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Variation in air pollution tolerance index and anticipated performance index of plants near a sugar factory: implications for landscape-plant species selection for industrial areas

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ABSTRACT:

Air pollution tolerance index (APTI) is used to select plant species which are tolerant to air pollution. Four biochemical parameters such as leaf relative water content (RWC), ascorbic acid (AA) content, total leaf chlorophyll (TCh), and leaf extract pH were used to develop an APTI. Five tree species growing near a sugar mill, an air pollution point source, were collected during six months from October, 2010 to March, 2011. The data suggested that combining a variety of biochemical parameters could give a more reliable result than those air pollution tolerance classifications based on a single biochemical parameter. High values of APTI were recorded in *Ficus religiosa* (44.39) and *Ficus benghalensis* (42.38). The order of tolerance is given as: *Ficus religiosa* > *Ficus benghalensis* > *Pongamia pinnata* > *Delonix regia* > *Azadirachta indica.* The percentage increase in APTI was maximum for *Delonix regia* (69.22%) and minimum for *Ficus benghalensis* (18.33%) when compared to control site. The Anticipated Performance Index (API) of these tree species were also calculated by considering their APTI values together with other socio-economic and biological parameters. According to API, the most tolerant plant species were Ficus *religiosa* (100%) and *Ficus benghalensis* (100%) whereas the species with poor tolerance were *Delonix regia* and *Azadirachta indica.* The APTI and API of species indicated an ideal candidate for landscape planting in the vicinity of polluting industry.

Keywords:

Air pollution tolerance index (APTI), Leaf-extract pH, Leaf total chlorophyll, Ascorbic acid, Leaf relative water content, Anticipated Performance Index (API), biological parameters.

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INTRODUCTION

India has been considered the original home of sugar cane and sugar. Industrial centrifugal sugar production in India started in the mid 1930s in sub-tropical belt. The Indian sugar industry has achieved the unique distinction of being largest producer of white plantation crystal sugar in the world through its extensive network of 540 sugar factories located throughout the country. The liquid and gaseous effluents produced from sugar industry have adverse impact on ecosystem and environment (Solomon, 2005).

Sugar industry is one of the most important agro based industries in India and is highly responsible for creating significant impact on rural economy in particular and countries economy in general. Sugar industries rank second amongst mavar agro based industries in India. Sugar industry is seasonal in nature and operates only for 120 to 200 days in a year (early November to April). A significant large amount of waste is generated during the manufacture of sugar and contains a high amount of production load particularly in items of suspended solids, organic matters, press-mud, and bagasses and air pollution (Bevan, 1971, Hendrickson et.al.1971).

Gaseous emissions such as CO_x, SO_x and NO_x were reported both from process and fired equipment from sugar industry (Khwaja and Quraishi, 2003). Air pollutants can directly affect plants via leaves or indirectly via soil acidification (Steubing et al, 1989). When exposed to airborne pollutants, most plants experienced physiological changes before exhibiting visible damage to leaves (Dohmen et al, 1990). Plants provide an enormous leaf area for impingement, absorption and accumulation of air pollutants to reduce the pollutant level in the air environment (Escobedo et al, 2008), with a various extent for different species (Hove et al, 1999).

Some plants thrive in environments that others would find toxic, these plants can clean-up various sources of manmade pollution; both organic (petrochemical) and inorganic (heavy metal toxins). Trees remove a significant amount of pollution from the atmosphere as part of their normal functioning. They directly increase the quality of the air in the city and its surrounding area and should be considered an integral part of any comprehensive plan aimed at improving overall air quality (Abida Begum et al, 2009).

Trees provide a large leaf surface onto which particles are deposited and gases are removed. Pollution is removed by nearly all parts of a tree; the soil, roots and vegetative portions of the tree species. Trees respirate and exchange gases through stomates, or holes, on their leaves; these gases include those necessary for the tree's functioning as well as other gaseous air pollutants. Once inside the leaf, gases diffuse into the spaces between the cells of the leaf to be absorbed by water films or chemically altered by plant tissues. Trees also reduce air pollution by intercepting airborne particles and retaining them on the leaf surface, called dry deposition. Some can be absorbed by the leaf surface itself, although most remain on the plant surface (Joshi et al, 2008).

Leaf surfaces are most efficient at removing pollutants that are water soluble including sulfur dioxide, nitrogen dioxide and ozone. Pollutants travel through plants by translocation via the xylem and phloem. Chemical pollutants absorbed by the leaves are translocated to the root areas where they can be broken down by microbes in the soil and pollutants absorbed by the roots can be broken down and translocated to the leaves where they are released into the atmosphere (Abida Begum et al, 2010).

Previous studies also showed the impact of air pollution on ascorbic acid content (Hoque et al., 2007), chlorophyll content (Flowers et al., 2007), leaf extract pH (Klumpp et al., 2000) and relative water content (Rao, 1979). These separate parameters gave conflicting results for same species (Han et al., 1995). However, the air pollution tolerance index (APTI) based on all four parameters has been used for identifying tolerance levels of plant species (Singh and Rao, 1983; Singh et al., 1991). Several contributors agree that air pollutants effect plant growth adversely (Sodhi, 2005; Henry and Heinke, 2005; Rao, 2006; Bhatia 2006; Sarala et al, 2009). Air pollution tolerance index is used by landscapers to select plant species tolerance to air pollution (Yan-Ju, 2008).

The present study was carried out for the selection of plant species which can be grown around industrial/urban areas in India. Plants differ considerably with reference to their responses towards pollutants, some being highly sensitive and others hardy and tolerant. On the basis of the APTI and some relevant biological and socioeconomic characters, the anticipated performance index (API) of various plant species was determined for green belt development.

MATERIALS AND METHODS

Selection of sampling area and sampling details

The research work was mainly confined near sugar factory. Five tree species were collected during the winter and summer season of 2010-2011 from polluted and controlled areas. The screening and selection of the tree species were partly based on literature survey of similar work and guidelines of Central Pollution Control Board (1999 - 2000). The five leaf samples were collected at the lower most position of canopy at a height of 6-7ft from the ground surface. Samples were cleaned with distilled water and then refrigerated (22ºC) under suitable condition for further biochemical analysis.

Method for biochemical parameters

Various biochemical parameters such as leaf extracts pH (Sing and Rao, 1983), relative water content (Sen and Bhandari, 1978), total chlorophyll (Arnon, 1949) and ascorbic acid (Keller and Schwager, 1977) were done from the collected leaf samples.

Calculation of Air Pollution Tolerance Index (APTI) of plants

Air pollution tolerance index (APTI) was proposed by Singh and Rao, (1983) to assess the tolerance/resistance power of plants against air pollution. The air pollution tolerance index was calculated using the formula (Singh and Rao, 1983):

$$\mathbf{APTI} = \frac{A(T+P)+R}{10}$$

Where: A =Ascorbic Acid (mg/g)
T =Total Chlorophyll (mg/g -f.w)
P = pH of the leaf extract
R = Relative water content of leaf (%).
Based on the development and evaluation of APTI values among the samples they were categorized into four groups as given in **table 1.**

TABLE 1. Categories of tree species based on APTI

APTI value	Response
30-100	Tolerant
29-17	Intermediate
16-1	Sensitive
< 1	Very sensitive

Calculation of Anticipated Pollution Index (API)

By combining the resultant APTI values with some relevant biological and socio-economic characters (plant habit, canopy structure, type of plant, laminar structure and economic value), the API was calculated for different species. Based on these characters, different grades (+ or -) are allotted to plants. Different plants are scored according to their grades (Dali Mondal et al, 2011). The criteria used for calculating the API of different plant species are given in **table 2 and 3.**

Statistical analysis

Linear regression analysis was performed between independent variables *viz.* Chlorophyll, pH, RWC, ascorbic acid and dependent variable such as APTI by using XL STAT (Version 10) software. These scatter plots illustrated the degree of correlation (R^2) between the said variables.

RESULTS AND DISCUSSION

Plants have been categorized into groups according to their degree of sensitivity and tolerance of various air pollutants on the basis of experiment and available data (Kagamimori et al., 1978; Bhattacharya, 1983; Khan and Abbasi, 2002). Levels of tolerance to air pollution vary from species to species, depending on the capacity of plants to withstand the effect of pollutants without showing any external damage. APTI is a unique index because it incorporates four different biochemical parameters: total chlorophyll, pH of leaf extract, ascorbic acid, and relative water content. The APTI has been determined for five plant species (**Table 4**).

As shown in Table 4, the highest mean total chlorophyll content (in mg/g fresh wt) was recorded in *Azadirachta indica* (0.2857) followed by *Pongamia pinnata* (0.2587), *Delonix regia* (0.2114), *Ficus benghalensis* (0.1476) and *Ficus religiosa* (0.0609) respectively at the polluted site. Higher chlorophyll content in plants might favour tolerance to pollutants (Joshi et al., 1993). Whereas a considerable loss in total chlorophyll, in the leaves of plants exposed air pollution stress supports the argument that the chloroplast is the primary site of attack by air pollutants such as SO_2 and NO_X (Tripathi and Gautam, 2007). Air pollutants make their entrance into the tissues through the stomata and cause partial denaturation of the chloroplast and decrease pigment contents in the cells of polluted leaves (Rao and Leblanc, 1966). High amount of gaseous SO_2 causes destruction of chlorophyll and that might be due to the replacement of Mg^{2+} by two hydrogen atoms and degradation of chlorophyll molecules to phaeophytin (Rao and Leblanc, 1966).

TABLE 2. Gradation of plant species on the basis of Air Pollution Tolerance Index (APTI) and other biological and socio-economic characters.

S. No.	Grading character		Pattern Assessment	Grade allotted
1	Tolerance	Air Pollution Tolerance Index (APTI)	12.0-16.0 16.1-20.0 20.1-24.0 24.1-28.0 28.1-32.0 32.1-36.0	+ ++ +++ ++++ +++++ ++++++
2	Biological and Socio-Economic	Plant Habitat	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	- +
		Economic value	Less than three uses Three or four uses Five or more uses	- + ++

Maximum grades that can be scored by a plant = 16

The mean values of leaf extract pH were given as 8.43, 7.13, 6.93, 6.73 and 6.54 for Ficus *religiosa, Azadirachta indica, Delonix regia, Pongamia pinnata* and *Ficus benghalensis* respectively. The low pH of the leaf extract showed a relationship with the type of air pollution. The more acidic nature demonstrates that the air pollutants are mostly gaseous types, namely SO_2, NO_X and their own acid radical formations in the leaf matrix by reacting with cellular water. These further affects the chlorophyll molecules (Turk and Wirth, 1975). A pH on the higher side improves tolerance against air pollution (Agarwal, 1986).

TABLE 3. Anticipated Performance Index (API) of plant 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

The mean relative water content (RWC) was lowest in *Azadirachta indica* (25.45%) and highest in *Ficus religiosa* (42.76%) at polluted site where as it was 27.23% for *Azadirachta indica* and 35.63% for *Ficus religiosa* at control site. The Relative Water Content (RWC) indicates change in leaf matrix hydration condition and will generate higher acidity condition when RWC is low. The RWC also helps to maintain physiological balance under stress condition higher relative water content is advantageous for drought resistance in plants (Dedio, 1975).

The highest content of ascorbic acid (in mg/ gm fresh wt) at polluted area was found in *Ficus benghalensis* (62.99) followed by *Ficus religiosa* (47.24), *Pongamia pinnata* (23.62), *Delonix regia* (17.32) respectively. Ascorbic acid is regarded as an antioxidant. It is found in large amounts in all

TABLE 4. Mean value of biochemical parameters along with APTI of the leaf samples. (Units are expressed as mg/g-f.w. except pH and Relative Water Content which is expressed in units and percentage respectively).

S. No.	Local Name	Scientific Name	Site	Chlorophyll	pH	RWC	Ascorbic Acid	APTI	Increase in APTI (%)
1	Banyan	*Ficus benghalensis*	Polluted	0.1476	6.54	32.57	62.99	42.38	18.33
			Control	0.0876	6.85	27.23	70.87	51.89	
2	Flamboyant	*Delonix regia*	Polluted	0.2114	6.93	27.08	17.32	15.08	69.22
			Control	0.1165	7.20	29.16	62.99	49.00	
3	Peepal	*Ficus religiosa*	Polluted	0.0609	8.43	42.76	47.24	44.39	39.02
			Control	0.0520	8.74	35.63	78.74	72.79	
4	Neem	*Azadirachta indica*	Polluted	0.2857	7.13	25.45	12.59	11.88	68.18
			Control	0.0541	7.10	35.32	47.24	37.33	
5	Indian Beech	*Pongamia pinnata*	Polluted	0.2587	6.73	36.92	23.62	20.19	57.16
			Control	0.0336	6.83	33.52	63.78	47.13	

growing plant parts and influences resistant to adverse environmental conditions, including air pollution (Keller and Schwager, 1977; Lima et al., 2000). Pollution load dependent increase in ascorbic content of all the species may be due to the more rate of production of reactive oxygen species (ROS) such as SO^{3-}, HSO^{3-}, OH^{-}, and O^{2-} during photo-oxidation of SO^{3-} to SO^{4-} where sulphites are generated from SO_2 absorbed. The free radical production under SO_2 exposure would increase the free radical scavengers, such as ascorbic acid, super oxide dismutase and peroxidase (Pierre and Queirz, 1981) based on dosage and physiological status of plant. Increased level of ascorbic acid may be due to the defense mechanism of the plant. Increased level of ascorbic acid in leaves will increase air pollution tolerance in plants (Chaudhury and Rao, 1977).

As shown in Table 4, plant species with higher APTI values were *Ficus religiosa* (44.39) and *Ficus benghalensis* (42.38) at polluted area and *Ficus religiosa* (72.79) and *Ficus benghalensis* (51.89) at control site respectively. Comparing the control area and polluted area, the percentage increase of APTI (%) was highest for *Delonix regia* (69.22) followed by *Azadirachta indica* (68.18).

Scatter Plot Interpretations

Figure 1, 2, 3 and 4 showed the linear regression plots of individual variables with APTI. The correlation between APTI and four biochemical parameters revealed that there exist a positive relation to each other. It was also observed that a high positive correlation exists between APTI and chlorophyll (ρ = 0.819), APTI and ascorbic acid (ρ = 0.908) and APTI and RWC (ρ = 0.531). It indicates that ascorbic acid and chlorophyll of leaf are the most significant and determining factors on which the tolerance depends.

Anticipated Performance Index (API) of plant species

Plant species for plantation in industrial urban areas were evaluated for various biological and socio-economic as well as a few biochemical characteristics, such as APTI, plant habit, canopy structure, type of plant, laminar structure and economic value. These parameters were subjected

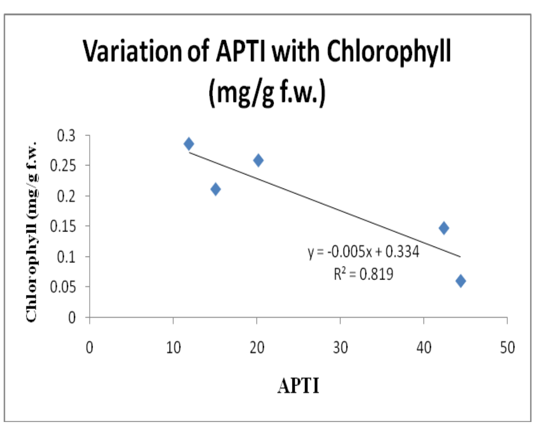

Figure 1

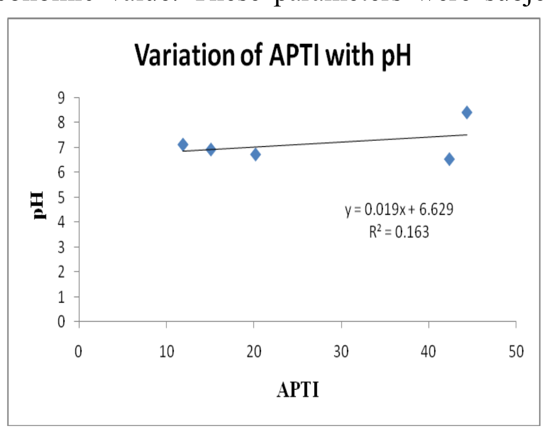

Figure 2

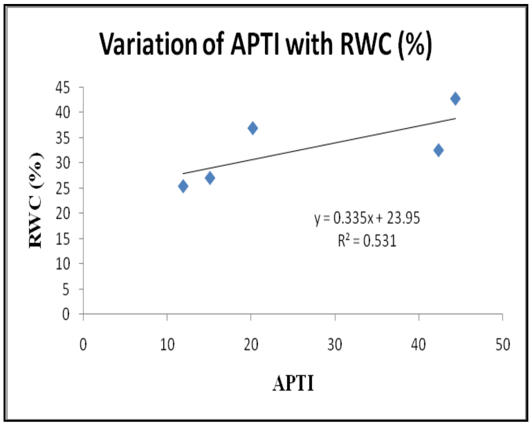

Figure 3

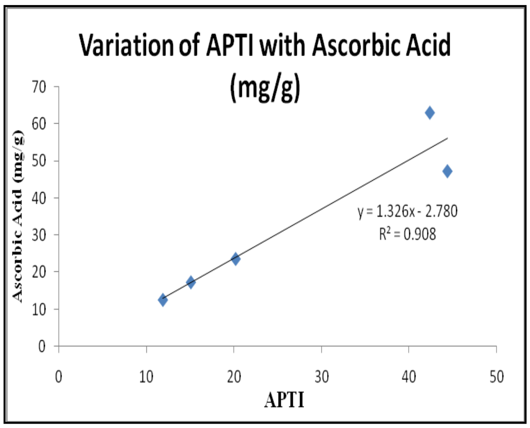

Figure 4

to a grading scale to determine the anticipated performance of plant species as advocated in reference (Sing and Rao, 1983). The grading pattern of five plant species evaluated in **Table 5,** and which fit into the grading pattern with respect to their anticipated performance index (API) were recommended (**Table 6**) for plantation in an industrial/urban area.

Table 6 showed that out of five species, *Ficus benghalensis* and *Ficus religiosa* were the most tolerant plant to grow in industrial areas and can be expected to perform well. It has a dense plant canopy of evergreen like foliage, which may afford protection from pollution stress. The economic and aesthetic values of these trees were well known and it may be recommended for extensive planting as a first curtain.

Pongamia pinnata was judged to be a good performer, while *Azadirachta indica* and *Delonix regia* were recorded as poor and very poor performers. Even though *Pongamia pinnata* was a good performing species, it was found to be unsuitable as a pollution sink because of its lower anticipated performance but can be planted in industrial areas for its aesthetic value and other

Table 5. Biochemical parameters along with APTI of leaf samples (Units are expressed as mg/g-f.w. except pH and Relative Water Content which is expressed in units and percentage

S. No	Trees	APTI	Tree Habitat	Canopy Structure	Types of tree	Size	Texture	Economic importance	Hardness	Total plus	Grade allotted % scoring	API grade
1	Ficus benghalensis	++++++	++	++	+	+	+	++	+	16	100	7
2	Delonix regia	+	+	-	-	-	+	+	+	5	31	1
3	Ficus religiosa	++++++	++	++	+	+	+	++	+	16	100	7
4	Azadirachta indica	+	+	-	+	+	-	++	+	7	44	2
5	Pongamia pinnata	+++	++	+	-	+	+	+	+	10	63	4

Table 6. Anticipated Performance Index (API) of plant species

S. No.	Local Name	Scientific Name	Grade Allotted	API value	Assesment	
			Total	%		
1	Banyan	*Ficus benghalensis*	16	100	7	Best
2	Flamboyant	*Delonix regia*	5	31	1	Very poor
3	Peepal	*Ficus religiosa*	16	100	7	Best
4	Neem	*Azadirachta indica*	7	44	2	Poor
5	Indian Beech	*Pongamia pinnata*	10	63	4	Good

economic uses. Thus, an evaluation of anticipated plant performance might be very useful in the selection of appropriate species.

CONCLUSION

Combining a variety of parameters can give a more reliable result than only based on a single biochemical parameter. This study also provides useful information to select tolerant species fit for landscape on sites continuously exposed to air pollutants. The present study reveals that evaluation of anticipated performance of plants might be very useful in the selection of appropriate tree species for plantation in the industrial areas to reduce the problem of pollution. *Ficus benghalensis* and *Ficus religiosa* were the most tolerant plants to be grown in industrial areas and can be expected to perform well for the development of green environment. Plants have the potential to serve as excellent quantitative and qualitative indices of pollution (Jyothi and Jeya, 2010). The species ranked as poor and very poor performer can be used as bio-indicators of air pollution stress.

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