease in different ways [20]. The experimental evidence showed that some plant-sensitive species are susceptible or vulnerable (such as stomatal damage, chlorosis. necrosis, degradation of chlorophyll, disruption of enzymatic reactions and cell permeability, etc.) to air pollution [21, 22]. However, the response and resistance or sensitivity of different plant species to air pollutants are diverse and unique [23]. As a general principle, plants with low tolerance to a particular pollutant are considered biological indicators because there is a synergistic action between plants and the air pollutant [24]. Plants are stationary organisms and continually exposed to numerous types of adverse environmental stresses. Also, they are unable to overcome severe environmental conditions like high air pollution levels [25, 26]. Assessing the plants' susceptibility or resistance to air pollutants is significant in finding whether they can monitor, mitigate, or remove air pollutants in vulnerable areas [27].

As a general rule, to plant species as mitigating and bio-ecological indicators of air pollution, it is necessary to select suitable characteristics (such as tolerance, canopy structure, economic value, environmental conditions, physical requirements, socioeconomic/ livelihood,

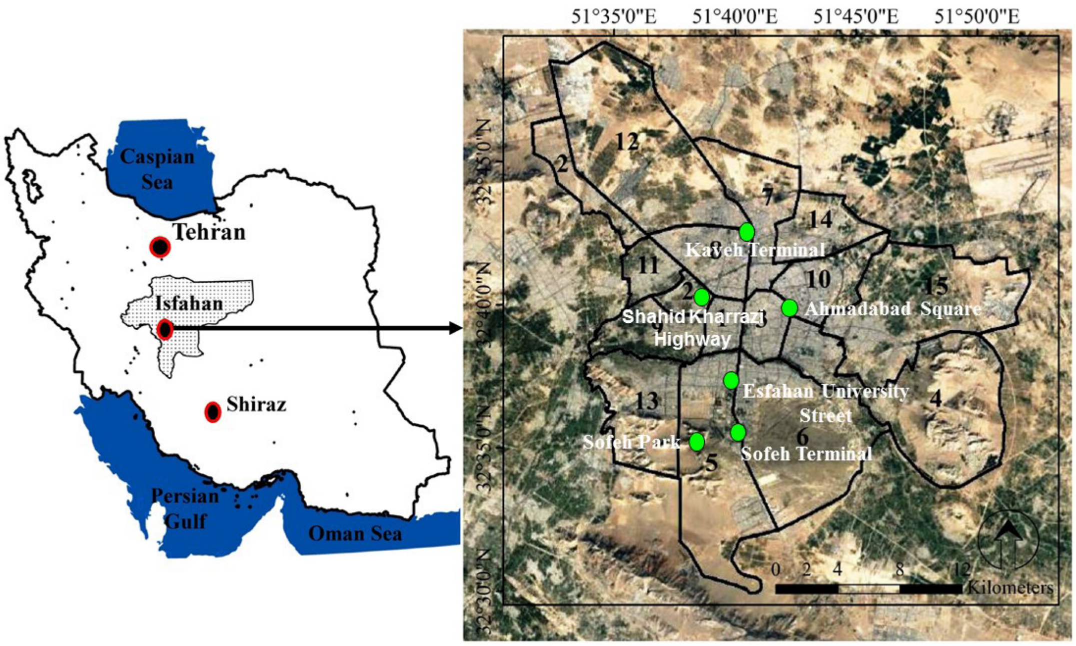

Figure 1. The distribution of the sampling sites within the case study

plant habit, etc.) [3]. In this regard, the plant's Tolerance to Air Pollution (APTI) depends on environmental conditions and related natural and intrinsic characteristics. [28]. APTI and Anticipated Performance Index (API) are practiced to find the resistance or susceptibility level of plant species to air pollutants and their suitability for green belt development. APTI assesses leaf physiological and biochemical parameters such as total chlorophyll content, leaf extract pH, Relative Water Content (RWC), and ascorbic acid content to express the susceptibility or tolerance of plant species towards various air pollutants [15, 29, 30]. API is a comprehensive index that uses a combination of APTI values and numerous biochemical, socioeconomic, and biological attributes of the species such as type of plant and its habitat, canopy structure, laminar structure (including texture hardiness, size), and economic value, to assess the suitability of plants for green space in the urban environment [1, 3, 31]. To optimize the advantages of plants in wall-plans urban planting and to monitor the urban atmosphere, the first approach must be to assess the reaction of various species to air pollutants and then using those plants as the bio-monitors or purifiers of environmental pollution.

This research evaluates the susceptibility levels of *Platanus orientalis*, *Morus nigra*, and *Ailanthus altissima* to air pollution based on the measurement of some biochemical parameters and the APTI. Also, the performance of these trees for green belt development has been determined based on their API. We used the API as a comprehensive index (integrating APTI index with socio-economical and biological attributes) for quantifying the performance of trees for green belt development in Isfahan City, Iran, at different pollutant areas. Hence this research aims to (1) assessing the biochemical and physiological response of trees to air pollution stress (in polluted areas) in Isfahan, and (2) measuring both the pollution sensitive and tolerant of some tree species (*Platanus orientalis*, *Morus nigra*, and *Ailanthus altissima*) as a suitable tool in air pollution monitoring, control, and mitigation.

2. Materials and Methods

Sampling

Study area, plant selection, and sample collection

The study was conducted on samples of leaves collected from different parts of Isfahan City. Isfahan is approximately located in the center of Iran (Figure 1). This city has important features. It is the economic and cultural center of Iran with the highest industrial (many different kinds of industries such as the largest steel and melting plant in the country, oil refinery, petrochemical, and chemical processing industries), population, and traffic intensity population [32, 33]. The population of Isfahan City is 5346518, according to the 2019 census. Today Isfahan is the second industrialized and one of the most crowded and populated cities of the country [34]. In the study, three common and abundant tree species

(*Platanus orientalis* L; *Morus nigra* L. [black mulberry]; *Ailanthus altissima* [Mill.] Swingle) at six stations were selected. Leaf samples of all species were cut and collected in September 2019. About 40 to 50 leaves from each tree (two trees per species at each site, N=34 trees) were taken randomly on all the four side of the tree at 1.0–2.5 m height above ground level and then leaves were mixed to form a representative sample [19, 35]. The fresh tree leaves samples were placed in paper bags, labeled, and immediately carried to the laboratory and stored at ambient temperature until analysis. Figure 1 shows the distribution of the sampling sites within the case study.

Analyses

Air Pollution Tolerance Index (APTI)

The Air Pollution Tolerance Index (APTI) was first presented and used by Singh and Rao (1983). In many previous studies, APTI is a relevant factor for assessing and selecting tolerant and sensitive plants for air pollution. APTI has been applied to evaluate air pollution in local plant species. Tolerant plant species with high APTI values are optimal, while sensitive species with low APTI values are usually used as bio-indicators [36]. The APTI factor was computed according to the standard Equation 1.

$$1.\ APTI=\frac{(AAC\times(TCH+P)+RWC)}{10}$$

, where AAC is Ascorbic Acid Content (mg/g), TCH refers to Total Chlorophyll content (mg/g), RWC denotes Relative Water Content (%) [37], and P is the pH of leaf extract.

Relative Leaf Water Content (RWC)

This approach estimated the Relative Water Content (RWC). In the first step, fresh leaves were weighted (FW). Then, the leaves were immediately immersed in deionized water in darkness condition at 4°C overnight. After that, the leaves were blotted dry with a filter paper and weighed again to obtain the TW (Turgid Weight). In the third step, the respective Dry Weight (DW) was acquired by oven-dried leaves for 3 h at 105°C in a hot air oven (K.M100, Pars Azma Co, Iran) and reweighed to acquire the DW. Finally, the tree leaf RWC (%) factor was computed using the method of Pathak et al. [38]. It is determined based on the standard Equation 2.

$$2.\ RWC(\%)=\frac{FW-DW}{TW-DW}\times 100$$

The Total Chlorophyll Content (TCH)

Total Chlorophyll (TCH) content was measured by the spectrophotometric method described by Arnon [39]. For this purpose, 1 g of fresh leaves tissue was taken, grinded, and homogenized in 80% acetone (v/v) (Merck, Darmstadt, Germany). The homogenate solution was kept for 10 min for complete extraction and centrifuged at 5000 rpm for 5 min (Laborzentrifugen, 2K15, Sigma, Germany). The supernatant was gathered, and the absorbance of the solution at 645, 663, and 652 nm was measured using a spectrophotometer (Hach DR6000, Germany). Then, the total chlorophyll value was found out by using the following equations (mg chlorophyll/g leaf tissue) (Equation 3, 4 & 5). Moreover, two blank samples were placed along with samples for the quality control experiments.

$$3.\ Chla(mg/g)=\frac{[(12.7\times A663)-(2.6\times A645)]\times VmlAcetone}{100mgLeaftissue}$$

$$4.\ Chla(mg/g)=\frac{[(22.9\times A645)-(4.68\times A663)]\times VmlAcetone}{100mgLeaftissue}$$

$$5.\ TCh=Chla+Chlb$$

Ascorbic acid

The ascorbic acid content of leaf samples was estimated using the colorimetric 2,6-dichlorophenol indophenol (DPIP) (Merck, Germany) procedure given by Keller and Schwager [40]. About 0.25 g of leaves was crushed and homogenized in 10 mL of extracting solution, containing 0.75 g of 99% EDTA (Razi Chemical Company, Iran), 5 g of 99% oxalic acid (Ghatran Shimi Tajhiz, Iran) in 1000 mL of deionized water. Then, the homogenate solution was centrifuged at 6000 rpm for 15 min (Laborzentrifugen, 2K15, Sigma, Germany), and the supernatant was gathered. Afterward, 1 mL of supernatant was added to DPIP solution (pink color appears). Next, the Optical Density (OD) of the solution at 520 nm (Es) was determined. After determining the OD, to bleaching the pink color, one drop of ascorbic acid was added to the solution, and again the absorbance of OD was determined at the same wavelength (Et). The absorbance of the DPIP solution was determined at 520 nm (Eo) using a spectrophotometer. Also, the standard curve was provided using ascorbic acid (99% Sigma-Aldrich, USA) with different concentrations by following the same procedure. The content of ascorbic acid (mg/g dry weight) is obtained by using Equation 6:

6. AAC (mg/g) =[Eo-(Es-Et)] ×V/W × 1000 Eq

where, V is the total volume of the mixture, and the values of [Eo - (Es - Et)] are measured by the standard curve, and W refers to the weight of the fresh leaf in gram.

Estimation of pH

The leaf extract pH was determined using the procedure given by Liu and Ding [41]. Fresh leaf sample (4 g) was grinded and homogenized in 40 mL deionized water, and the homogenate mixture was centrifuged at 5000 rpm for 20 min. Then, the supernatant solution was collected and its pH measured by using calibrated pH meter (MI151, Milwaukee, Italy).

Anticipated Performance Index (API)

The Anticipated Pollution Index (API) can be applied as a favorable and eco-friendly factor to assess various plant species for selection in the plantation program and green belt development project. This index can be calculated by using the morphological (like the type of plant, canopy or crown structure, plant habit), biological and socioeconomic aspects of plants. Grades (+ or −) are given for each attribute based on criteria given by Prajapati and Tripathi. API can be computed by the Equation 7 [1,

Table 1. Gradation of urban tree species according to APTI, socioeconomic attributes, and morphobiological parameters [38]

Classifying Character	Criteria (Index)	Pattern of Valuation	Grading of Characters (Grades Allocated)
Tolerance	APTI	9.0-12.0	+
		12.1-15.0	++
		15.1-18.0	+++
		18.1-20.0	++++
		20.1-24.0	+++++
		24.1-32.0	++++++
Biological and socioeconomic attributes	Plant habit	Small	-
		Medium	+
		Large	++
	Crown structure	Sparse/Irregular/globular	-
		Spreading Crown/open/semi-dense	+
		Spreading dense	++
	Type of tree	Deciduous	-
		Evergreen	+
Laminar Structure	Size	Small	-
		Medium	+
		Large	++
	Texture	Smooth	-
		Pubescent (Coriaceous)	+
	Hardiness	Soft	-
		Hard	+
Socioeconomic	Economic value	Less than 3 uses	-
		Three or 4 uses	+
		Five or more uses	++

42]. The results of the studies are shown in Table 1 and different categories of the assessment of trees with API have been presented in Table 2.

$$7.\ API\% = \frac{\text{Positive grades obtained by trees}}{\text{Maximum possible grades score for each tree species(16)}}$$

3. Results and Discussion

Ascorbic Acid Content (AAC)

Ascorbic acid is a natural antioxidant compound that plays an essential role in plant tissue physiology, such as cell wall synthesis, decreasing reactive oxygen species, cell division, photosynthetic, and carbon fixation. It is known as a crucial indicator of pollution and also can prevent or reduce the damaging effect of air pollutants by decreasing reactive oxygen species and saving thylakoid membrane from oxidative injury under worst situation [15]. The average AAC level in the leaves of the three selected trees at the different sites (control and polluted) is given in Figure 1. The AAC content ranged from 4.35 to 10.53 mg/g. The lowest and highest ascorbic acid were detected in *A. altissima* (at Sofeh park -low pollution) and *M. nigra* (at Ahmadabad Square- high pollution), respectively (Figure 2). The highest ascorbic acid in leaves of *M. nigra*; *P. orientalis*, *A. altissima* species were recorded in Sofeh park (low pollution), but the lowest was recorded at Shahid Kharazi highway (6.32 mg/g), Kaveh terminal (5.28 mg/g), and Ahmadabad Square (4.35 mg/g). In general, the increased levels of ascorbic acid in species tissue demonstrate the high resistance to soil and air pollution [15]. This subject can probably be due to the defense mechanism of the plant species against pollutants in contaminated areas [43-

Table 2. Categories for the assessment of trees with API

Grading (API)	Score (%)	Categories
0	Lower than 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

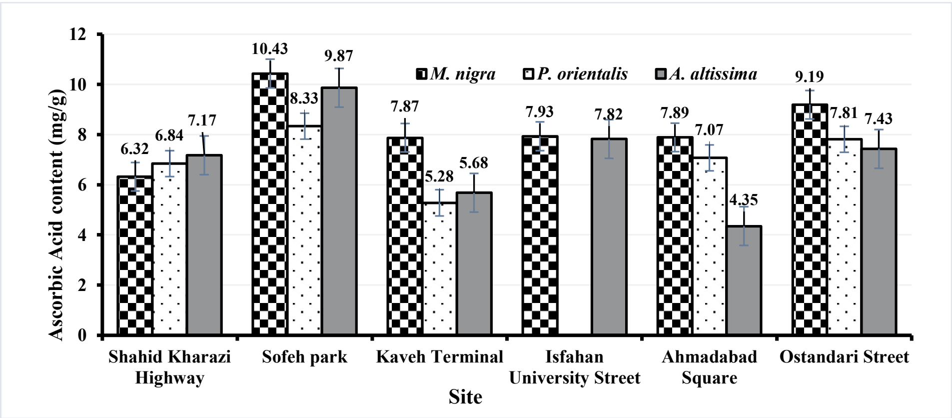

Figure 2. Values of AAC content (mg/g) in the fresh leaves of selected tree species in the control and polluted sites (in Isfahan City)

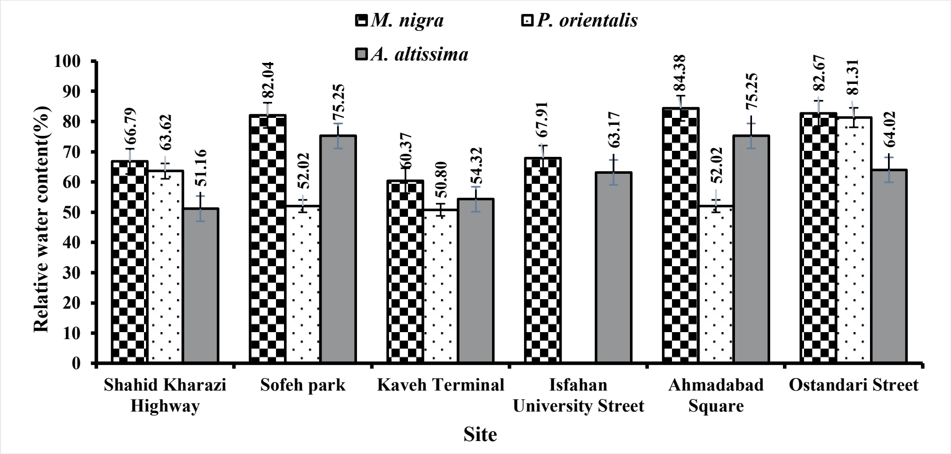

Figure 3. Variations in the values of RWC content (%) of the fresh leaves of selected tree species in the control and polluted sites (Isfahan City)

45]. A similar result of ascorbic acid content was also reported by Ogunkunle et al. [46], Leghari et al. [47], and Yadav and Pandey [7]. Furthermore, the amount of ascorbic acid content in some trees is varied according to sampling area such as *M. alba* [23], *J. excelsa* and *J. excels* [34], *P. caspicaand*, *A. scholaris*, *B. cieba* [15], *F. excesio*, and *L. texanum* [48].

Relative Water Content (RWC)

The Relative Water Content (RWC) value ranged from 50.08% to 84.37%. The lowest and highest RWC were observed in *A. altissima* (at Kaveh terminal) and *M. nigra* (at Ahmadabad Square), respectively (Figure 3). The highest RWC in leaves of *M. nigra*, *P. orientalis*, *A. altissima* species were observed with the amounts of 84.37%, 77.28%, and 81.38%, respectively. But the lowest was recorded at Kaveh terminal (60.37%), Kaveh terminal (50.80%), and Shahid Kharazi highway (61.18%). At the control site, the highest values of RWC were found in *M. nigra* (84.37%) and the lowest in *P. orientalis* (77.28%). Whereas at the polluted sites, it ranged from 50.08% to 84.37% in *A. altissima* and *M. nigra* and at the Kaveh terminal and Ahmadabad Square sites, respectively. A higher amount of RWC is an effective indicator to save and improve tolerant species from drought conditions. RWC is also a beneficial tool for pollution resistance of the species because water content could maintain and regulates physiological balance under worse conditions of air pollutants [15]. Similar to our study, relative water content was reported for *Samanea saman* [49], *F. carica* [47], *A. indica*, *F. benghalensis*, *M. azedarach*, and *P. longifolia* [7]. The results showed that the decrease in RWC infected areas may be due to the effect of algae on the reduction of plant transpiration [50, 51].

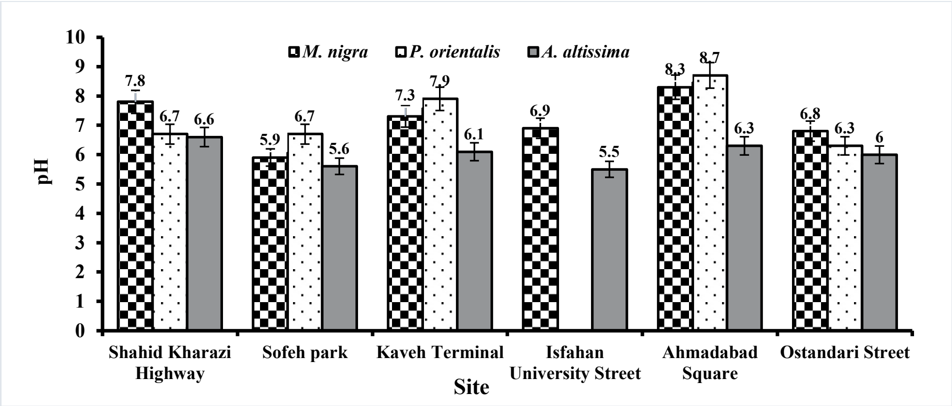

Figure 4. Values of leaf extract pH in the fresh leaves of selected tree species in the polluted and control sites (Isfahan City)

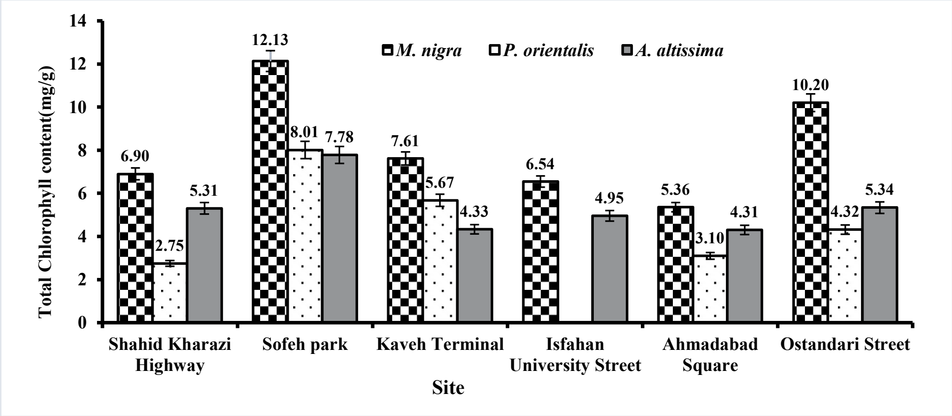

Figure 5. Values of TCH content (mg/g) in the leaves samples of tree species in the control and polluted sites (Isfahan City)

Table 3. Biochemical and physiological parameters along with APTI of studied trees species

Tree Species	RWC	pH	A. Acid	TCH	APTI	Category
M. nigra	74.03	7.20	8.33	8.25	20.27	Intermediate
P. orientalis	63.99	7.26	7.07	4.77	14.90	Sensitive
A. altissima	64.20	6.02	7.05	5.34	14.43	Sensitive

RWC:Relative Leaf Water Content; TCH:Total Chlorophyll Content; APTI:Air Pollution Tolerance Index

Leaf extract pH

The mean leaf extract pH in leaves samples at the control and various polluted sites is shown in Figure 4. The highest and lowest content of leaf extract pH were detected in *P. orientalis*, and *A. altissima* leaves with an amount of 8.7 (at Ahmadabad Square) and 5.5 (at Isfahan university street), respectively (Figure 3). The highest pH was observed in *P. orientalis* (8.7), followed by *M. nigra* (8.3) and *A. altissima* (5.50). The variation in leaf pH levels can influence stomatal susceptibility due to air pollution. Similarly, Ogunkunle et al., Bahadoran et al., and Yadav et al. reported that high pH levels of leaves was observed in trees at polluted sites [7, 34, 46], and play an essential role in maintaining the physiological balance of plants under stress condition such as exposure to air pollution. Plants with lower pH are more sensitive to air pollution, whereas species with a higher pH level are more resistant plants [34]. Most trees showed pH above 6, so according to the amount of pH value in tree leaves (pH around 7), they are more tolerant (Figure 4) [50, 52]. Lower contents of pH of leaves may decrease the efficiency of conversion of hexose sugar to AAC, which is related to the sensitivity to an acidic pollutant [41, 53, 54]. Alkaline pH plays a vital role in plant tissue, such as regulating the conversion of hexose sugar into ascorbic acid, increasing the photosynthetic activities, and improving plant tolerance to air pollutants [15].

Table 4. Evaluation of selected tree species

SUM Positive	Economic value	Hardiness	Texture	Size	Type	Canopy	Habit	APTI	Plant species
13	++	+	+	+	-	++	+	+++++	*M. nigra*
9	+	+	+	+	-	+	+	+++	*A. altissima*
12	++	+	+	++	-	++	+	+++	*P. orientalis*

Table 5. Assessment of API of selected tree species

Assessment	API Grades	Score (%)	Total Grade Allotted	Species
Excellent	6	81.25	13	*M. nigra*
Intermediate	3	56.25	9	*A. altissima*
Very Good	5	75	12	*P. orientalis*

Total Chlorophyll Content (TCH)

The total chlorophyll content in the tree species varied from 3.75 to 12.13 mg/g. *M. nigra* showed the highest chlorophyll value at Sofeh park site (Figure 5), and the lowest TCH value was seen in *P. orientalis* at Shahid Kharazi highway site (Figure 5). The highest TCH in leaves of *M. nigra*, *P. orientalis*, and *A. altissima* species were observed with the amount of 12.13, 8.01, and 7.78 mg/g. But the lowest was recorded at Kaveh terminal (4.33 mg/g), Shahid Kharazi highway (2.77 mg/g), and Ahmadabad square (4.31 mg/g). Reduction of TCH has been widely used to indicate air pollution in contaminated areas because the TCH values are sensitive to pollutants. Also, Jyothi and Jaya, Lohe et al., and Zhang et al. reported that a high amount of pollution decreases and degrades chlorophyll content in plants at polluted sites. [35, 50, 53]. High TCH content reduces the production of reactive oxygen species in the chloroplast organ during water stress. The experimental evidence showed that the chlorophyll values of plants vary among different species and varieties. Because of their various responses to environmental conditions, plant growth stage, age of leaf, pollution status, seasonal variation, and several others factors (biotic and abiotic) [55, 56]. For example, one pollutant compound may decrease the total chlorophyll content while the other increase it [57, 58]. The most important variation in TCH values in the tree leaves from the control (or low pollution) site, and the polluted site was found in *M. nigra*, i.e., from 12.13 to 5.36 mg/L (Figure 1). Higher content of TCH detected in *M. nigra* was probably due to its tolerant nature [32].

Air Pollution Tolerance Index (APTI)

In general, the classification of trees (susceptible) according to only one single variable (such as leaf extract pH, TCH, ascorbic acid content, and RWC) could not provide a complete picture. Hence, calculating the comprehensive index such as APTI based on those variables is a more appropriate and reliable method to indicate the tolerance level of plant species [14, 30]. APTI is known as a significant index to categorize species in terms of their sensitivity against air pollution. In our research, the APTI value varies from 14.43 to 20.27 (Table 3). The greater score of APTI index was found in *M. nigra* (20.27), followed by *P. orientalis* (14.90) and *A. altissima* (14.43). The amount of APTI values differs from species to species related to trees' response to the pollutants without illustrating any external manifest damage [59]. The trees with higher APTI scores are considered tolerant species and have high RWC and TCH content with a low acidic pH in their leaves [54]. Thus these groups of species can be applied for mitigating the pollution.

In contrast, the trees with lower APTI scores showed higher sensitivity and can be used as an indicator of air pollution levels [30]. The tolerance of plants based on APTI values are categorized into four classes (very sensitive=lower than 1, sensitive=1–16, intermediate=17–29, and tolerant if APTI value equals 30–100) [50, 60]. So, in the present study depending on APTI values, *P. orientalis* and *A. altissima* species are sensitive, while *M. nigra* is an intermediately tolerant species. Therefore, *M. nigra* can be used as a suitable tree to improve the air condition of polluted areas (even in highly contaminated zones). Similarly, Leghari et al. and Javanmard et al. introduced and recommended *M. nigra* and *M. alba* (with APTI scores of 22.53 and 17.25, respectively) as favorable trees for urban green spaces development due to their high APTI score and good performer.

Anticipated Performance Index (API)

The detection of tolerant species to expand the green space and improve air quality using the APTI alone is not enough. So, by integrating this index and socioeconomic and biological attributes, the API is computed. This index can assign a good and logical reason to integrate physiognomy, ecological, and economic attributes of various plant species for afforestation, and eco-control pollution development [59]. The results demonstrated that all three species are tolerant and good performers. *M. nigra* with the highest API value (score=6) is classified as an excellent performer (Table 4). Followed by *P. orientalis* (very good performer) and *A. altissima* (intermediate) with an API score of 5 and 3 (Table 5). Overall, the plant with the highest API value can be highly recommended as a superior bio-filter for green space development. *M. nigra* had the highest performance (excellent), so it was recommended as appropriate plant species for the green belt development zones given abating the urban air pollution and traffic generated noise. Similarly, Kwak et al. suggested that trees with high API score such as *P. densiflora* and *P. × yedoensis* are favorable trees for the development of planting plans around urban areas and polluted zones [1]. Besides, our finding was similar to the result by Leghari et al.. They reported that *M. nigra* (score=5) and M. alba (score=6) had the highest API value among all studied trees [47].

4. Conclusion

In this research, we aimed to assess the potential (sensitivity or tolerance) and efficiency of three tree species (*P. orientalis*, *M. nigra*, and *A. altissima*) for green-belt development and landscaping in Isfahan City. For this purpose, the APTI and API can be favorable and reliable indices. In this regard, species with lower APTI values are categorized as sensitive species. So they can be used as a bio-indicator, and in contrast, species with higher APTI and API levels (categorized as tolerant species) can be used in plantation plans in pollutant and industrial zones to attenuate the pollution level. Overall, the measurement of leaf biochemical and physiological (ascorbic acid, RWC, chlorophyll content, leaf extract pH) and APTI values showed that depending on species and sites, trees' response to air pollution is very different. According to the APTI values, *M. nigra* is the most tolerant species (intermediate), followed by P orientalis and *A. altissima*. Besides, *M. nigra* has a higher API score (excellent performer). Hence, this species is recommended as a more suitable species for plantation programs as a tolerant and pollutant accumulating tree to improve air quality in Isfahan City. Our results suggest that *P. orientalis* and *A. altissima* can be introduced as bio-indicators of air pollution due to their low APTI scores (lower than 16). Besides, our finding suggests that more studies are required to evaluate and fully understand the exact responses of plants to a specific pollutant in urban climate and industrial zones. The combination of both APTI and API indices to identify and select plant species is very useful for plantations in urban areas.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed of the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

References

[1] Kwak MJ, Lee JK, Park S, Lim Y, Kim H, Kim KN, et al. Evaluation of the importance of some east asian tree species for refinement of air quality by estimating air pollution tolerance index, anticipated performance index, and air pollutant uptake. Sustainability. 2020; 12(7):3067. [DOI:10.3390/su12073067]

[2] Shahid M, Dumat C, Khalid S, Schreck E, Xiong T, Niazi NK. Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. J Hazard Mater. 2017; 325:36-58. [DOI:10.1016/j.jhazmat.2016.11.063] [PMID]

[3] Roy A, Bhattacharya T, Kumari M. Air pollution tolerance, metal accumulation and dust capturing capacity of common tropical trees in commercial and industrial sites. Sci Total Environ. 2020; 722:137622. [DOI:10.1016/j.scitotenv.2020.137622] [PMID]

[4] Nowak DJ. Urban trees, air quality and human health. In: Gallis CH, Shi WS, editors. Forests for public health. Newcastle Upon Tyne: Cambridge Scholars Publishing; 2020. https://www.fs.usda.gov/treesearch/pubs/60881

[5] Alahabadi A, Ehrampoush MH, Miri M, Aval HE, Yousefzadeh S, Ghaffari HR, et al. A comparative study on capability of different tree species in accumulating heavy metals from soil and ambient air. Chemosphere. 2017; 172:459-67. [DOI:10.1016/j.chemosphere.2017.01.045] [PMID]

[6] Sevik H, Ozel HB, Cetin M, Özel HU, Erdem T. Determination of changes in heavy metal accumulation depend-

ing on plant species, plant organism, and traffic density in some landscape plants. Air Qual Atmosphere Health. 2019; 12(2):189-95. [DOI:10.1007/s11869-018-0641-x]

[7] Yadav R, Pandey P. Assessment of Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of roadside plants for the development of greenbelt in urban area of Bathinda City, Punjab, India. Bull Environ Contam Toxicol. 2020; 105(6):906-14. [DOI:10.1007/s00128-020-03027-0] [PMID]

[8] Durkan N, Ugulu I, Unver M, Dogan Y, Baslar S. Concentrations of trace elements aluminum, boron, cobalt and tin in various wild edible mushroom species from Buyuk Menderes River Basin of Turkey by ICP-OES. Trace Elem Electrolytes. 2011; 28(4):242. [DOI:10.5414/TEX01198]

[9] Sen A, Khan I, Kundu D, Das K, Datta JK. Ecophysiological evaluation of tree species for biomonitoring of air quality and identification of air pollution-tolerant species. Environ Monit Assess. 2017; 189(6):262. [DOI:10.1007/s10661-017-5955-x] [PMID]

[10] Unver MC, Ugulu I, Durkan N, Baslar S, Dogan Y. Heavy metal contents of Malva sylvestris sold as edible greens in the local markets of Izmir. Ekoloji. 2015; 24(96):13-25. [DOI:10.5053/ekoloji.2015.01]

[11] Selmi W, Weber C, Rivière E, Blond N, Mehdi L, Nowak D. Air pollution removal by trees in public green spaces in Strasbourg city, France. Urban For Urban Green. 2016; 17:192-201. [DOI:10.1016/j.ufug.2016.04.010]

[12] Martínez-López S, Martínez-Sánchez MJ, Pérez-Sirvent C, Bech J, Martínez MDCG, García-Fernandez AJ. Screening of wild plants for use in the phytoremediation of mining-influenced soils containing arsenic in semiarid environments. J Soils Sediments. 2014; 14(4):794-809. [DOI:10.1007/s11368-013-0836-6]

[13] Hu Y, Wang D, Wei L, Zhang X, Song B. Bioaccumulation of heavy metals in plant leaves from Yan' an city of the Loess Plateau, China. Ecotoxicol Environ Saf. 2014; 110:82-8. [DOI:10.1016/j.ecoenv.2014.08.021] [PMID]

[14] Nadgórska-Socha A, Kandziora-Ciupa M, Trzęsicki M, Barczyk G. Air pollution tolerance index and heavy metal bioaccumulation in selected plant species from urban biotopes. Chemosphere. 2017; 183:471-82. [DOI:10.1016/j.chemosphere.2017.05.128] [PMID]

[15] Irshad MA, Nawaz R, Ahmad S, Arshad M, Rizwan M, Ahmad N, et al. Evaluation of anticipated performance index of tree species for air pollution mitigation in Islamabad, Pakistan. JASEM. 2020; 23(1). https://ovcre.uplb.edu.ph/journals-uplb/index.php/JESAM/article/view/335

[16] Goyal D, Yadav A, Vats T. Air Pollution and Its Role in Stress Physiology. Air Pollution and Environmental Health. Springer; 2020. [DOI:10.1007/978-981-15-3481-2_6]

[17] Balasubramanian A, Prasath CH, Gobalakrishnan K, Radhakrishnan S. Air Pollution Tolerance Index (APTI) assessment in tree species of Coimbatore urban city, Tamil Nadu, India. Int J Env Clim Change. 2018; 8:27-38. [DOI:10.9734/ijecc/2018/v8i127106]

[18] Morani A, Nowak DJ, Hirabayashi S, Calfapietra C. How to select the best tree planting locations to enhance air pollution removal in the MillionTreesNYC initiative. Environ Pollut. 2011; 159(5):1040-7. [DOI:10.1016/j.envpol.2010.11.022] [PMID]

[19] Dzierżanowski K, Popek R, Gawrońska H, Sæbø A, Gawroński SW. Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. Int J Phytoremediation. 2011; 13(10):1037-46. [DOI:10.1080/15226514.2011.552929] [PMID]

[20] Braun S, Achermann B, De Marco A, Pleijel H, Karlsson PE, Rihm B, et al. Epidemiological analysis of ozone and nitrogen impacts on vegetation-Critical evaluation and recommendations. Sci Total Environ. 2017; 603:785-92. [DOI:10.1016/j.scitotenv.2017.02.225] [PMID]

[21] Khalid S. Phytomonitoring of air pollution around brick kilns in Balochistan province Pakistan through air pollution index and metal accumulation index. J Clean Prod. 2019; 229:727-38. [DOI:10.1016/j.jclepro.2019.05.050]

[22] Shah K, Ul Amin N, Ahmad I, Ara G. Impact assessment of leaf pigments in selected landscape plants exposed to roadside dust. Environ Sci Pollut Res Int. 2018; 25(23):23055-73. [DOI:10.1007/s11356-018-2309-3] [PMID]

[23] Javanmard Z, Kouchaksaraei MT, Hosseini SM, Pandey AK. Assessment of anticipated performance index of some deciduous plant species under dust air pollution. Environ Sci Pollut Res. 2020; 27(31):38987-94. [DOI:10.1007/s11356-020-09957-w] [PMID]

[24] Noor MJ, Sultana S, Fatima S, Ahmad M, Zafar M, Sarfraz M, et al. Retracted Article: Estimation of anticipated performance index and air pollution tolerance index and of vegetation around the marble industrial areas of Potwar region: bioindicators of plant pollution response. Environ Geochem Health. 2015; 37(3):441-55. [DOI:10.1007/s10653-014-9657-9] [PMID]

[25] Yoshimoto K, Ohsumi Y. Unveiling the molecular mechanisms of plant autophagy—from autophagosomes to vacuoles in plants. Plant Cell Environ. 2018; 59(7):1337-44. [DOI:10.1093/pcp/pcy112]

[26] Dayan J. Gibberellin transport. Annual Plant Rev online. 2018; 49. [DOI:10.1002/9781119312994.apr0533]

[27] Ogbonna C, Nwafor F, Ugbogu E. Physiochemical Properties and Anticipated Performance of Selected Plant Species in Lokpaukwu Quarry Site in Abia State, Nigeria. J Environ Pollut Hum Health. 2019; 7(1):7-14. https://www.researchgate.net/profile/Felix-Nwafor/publication/333311173_

[28] Rai PK. Particulate matter tolerance of plants (APTI and API) in a biodiversity hotspot located in a tropical region: Implications for eco-control. Particul Sci Technol. 2020; 38(2):193-202. [DOI:10.1080/02726351.2018.1527800]

[29] Pathak RK, Tomar C, Mahajan S. Phytomonitoring of atmospheric pollution in road side perennial trees of Indore city (MP) India. Int J Adv Eng Technol. 2015; 7(6):1727. https://search.proquest.com/openview/427ad03d9eff5d30071a3b900201438a/1?pq-origsite=gscholar&cbl=1486350

[30] Karmakar D, Padhy PK. Air pollution tolerance, anticipated performance, and metal accumulation indices of plant species for green-belt development in urban industrial area. Chemosphere. 2019; 237:124522. [DOI:10.1016/j.chemosphere.2019.124522] [PMID]

[31] Rai PK, Panda LL. 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 Qual Atmosphere Health. 2014; 7(1):93-101. [DOI:10.1007/s11869-013-0217-8]

[32] Bakiyaraj R, Ayyappan D. Air pollution tolerance index of some terrestrial plants around an industrial area. Int J Modern Res Rev. 2014; 2(1):1-7. http://journalijmrr.com/wp-content/uploads/2014/01/8.pdf

[33] Norouzi S, Khademi H, Cano AF, Acosta JA. Using plane tree leaves for biomonitoring of dust borne heavy metals: A case study from Isfahan, Central Iran. Ecol Indic. 2015; 57:64-73. [DOI:10.1016/j.ecolind.2015.04.011]

[34] Bahadoran M, Mortazavi SN, Hajizadeh Y. Evaluation of anticipated performance index, biochemical, and physiological parameters of cupressus arizonica greene and juniperus excelsa bieb for green-belt development and biomonitoring of air pollution. Int J Phytoremediation. 2019; 21(5):496-502. [DOI:10.1080/15226514.2018.1537251] [PMID]

[35] Zhang W, Zhang Y, Gong J, Yang B, Zhang Z, Wang B, et al. Comparison of the suitability of plant species for green-belt construction based on particulate matter capture capacity, air pollution tolerance index, and antioxidant system. Environ Pollut. 2020; 263:114615. [DOI:10.1016/j.envpol.2020.114615]

[36] Molnár VÉ, Simon E, Tóthmérész B, Ninsawat S, Szabó S. Air pollution induced vegetation stress-the air pollution tolerance index as a quick tool for city health evaluation. Ecol Indic. 2020; 113:106234. [DOI:10.1016/j.ecolind.2020.106234]

[37] Singh S, Rao D. Symposium on Air Pollution Control. Pennsylvania: ASTM; 1983. https://books.google.com/books?id=APhsAQAACAAJ&dq

[38] Pathak V, Tripathi B, Mishra V. Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. Urban For Urban Green. 2011; 10(1):61-6. [DOI:10.1016/j.ufug.2010.06.008]

[39] Arnon DI. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. Plant Physiol. 1949; 24(1):1. [DOI:10.1104/pp.24.1.1] [PMID] [PMCID]

[40] Keller T, Schwager H. Air pollution and ascorbic acid. Eur J For Pathol. 1977; 7(6):338-50. [DOI:10.1111/j.1439-0329.1977.tb00603.x]

[41] Liu YJ, Ding H. Variation in air pollution tolerance index of plants near a steel factory: Implication for landscape-plant species selection for industrial areas. WSEAS Trans Environ Dev. 2008; 4(1):24-32. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.576.5497&rep=rep1&type=pdf

[42] Prajapati SK, Tripathi B. Anticipated Performance Index of some tree species considered for green belt development in and around an urban area: A case study of Varanasi city, India. J Environ Manage. 2008; 88(4):1343-9. [DOI:10.1016/j.jenvman.2007.07.002] [PMID]

[43] Bora M, Joshi N. A study on variation in biochemical aspects of different tree species with tolerance and performance index. Bioscan. 2014; 9(1):59-63. http://thebioscan.in/Journals_PDF/9113%20MEHA%20BORA_2482.pdf

[44] Tsega YC, Prasad A. Variation in air pollution tolerance index and anticipated performance index of roadside plants in Mysore, India. J Environ Biol. 2014; 35(1):185-90. http://jeb.co.in/journal_issues/201401_jan14/paper_05.pdf

[45] Tripathi A, Gautam M. Biochemical parameters of plants as indicators of air pollution. J Environ Biol. 2007; 28(1):127. https://d1wqtxts1xzle7.cloudfront.net/32863646/5._Journal_of_Env_

[46] Ogunkunle C, Suleiman L, Oyedeji S, Awotoye O, Fatoba P. Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. Agroforestry Syst. 2015; 89(3): 447-454. [DOI:10.1007/s10457-014-9781-7]

[47] Leghari SK, Akbar A, Qasim S, Ullah S, Asrar M, Rohail H, et al. Estimating anticipated performance index and air pollution tolerance index of some trees and ornamental plant species for the construction of green belts. Polish J Environ Stud. 2019; 28(3):1759-69. [DOI:10.15244/pjoes/89587]

[48] Ghafari S, Kaviani B, Sedaghathoor S, Allahyari MS. Assessment of Air Pollution Tolerance Index (APTI) for some ornamental woody species in green space of humid temperate region (Rasht, Iran). Environ Dev Sustain. 2021; 23(2):1579-600. [DOI:10.1007/s10668-020-00640-1]

[49] Sumangala H, Aswath C, Laxman R, Namratha M. Evaluation of Air Pollution Tolerance Index (APTI) of selected ornamental tree species of Bengaluru, India. Int J Pure App Biosci. 2018; 6(3):366-73. [DOI:10.18782/2320-7051.6382]

[50] Lohe R, Tyagi B, Singh V, Kumar TP, Khanna D, Bhutiani R. A comparative study for air pollution tolerance index of some terrestrial plant species. Glob J Environ Sci Manage. 2015; 1(4):315-24. https://www.sid.ir/en/Journal/ViewPaper.aspx?ID=455283

[51] Swami A, Bhatt D, Joshi P. Effects of automobile pollution on sal (Shorea robusta) and rohini (Mallotus phillipinensis) at Asarori, Dehradun. Himalayan J Environ Zool. 2004; 18(1):57-61. https://www.researchgate.net/publication/303002577_

[52] Kumar M, Nandini N. Identification and evaluation of air pollution tolerance index of selected avenue tree species of urban Bangalore, India. Int J Emerg Technol Comput Appl Sci. 2013; 4(5):388-90. https://www.researchgate.net/publication/316076075_

[53] Jyothi SJ, Jaya D. Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. J Environ Biol. 2010; 31(3):379-86. http://www.jeb.co.in/journal_issues/201005_may10/paper_26.pdf

[54] Madan S, Verma P. Assessment of air pollution tolerance index of some trees in Haridwar City, Uttarakhand. J Environ Biol. 2015; 36(3):645. http://www.jeb.co.in/journal_issues/201505_may15/paper_20.pdf

[55] Ubuoh E, Kanu C, Mpamah I. Assessment of Air Quality Status Using Pollution Standard Index in Udeagbala Industrial Area, Abia State, Nigeria. Int J Geogr Environ Manage. 2017; 3(3):47-57. http://iiardpub.org/get/IJGEM/VOL.%203%20NO.%203%202017/Assessment%20of%20Air%20Quality.pdf

[56] Begum A, Harikrishna S. Evaluation of some tree species to absorb air pollutants in three industrial locations of South Bengaluru, India. J Chem. 2010; 7(S1):S151-S156. [DOI:10.1155/2010/398382]

[57] Gholami A, Mojiri A, Amini H. Investigation of the Air Pollution Tolerance Index (APTI) using some plant species in Ahvaz region. J Anim Plant Sci. 2016; 26(2):475-80. http://www.thejaps.org.pk/docs/v-26-02/24.pdf

[58] Allen Jr L, Boote K, Jones J, Jones P, Valle R, Acock B, et al. Response of vegetation to rising carbon dioxide: Photosynthesis, biomass, and seed yield of soybean. Global Biogeochem Cycles. 1987; 1(1):1-14. [DOI:10.1029/GB001i001p00001]

[59] Nayak A, Madan S, Matta G. Evaluation of Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of Some Plants Species in Haridwar City. Int J Enviro Rehabil Conserv. 2018; 9:1-7. [DOI:10.31786/09756272.18.9.1.101]

[60] Aji MM, Adamu M, Borkoma MB. Determination of air pollution tolerance index of selected trees in selected locations in Maiduguri. Appl Res J. 2015; 1(7):378-83. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.695.4245&rep=rep1&type=pdf