The Pharma Innovation Journal 2023; 12(5): 2626-2631

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(5): 2626-2631

www.thepharmajournal.com
Received: 06-02-2023
Accepted: 17-03-2023

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Air pollution tolerance index and anticipatory performance index of horticultural plants as a tool for assessing air quality: A review

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Abstract
In modern times air pollution has become a menace for the survival of all living beings. The use of plants in cleansing the environment and for abatement of pollution and improvement of environment is an effective way which is well recognized throughout the world. Different plant species respond differently to air pollution with certain species being very sensitive and shows visible and measurable symptoms, while some others may be highly tolerant to air pollution. The morphological damage of plants is generally visible through lesions on the aerial parts, while the biochemical and invisible physiological changes can be measured and quantified. From various researches of different researchers across the globe, Anticipated Performance Index (API) and Air pollution tolerance index (APTI) in combination has proved to be an innovative ecological approach in selecting plant species for reducing air pollution. This review suggests that a combination of APTI and API can be of immense importance for the evaluation of plant responses to a variety of pollutants for green belt purposes. Plants having high APTI and API value can be selected for the green belt improvement and long term air pollution management in city and developed areas.

Keywords: Air pollution tolerance index, anticipatory performance index, phytoremediation

Introduction
Air pollution has become a major problem today due to rapid urbanization and industrialization. The quality of lives of all living organisms including humans is affected by the quality of air. Gases and particles are added to the air due to natural factors, such as windstorms, extreme temperatures, and dust. Human activities, industrial and agricultural plants, and vehicles are also added factors that result in the presence of such materials into the air (Gholami *et al.*, 2016) [62]. Air is considered polluted when there is a high concentration of one or more contaminants in the atmosphere (Phalen *et al.*, 2013) [33]. According to Gawronski *et al*., 2017 [63] air becomes polluted when excess number of aerosols and chemicals are present in the atmosphere as compared with pristine conditions. Pollutants found in the atmosphere comprised mainly of gaseous pollutants, such as sulphur dioxide (SO2), carbon monoxide (CO), nitrogen oxides (NOX), ozone (O3), lead (Pb), and particulate matter (PM2.5 and PM10). The concentrations of these pollutants in the atmosphere depends on the sources, distribution pattern, meteorological conditions, and the topographical features of an environment (Chattopadhyay *et al.*, 2012) [5]. The application of plants for reducing and absorbing pollutants from the atmosphere has been proposed as the only eco management approach to lessen the harmful impact of human activity on the environment due to air pollution It is termed as phytoremediation. It refers to the natural ability of certain plants to bioaccumulate, degrade, or render harmless contaminants in soil, water, or air. The different techniques of phytoremediation are Phytoextraction (Phytoaccumulation, Phytoabsorption, or Phytosequestration), Phytovolatilization, Phytodegradation (Phytotransformation), Phytostabilization (Phytoimmobilization or in-place inactivation), Rhizodegradation (Phytostimulation) and Rhizofiltration. Phytoremediation is a cost-efficient plant-based approach that takes advantage of the ability of plants to concentrate elements and compounds from the environment and metabolize various molecules in their tissues. Plants therefore, can play a significant role in controlling air pollution. Phytoremediation helps in remediating particulate matter, inorganic air pollutants, and volatile organic compounds in the air as well as persistent organic pollutants in the air (Lee *et al.*, 2020) [3].

Due to the ability of plants to absorb air pollutants with no adverse effect to them, several reports have proposed treating air pollutants by various plant parts as the new sustainable environmental health method, using various phytoremediation techniques (Nawahwi *et al.*, 2014; Kaoor *et al.*, 2017; Reshma *et al.*, 2017) [28, 39].

Air pollution affects the biochemical, physiological, and morphological parameters of plants. The effect of air pollution in plants may be direct or indirect through acidification of leaves and soil (Jones *et al.*, 2012 and Rai *et al.*, 2013) [15, 37]. When exposed to air pollution, most plants experience physiological changes before exhibiting visible damage to leaves [Seyyednejad, 2011 and Rai *et al.*, 2013] [44, 37]. Air pollutants such as SOx, NOx, and COx diffuse into plant leaves and react with the stomatal and cellular water, thereby affecting the RWC and reducing pH (Dwivedi *et al.*, 2008; Patel & Kousar, 2011) [7, 32]. Plant morphological structure might also change due to the acclimatization of plants to air pollutants, for example thicker epidermal cells and longer trichomes (Liu and Ding, 2008) [24]. These alterations in morphological, biochemical, and physiological characteristics of plants can act as efficient indicators of impact air pollution on the vegetation and all other living organisms. On the basis of responses of plants towards air pollution, some biological parameters of each plant species can be analysed, which aids in figuring out how much these species can tolerate. By assessing specific biochemical and socioeconomic traits, which may be found from the two indices known as the air pollution tolerance index (APTI) and anticipated performance index (API), respectively, the right plant species can be identified.

Morphological, biochemical and physiological changes in plants growing in polluted environment

Air pollution significantly affects important physiological processes, like photosynthesis, respiration, carbon allocation and stomatal function besides bringing changes in biochemical and morphological traits specifically of the leaves in plants. Thawale *et al.* (2010) [52] observed that the correlated values of air pollutants and plant leaves characteristics alter foliar biochemical features (i.e., chlorophyll and ascorbic acid content, pH and relative water content) of plants. According to Winner, 1981 air pollutants cause damage to leaf cuticles and also affect stomatal conductance. They can also have direct effects on photosynthetic systems, leaf longevity, and patterns of carbon allocation within plants. Changes in stomatal and epidermal cell size, thickening of cell wall, epicuticular wax deposition alterations and chlorosis are among the auxiliary alterations that occur in leaves subjected to air pollution (Rao and Dubey, 1991; Srivastava, 1999) [38, 50]. Increase in the number of trichomes and formation of thicker epidermal cells in plants for acclimatization during pollution stress have been reported by Neverova *et al*. (2013) [29]. Increment in densities of stomata, trichomes and epidermal cells, longer trichomes and decrease in size of epidermal cells at polluted sites were observed in *C. siamea* by Preeti (2000) [36] when contrasted with at reference site. The morphological traits of leaves of E. camaldulensis like leaf area, leaf length, leaf width and petiole length were significantly reduced in polluted region compared with clean region as reported by Aghil *et al.* (2011) [2]. Tiwari *et al.* (2006) [53] reported that in sensitive plant species, pollutants can cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic activity, disturb membrane permeability and reduce growth and yield. Increase in length, breadth of leaflets and decrease in area of leaf was seen in leaves of *Albizia lebbeck* under the stress of air pollution by Seyyednejad *et al.*, 2009 [45]. Saadullah and Muddasir (2013) [40] studied how air pollution affected the morphological traits of 13 common plant species' leaves *viz*., *Elaeagnus angustifolia* L., *Eucalyptus tereticornis* L., *Fic us carica* L., *Fraxinus excelsior* L., *Melia azadirach* L., *Moru s alba* L., *Morus nigra* L., *Pistacia vera* L., *Prunus armeniaca* L., *Punica granatum* L., *Robinia pseudoacacia* L., *Rosa indic a* L. and *Vitis vinifera* L. grown in polluted site and observed that when compared to the same plant species at a non-polluted site, all plant species showed a substantial reduction in their leaf length, width, area, and petiole length at polluted site. The growth of morphological features in these plant species varied noticeably from season to season as well. Long back in 1992, Jahan and Iqbal also reported significant (p<0.05) reduction in leaf variables in polluted environment compared to clean atmosphere.

Since the major system and organs of plants are exposed to the atmosphere and the leaves continuously exchange gases in and out of the systems, any change in the atmosphere is reflected in the plants' physiology. (Kulshresht and Saxena, 2016) [22].

Chlorophyll is one of the main essential component for production of energy in green plants which is significantly affected by environmental the condition. Depletion in chlorophyll content results in the decrease in the productivity of plants. The total chlorophyll level in plants decreasesunder stress condition (Speeding and Thomas 1973) [49].

Aghil *et al.* (2011) [2] reported that the in a polluted area, *Eucalypus camaldulensis* had higher levels of total chlorophyll, chlorophyll a, and b, as well as carotenoids, soluble sugar, and proline. Additionally, compared to clean areas, the morphological characteristics of *Eucalypus camaldulensis* leaves were diminished in polluted areas. Proline concentration and soluble sugar levels rise in response to air pollution stress. (Prado *et al.*, 2000; Seyyednejad and Koochac, 2011) [34, 44]. Due to the presence of a higher level of air pollutants, the concentration of soluble sugar and protein were higher in the case zones, which serve as the plant's storage and structural components. The breakdown of reserved polysaccharides or their enhanced production may be the cause of the reduction in soluble sugar. (Fiseher, 1971). Under air polluted conditions, the free amino acid level has increased (Malhotra, 1984). Zhao *et al.* (2021) [55] observed that the leaf area and soluble sugar content of *Ligustrum lucidum* Ait. decreased, while the aspect ratio of leaves increased in heavily polluted areas. Zouari *et al.* (2021) [56] observed that, in *P. armeniaca,* lipid peroxidation level increased in the leaves, grown in polluted areas, whereas photosynthetic capacity (Net photosynthesis, transpiration rate and chlorophyll) declined, compared to the leaves of trees grown in non polluted areas. They concluded that these symptoms can be used as indicators of air pollution stress for its early diagnosis, making them a reliable markers for a particular physiological disorder. A reduction in the photosynthetic pigments chlorophyll a, chlorophyll b and carotenoids of plant leaves of of *Azadirachta indica*, *Nerium oleander, Mangifera indica* and *Dalbergia sissoo* growing in higher polluted site as compared to non or less polluted oneswere also observed by Giri *et al.* (2013) [9]

Air pollution tolerance Index (APTI)

Air Pollution Tolerance Index (APTI) refers to the capability of tree species to measure the impacts of air pollutants (Girish *et al.*, 2017) [10]. Singh and Rao (1983) [47] suggested the use of APTI to screen out the tolerant species from the sensitive ones. This index takes into account all the important biochemical and physiological parameters of plants. Air pollution tolerance index is an inherent quality of plants to encounter air pollution stress, which is presently of prime concern, particularly in industrial and nonindustrial areas (Enitan, 2022). Plants show visible damages and changes in their physiological parameters, which are used to define the air pollution tolerance index (APTI) for plants (Khureshi, 2013) [20] APTI helps in sorting trees into tolerant and sensitive species. Sensitive trees have low APTI values and are used as bio-indicator, while the tolerant species which have high APTI values could be used as a reservoir for the pollutants in an industrial area (Kuddus *et al.*, 2011, Bharti *et al.*, 2018) [21, 4]. The calculation of APTI depends on some biochemical variables that are negatively impacted by air pollutants such as ascorbic acid content, total chlorophyll, relative water content, and pH of leaf extract (Karmakar *et al.*, 2021) [18]. For example, the decrease in chlorophyll content can be increased by SO2 emission particulate deposit on the leaf area (Pathak *et al.*, 2015; Molnár *et al.*, 2018) [57, 26]. APTI can be calculated using Equation given below: (Singh and Rao, 1983) [47].

$$APTI = [AA(TC + pH) + RWC] / 10$$

Where,
A is ascorbic acid (mg/g),
T is total chlorophyll (mg/g)
P is leaf extract pH
R is relative water content (%)

Photosynthetic pigment degeneration has been widely considered as an indicator of air pollution (Ninave *et al.*, 2001) [30] The presence of high chlorophyll contents in the leaves of different plant species reflects the tolerance of these species to air pollution stress (Santosh *et al.*, 2008) [42] Ascorbic acid as an antioxidant plays an important role in defending against oxidative damage and plays a crucial role in the synthesis of cell walls (Girish *et al.*, 2017; Sahu *et al.*, 2020) [10, 41]. Chlorophyll is safeguarded by ascorbic acid against H2O2-induced destruction. The plant needs a lot of ascorbic acid in order to become immune to contamination in this way. Because ascorbic acid promotes chlorophyll combination, a decrease in ascorbic acid may prevent chlorophyll union in the plant's green sections (Agrawal *et al.*, 1991) [1]. The pH of the leaves controls how effectively plants use photosynthesis. The acidity of pollutants reduces the leaf extract pH (Girish *et al.*, 2017) [10]. For the transfer of tiny molecules involving hormones and intracellular trafficking of a vesicle, the balance of pH in cell sections is significant. At alkaline pH, the detoxification mechanism is developed in plants. Hence, when leaf extracts become at neutral or alkaline pH, trees are considered tolerant species. The relative water content (RWC) of the leaf improves transpiration, gives plants a cooling sensation, and assists in restoring vigor during droughts. As a result, the amount of water in the leaves drives the engine that extracts minerals from the soil through the roots of the plants (Sahu *et al.*, 2020) [41]. Besides, increasing in RWC of the leaves under pollution stress helps to maintain the biochemical balance of trees (Tanee & Albert, 2013; Nadgórska-Socha *et al.*, 2017) [51, 27]. The ascorbic acid concentration, total chlorophyll content, leaf extract pH, and RWC of the APTI all have a substantial impact on how resilient plants are to air pollution. (Gharge and Menon, 2012; Liu and Ding, 2008) [24]. According to Kalyani and Singaracharya (1995) [16] and Lakshmi *et al.* (2009) [23], APTI values vary from 1 to 100, and they can be used to identify the sensitivity or tolerance of a certain plant species:

<1= extremely sensitive
1-16=sensitive
17-29=intermediate
30-100=tolerant

Anticipatory performance Index (API)

The most suitable plant species for eco management can also be determined by calculating API. API for different plant species can be calculated by combining the results of APTI values with some biological and socio-economic characters like plant habitat, canopy structure, type of plant, laminar structure as well as economic value. Based on these characters, different grades (+ or -) are allotted to the plant species and grading is done based on these scores. The API score (%) is further calculated using Equation API = No of (+) obtained/ 16 × 100. (Govidaraju *et al.*, 2012). API is particularly useful in the selection of plants species that can perform a dual purpose of improving the air quality by cleaning up atmospheric pollutants and supporting the recreational benefit. (Chaudhary and Panwar, 2016) [6]. Thus evaluation of API helps to assess the capability of the plant species to reduce the atmospheric pollution as well as indicate their socio-economic benefits. To assess the plants' tolerance to air pollution Gopamma *et al.*, 2021 [11], studied the parameters of air pollution tolerance index (APTI) and anticipated performance index (API) of 17 plant species in the traffic density area of Visakhapatnam Out of 17 species studied, eight tree species (*Ficus benghalensis*, *Eucalyptus citriodora*, *Mangifera indica*, *Artocarpus heterophyllus*, *Syzygium cumini*, *Azadirachta indica*, *Bauhinia purpurea* and *Pongamia pinnata*) have shown API values above 81 and were categorized as excellent that could be grown in urban areas. Among them, *Azadirachta indica* and *Pongamia pinnata* are suitable for avenue plantation in traffic density areas because of their resistance to pollution and extreme winds during cyclones. Garg *et al.*, 2021 also concluded that *Dalbergia sissoo*, *Mangifera indica*, *Psidium guajava* and Azadirachta indica are the most tolerant as well as anticipated performers to grow in pollutant areas and can be recommended for the development of greenbelts. Sharma *et al.*, 2020 evaluated API of 11 plant species (6 trees and 5 shrubs) for the recommendation of green belt. The findings indicated that *Dalbergia sisso* (API=4) is a "good" performer in the development of green belts, while *Leucaena leucocephala* and *Toona ciliata* (API=5) qualified as "very good" performers. The performance of *Grewia optiva* and *Ficus palmata* was rated as "moderate" (API = 3). All other remaining studied trees and shrubs with lower API values can serve as bio-indicators and are particularly not highly advised for the creation of green belts.

Table 1: APTI value of different plant species

Plants	T	P	A	R	APTI	References
1.Fruit crops						
Zizyphus jujuba	10.26	6.00	10.60	**80**	**25**	Agrawal, 2006 [58]
Psidium guajava	10.00	6.00	4.27	75	14	Agrawal, 2006 [58]
Tamarindus indica	4.87	4.00	6.00	85	14	Agrawal, 2006 [58]
Delonix regia	6.27	6.40	2.00	45	7	Agrawal, 2006 [58]
Magnifera indica	4.28	5.40	3.78	87	12	Chakre, 2006 [59]
Phyllanthus emblica	10.00	6.00	4.27	75	14	Singh *et al.*,1989 [60]
Annona squamosa	4.00	5.00	3.75	71	10	Singh *et al.*,1989 [60]
Artocarpus heterophyllus	6.60	6.30	3.56	48	9	Singh *et al.*,1989 [60]
Litchi chinensis	2.51	6.20	0.75	48	5	Singh *et al.*,1989 [60]
Aegle marmelos Correa.	3.28	6.00	1.92	74	9	Singh *et al*,1991 [48]
2. Flower crops						
Bougaivellia spectabilis	11.70	6.10	12.39	74	30	Mark, 1997 [61]
Poinsettia species	17.10	6.00	7.00	80	24	Mark, 1997 [61]
Lantana indica	7.51	7.60	4.63	65	14	Mark, 1997 [61]
Rosa indica	4.50	5.50	4.75	74	12	Mark, 1997 [61]
3. Roadside trees						
Ficus religiosa	14.86	8.00	4.78	87	20	Singh *et al*, 1991 [48]
Eucalyptus citriodora	4.25	5.00	4.49	80	12	Chakre, 2006 [59]
Casuarina equisetifolia	0.75	5.40	2.59	58	5	Chakre, 2006 [59]
Azadirachta indica	7.50	6.30	10.21	77	22	Agrawal, 2006 [58]
Bambusa bambos Rotz.	13.60	6.80	7.26	66	21	Singh *et al*, 1991 [48]
Morus alba L.	3.45	5.40	6.42	60	12	Singh *et al*, 1991 [48]
Polyalthia longifolia Benth.	5.78	6.20	8.68	80	18	Singh *et al*, 1991 [48]

T = total chlorophyll (mg g-1 of dry weight); A= ascorbic acid (mg g-1 of fresh weight); P= leaf extract pH; R= relative water content (%).

Table 2: Criteria used for calculating API

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

Source: Kaur and Nagpal (2017)

The API is estimated for the various plant species by combining the biological and socioeconomic characteristics such as plant habit, canopy structure, kind of plant, laminar structure, economic value and resultant APTI. Plants are assigned various grades (good or negative) based on these characteristics, and their scores are then calculated (Kaur and Nagpal, 2017) [19]. According to Prajapati and Tripathi (2008) [35], any plant species can achieve a maximum grade of 16. A specific species' API value is determined by the species' percentage score. The percentage score can be calculated as

% score = Grades obtained by plant species/ Maximum possible grades for any plant species×100

The examination of API aids in determining the plant species' ability to reduce air pollution and also identifies the socioeconomic advantages of certain species. Plants with higher API values can be recommended for green belt development, whereas plants with lesser API values can act as bio-indicators for identifying regions having bad air quality.

Table 2: The criteria used for calculating the API of different plant species

Conclusion

Studies on air pollution tolerance Index and Anticipated Performance Index of plants have indicated that these indices can be utilized to choose most appropriate plants for greenbelt development. Although a lot of studies have been done on these themes over the globe, many species of plants in different areas are yet to be explored. Therefore, researchers have a great responsibility to carry more studies in order to distinguish plants that can be utilized for air pollution alleviation in those areas and also sensitive plant species can indicate the air pollution health of the area. This review infers that plants with higher APTI and API values can be recommended best for green belt development, whereas plants with lesser APTI and API values can act as bio-indicators for identifying regions having bad air quality.

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