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ROADSIDE AUTOMOBILE STRESSED PLANTS AS BIOINDICATOR BASED ON AIR POLLUTION TOLERANCE INDEX IN DHAKA, BANGLADESH

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Abstract

The evaluation of plants' ability to resist pollution was conducted by studying two distinct plant species, *Swietenia mahagonia* and *Polyalthia longifolia*, obtained near the urban roadsides in Dhaka during the winter season. The air pollution tolerance index (APTI) was assessed for both *Polyalthia longifolia* and *Swietenia mahagoni*. Between the two species, *Polyalthia longifolia* exhibited the highest air pollution tolerance index (APTI 12.54), indicating its lower sensitivity towards pollution. On the other hand, *Swietenia mahagoni* (APTI 12.27) demonstrated a comparatively higher sensitivity to pollutants. *Polyalthia longifolia* had the highest total chlorophyll concentration (TCC) (1.080 mg/g), relative water content (RWC) (88.50%), pH value (6.73), ascorbic acid concentration (ACC) (4.303). On the other hand, *Swietenia mahagoni* showed the lowest scores across almost all the indicators (except ACC: 5.44), demonstrating the most pollutant-sensitive species. The assessment of plants in relation to their capacity to withstand air pollution is crucial due to their role as a pollution sink. Consequently, planting species that exhibit tolerance to pollution in contaminated regions can provide several environmental advantages.

Key words: Air pollution; Chlorophyll content; ACC; pH; Relative water content; APTI.

INTRODUCTION

Air pollution stands as a critical global concern due to its multifaceted impact on human health, climate dynamics, and ecosystem equilibrium. Within the intricate fabric of ecosystems, a delicate interplay unfolds between biotic and abiotic elements, encapsulating the essence of natural processes within a biosphere region. A pivotal participant in this intricate symphony is the plant kingdom, which serves as both a mitigator of air pollutants and a recipient of their detrimental effects. Despite the notable contributions of plants in mitigating pollution, they are not immune to the ramifications of airborne contaminants. The consequences manifest in multifarious ways, ranging from compromised photosynthesis to altered biochemical compositions, ultimately impeding their growth and overall fitness. The ecological significance of plants, particularly in the context of air quality improvement, has been well documented. Their expansive leaf surfaces provide a mechanism for the absorption and sequestration of pollutants, thereby contributing to the amelioration of air quality (Joshi and Swami 2009, Rawat and Banerjee 1996). This distinct role positions plants as sentinel organisms, promptly responding to shift in atmospheric composition by accumulating a diverse array of particulates and pollutants (Liu and Ding 2008). However, the intricate interplay between plants and pollutants is marked by reciprocity; the plants that harbor pollutants can suffer myriad adverse effects, including leaf damage, disruption of stomatal functionality, compromised photosynthesis, altered membrane permeability, stunted growth, and diminished yields (Tiwari *et al*. 2006). These effects are particularly evident in the context of gaseous and particulate pollutants, such as SO_2, NOx, CO_2, and suspended particulate matters, which can infiltrate foliage and directly impede crucial photosynthetic compounds, such as chlorophyll and carotenoids, resulting in a measurable reduction in overall plant productivity. An observable manifestation of such stress-induced adversity is the gradual chlorophyll degradation, leading to characteristic foliar yellowing. The intricate manifestation of these morphological and physiological modifications hinges upon the specific pollutant types prevailing within the environment (Joshi and Swami 2007).

To evaluate the intricate dynamics between air quality and plants, the air pollution tolerance index (APTI) serves as a pivotal gauge. The APTI encapsulates the inherent resilience of plant species against the backdrop of air pollution. This comprehensive metric is constructed upon the foundation of various biochemical parameters, encompassing the total chlorophyll concentration (TCC), levels of ascorbic acid, relative water content (RWC), and pH of leaf extracts (Singh and Rao 1983). Additionally, plants emerge as biomarkers, reflecting the ecological health of their surroundings through their differential resistance to airborne pollutants (Lakshmi *et al*. 2009). Investigations into APTI values, as exemplified by Babu *et al*. (2013), offer nuanced insights into the sensitivity of diverse plant species to air pollution across contrasting environmental settings. Kuddus *et al*. (2011) have contributed to this understanding by ascertaining APTI values for commercially vital plant species within urban-industrial domains, discerning the resilience of certain species and the susceptibility of others. Similar explorations by Rafiq and Kumawat (2016) have underscored the adverse impact of cement dust on apricot trees, showcasing alterations in chlorophyll content, leaf wash pH, and leaf length due to dust exposure. In support of this methodology, Tsega and Prasad (2014) have utilized biological indicators to establish the air pollution tolerance index (APTI) and the anticipated performance index (API) for plant species located alongside roadways.

Bangladesh, a country undergoing rapid urbanization and industrialization, grapples with substantial air quality issues, predominantly in major cities. The surge in industrial activities and economic expansion facilitates the introduction of novel pollutants into the ambient environment. Urban centers like Dhaka bear the brunt of particulate matters emanating from diverse sources, such as coal combustion, fossil fuel utilization, transportation emissions, and residential and industrial discharges (Pavel *et al*. 2021, Zaman *et al*. 2021a, b, Zaman *et al.* 2022). However, the specific implications of air pollution on plant species within the unique context of Bangladesh remain inadequately explored.

Hence, this study endeavors to bridge this research gap by delving into the intricacies of air pollution's effects on distinct tree species within Bangladesh. The assessment of air pollution tolerance index (APTI) values considering parameters such as ascorbic acid concentration, total chlorophyll concentration, relative water content, and pH of leaf extracts, emerge as the focal methodology to comprehend the nuanced physiological responses of these species to prevailing air quality conditions. Through this research, a more comprehensive understanding of the intricate interactions between air pollution and plant health within Bangladesh could be gained.

MATERIAL AND METHODS

Sample collection

Two distinct leaf samples, namely *Polyalthia longifolia* (locally known as Debdaru) and *Swietenia mahagoni* (locally known as Mehgoni), were meticulously gathered from two traffic-impacted locations, identified as Azimpur (Site-1) and Kamalapur (Site-2), along with a control site - a botanical garden - within the urban expanse of Dhaka in the months of January and February, 2023. Manual leaf collection was conducted at a consistent height of 8-10 feet above ground level, precisely at the lower periphery of the tree crown.

Biochemical parameters

In order to assess the air pollution tolerance index (APTI), a suite of distinct biochemical parameters extracted from leaf samples were employed. The ensuing section delineates the methodologies utilized for determining relative water content (RWC), total chlorophyll content (TCC), pH, and ascorbic acid content (AAC).

Determination of total chlorophyll content (TCC)

The quantification of chlorophyll content followed the established protocol outlined by Singh *et al.* (1991). Leaf samples (500.0 mg) were ground with 80 per cent acetone (10.0 mL) using a mortar and pestle. Subsequently, the filtered extract's absorbance was measured at 645 nm and 663 nm using a UV-Visible spectrophotometer. The calculation of TCC employed the formula:

$$\text{Total chloropyll content}\left(\frac{mg}{g}\right) = (20.2 \times A_{645} + 8.02 \times A_{663}) \times \frac{V}{1000 \times W}$$

Where, A_{645} and A_{663} correspond to absorbance at 645nm and 663nm, V represents the total volume of extract, and W signifies the weight of leaf material in grams.

Assessment of relative water content (RWC)

The evaluation of RWC was conducted in accordance with the procedure outlined by Sivakumaran and Hall (1978) as described by Keller and Schwager (1977). Individual leaves were promptly weighed (initial weight) upon excision and placed in a beaker containing water for approximately 8.0 hours. Following this period, the leaves were blotted and weighed to determine the saturated weight. Subsequently, the leaves were subjected to a sixteen hour drying process at 80°C, with the resultant dry weight recorded. The RWC was computed using the equation:

$$\text{RWC}(\%) = \frac{Initial\ weight - Dry\ weight}{Saturated\ weight - Dry\ weight} \times 100$$

Ascorbic acid determination (AAC)

The determination of ascorbic acid content adhered to the methodology established by Keller and Schwager (1977), involving the homogenization of fresh leaf samples (500.0 mg) with an extracting solution (20 mL) comprising oxalic acid (500.0 mg) and EDTA (75.0 mg) dissolved in 100 mL of distilled water. To this solution, 2,6-dichlorophenol indophenol (DCPIP) (3.0 mg in 100 mL distilled water) was added, and the absorbance of the resulting mixture (E_s) was measured at 520 nm. Subsequently, a few drops of ascorbic acid were introduced to bleach the pink color, following which the absorbance was measured once more at 520 nm (E_t). A similar measurement was carried out for the absorbance of the DCPIP solution (E_0). The concentration of ascorbic acid in the leaf samples was determined using the equation:

$$\text{Ascorbic acid}\left(\frac{mg}{g}\right) = \frac{[Eo - (Es - Et)] \times V}{W \times V_1 \times 1000}$$

Where, W denotes the weight of the fresh leaf taken (g), V_1 represents the volume of the supernatant taken (mL), and V signifies the total volume of the mixture (mL).

pH determination: The pH of the leaf extract was ascertained by homogenizing approximately 2.0 g of samples with 20.0 mL of deionized water. The pH of the resultant suspension was determined using a digital pH meter (Hanna HI-98107).

Air pollution tolerance index (APTI) determination: The APTI of the leaf samples was calculated by using the following equation, which is developed by Singh and Rao (1983).

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

Where A represents the ascorbic acid content in the leaf (mg/g), T denotes the total chlorophyll content of the leaf (mg/g), P signifies the pH of the leaf extract, and R corresponds to the percentage of RWC of the leaf samples.

RESULTS AND DISCUSSION

Relative water content

A leaf's RWC is the amount of water it contains in relation to its full turgidity. The loss of water and dissolved water-soluble ions caused by the plant's relative water content is linked to protoplasmic permeability in cells, resulting in early leaf senescence (Escobedo *et al*. 2008). When a plant is stressed, such as when it is exposed to air pollution, high water content within the plant body will help it maintain its physiological balance. Relative water content in the control site was found maximum (average RWC 91.7%) compared to traffic sites like Azimpur (RWC 81.5%) and Kamalapur (RWC 79.9%) which were continuously affected by exposure to toxic greenhouse gases like CO, CO_2, SO_X, NO_X, O_3 *etc*. *Polyalthia longifolia* contained higher degree of water content (RWC 88.5%) than that of *Swietenia mahagoni* (RWC 80.24%) (Table 1).

Table 1. Leaf RWC values of two plant species at three sampling sites (S1= Azimpur, S2= Kamalapur, C=Botanical garden).

Leaf samples	Sampling sites	Initial weight (g)	Saturated weight (g)	Dry Weight (g)	RWC (%)
Swietenia mahagoni	S1	1.0497	1.2389	0.4174	76.96
	S2	1.0124	1.1956	0.4242	76.25
	C	0.9967	1.0713	0.4740	87.51
Polyalthia longifolia	S1	0.9961	1.0924	0.4056	85.97
	S2	0.9901	1.1080	0.3846	83.70
	C	0.9899	1.0132	0.4530	95.84

Total chlorophyll content (TCC)

Chlorophyll is a plant productivity index (Sivakumaran and Hall 1978). The amount of chlorophyll in plants varies depending on the species, age of the leaf, pollution level, and other biotic and abiotic factors. The results showed that the control site had the maximum value of total chlorophyll content in mg g^{-1} for all species and *Polyalthia longifolia* contained maximum average TCC (1.083 mgg^{-1}) and *Swietenia mahagoni* of average TCC 0.885 mgg^{-1} in the three sites. The lowest value of TCC was found in Kamalapur region with average TCC 0.817 mgg^{-1}, whereas, on average, TCC-0.9364 mgg^{-1} was found in Azimpur and TCC-1.166 mgg^{-1} was found in botanical garden (Fig. 1).

The amount of total chlorophyll lost in a plant is proportional to the level of pollution. The decrease in chlorophyll concentration could be due to the deposition of suspended particulate matter on the leaf surface. Chlorophyll and the leaf membrane are damaged by oxygen radicals produced by interactions with SO_2, NO_2, and O_3 (Shakaki *et al*. 1983).

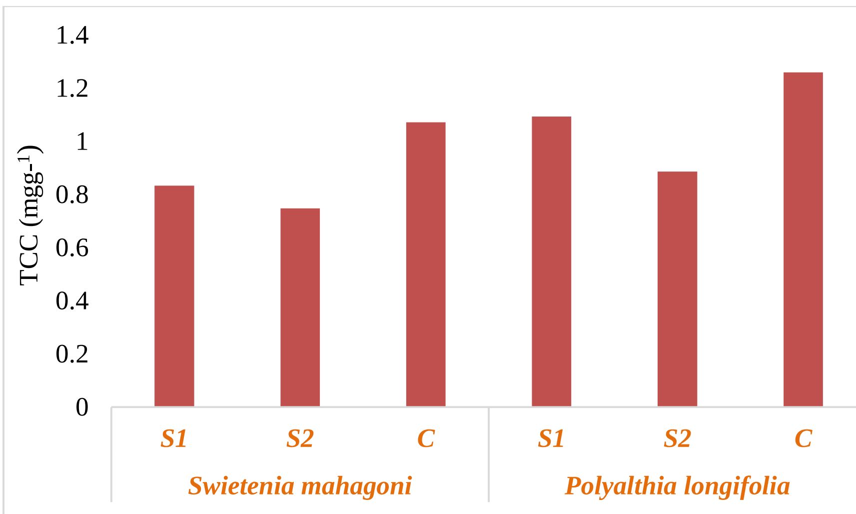

Fig. 1. Total chlorophyll contents (TCC) of two plant species (*Swietenia mahagoni* and *Polyalthia longifolia*) at three sampling sites (S1=Azimpur, S2=Kamalapur, C=Botanical garden).

Ascorbic acid concentration (AAC)

Ascorbic acid plays a significant role as a potent reductant within plant systems, instigating a diverse array of physiological and defensive responses. The reductive efficacy of ascorbic acid correlates directly with its concentration (Wahid 2006). Furthermore, its reductive functionality is intrinsically tied to pH levels, where elevated pH values are indicative of heightened effectiveness in transforming hexose sugar into ascorbic acid. This aspect holds relevance for pollution tolerance mechanisms (Salam *et al*. 2008).

The total ascorbic acid concentration in botanical garden was found 5.44 mgg^{-1} for *Swietenia mahagoni* and 4.30 mgg^{-1} for *Polyalthia longifolia* (Fig. 2). Among the sampling sites, S2 showed the highest concentration followed by C and S1. In all the sites *Swietenia mahagoni* showed higher ACC concentration than to *Polyalthia longifolia.*

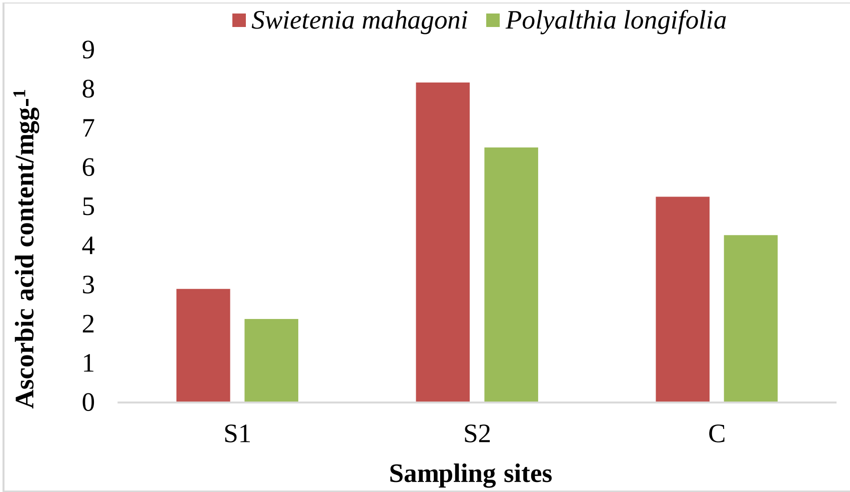

Fig. 2. Total ascorbic acid concentration (AAC) of two plant species (*Swietenia mahagoni* and *Polyalthia longifolia*) at three sampling sites (S1=Azimpur, S2=Kamalapur, C=Boanical garden).

pH

The role of pH in modulating plant responses to pollution is a pivotal aspect warranting investigation, as demonstrated by Singh and Verma (2007). pH levels within plants serve as an important indicator of their vulnerability to pollution stress. Notably, lower pH values are associated with increased susceptibility, while the plants with pH levels around 7 exhibit greater tolerance. The current study delved into the pH dynamics within the leaf samples collected from various locations, shedding light on their implications for plant-environment interactions and stress responses.

Consistent with the influence of pollutants, the observed pH values of the sampled leaf tissues indicated an overarching trend towards acidity. This phenomenon can be attributed to the impact of acidic pollutants in the ambient air, which elevate acid levels within plant tissues, thereby lowering pH. The significance of pH fluctuations extends beyond mere chemical changes, as it intricately intersects with physiological responses triggered by stress.

Table 2. The pH values obtained from the leaf extracts of different plant species (*Swietenia mahagoni* and *Polyalthia longifolia*) at different sites (S1= Azimpur, S2= Kamalapur, C= Botanical garden).

Leaf Samples	Sampling sites	pH
Swietenia mahagoni	S1	6.8
	S2	6.1
	C	6.5
Polyalthia longifolia	S1	6.8
	S2	7.1
	C	6.3

Turning to the specific species under scrutiny, the average pH values emerged as noteworthy indicators. For *Swietenia mahagoni*, the average pH stood at 6.5, while *Polyalthia longifolia* exhibited a slightly higher average pH of 6.7 (Table 2). Furthermore, the comparative analysis across distinct sampling sites unveiled differential pH profiles. The control site manifested the lowest pH values, whereas Site-2 (S2) displayed the highest pH values. This trend resonates with the acidic nature of pH, often indicative of the presence of acidic pollutants such as sulfur oxides (SO_x) and nitrogen oxides (NO_x) within the surrounding environment. Specifically, the diffusion of gaseous SO_2 through stomata emerges as a critical mechanism influencing cellular pH. Upon contact with water, gaseous SO_2 undergoes dissolution, leading to the formation of sulfites, bisulfates, and ionic species, concomitantly releasing protons and thereby shifting the pH dynamics within plants.

The observed inclination towards an acidic pH range across diverse plant species underscores the substantial impact of SO_2 infiltration into leaf mesophyll tissue, an insight congruent with findings from Singh and Verma (2007). The consequential perturbation of cellular pH exemplifies the intricate interplay between environmental pollutants and plant physiology, underscoring the need to consider pH as a potent marker for pollution-induced stress within plant systems.

Air pollution tolerance index (APTI)

Polyalthia longifolia had the highest level of APTI (12.54) compared to *Swietenia mahagoni* (12.27) (Fig. 3). The plants growing in the control site of the botanical garden showed very high degree of APTI due to less concentration of dust deposition on leaf samples.

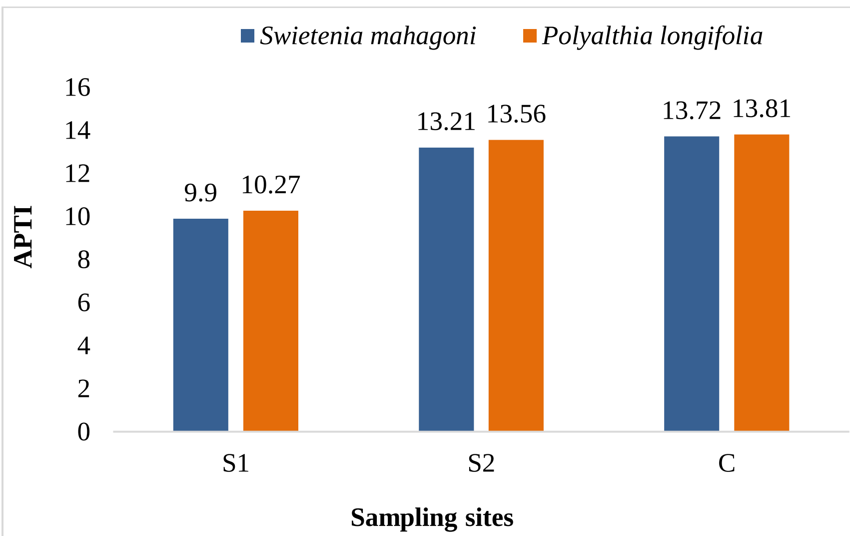

Fig. 3. Air pollution tolerance index (APTI) in the leaf samples (*Swietenia mahagoni* and *Polyalthia longifolia*) from different sites (S1=Azimpur S2=Kamalapur C=Botanical garden).

The study also elicited that around 37% APTI values were found in the plant leaves growing in the botanical garden, whereas 36% and 27% of APTI were found in that of Kamalapur and Azimpur, respectively (Fig. 4). The value of APTI was found 13.72 in the control site for *Swietenia mahagoni*, whereas this value decreased to 9.9 and 13.21 in Azimpur and Kamalapur, respectively which were equivalent to 27.84% and 3.71% decreased from the control site. The almost identical result was observed in case of *Polyalthia longifolia*. The Control site (13.81) showed the highest level of APTI followed by Kamalapur (13.56) and Azimpur (10.27), and the percentage decrease of APTI of the plant growing sites in Azimpur and Kamalapur was 25.6 and 1.8, respectively. APTI levels were found similar to the sites in both Botanical Garden and Kamalapur (Fig. 4).

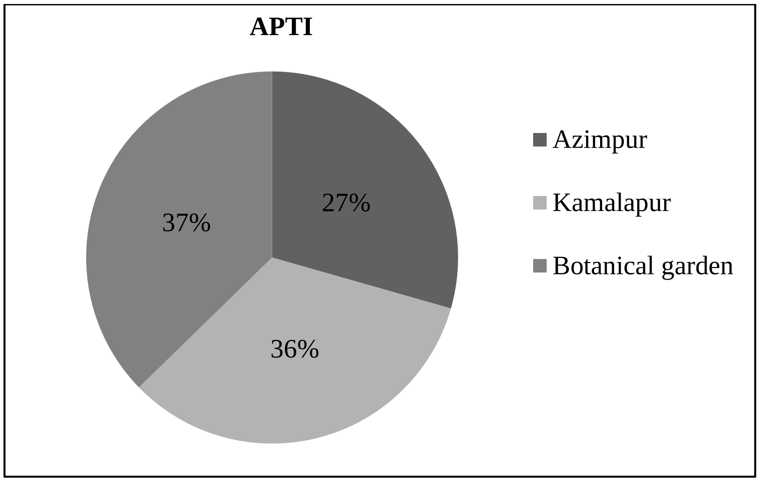

Fig. 4. Variations of APTI in three sampling sites (Azimpur, Kamalapur and Botanical Garden).

The outcomes of this study underscore the heightened vulnerability of *Swietenia mahagoni* and *Polyalthia longifolia* to atmospheric pollutants. Urgent action is recommended on the part of relevant authorities to mitigate the deleterious effects of air pollution on these tree species (Fig. 5). Moreover, when strategizing afforestation initiatives, meticulous deliberation is essential in selecting appropriate tree species. The assessment of susceptibility to air pollutants should play a pivotal role in the decision making process, safeguarding the efficacy and environmental robustness of such projects.

a **b**

Fig. 5. Automobile stressed plants: **a**. *Swietenia mahagoni* and **b**. *Polyalthia longifolia* at the roadsides of the urban habitats in Dhaka.

The diversity observed in APTI profiles among plant species underscores the multifaceted nature of pollutant impact on plant systems. The comparative analysis of APTI values for *Polyalthia longifolia* and *Swietenia mahagoni* highlights their varying responses, with the former displaying resilience and the latter exhibiting heightened sensitivity to pollutants. In the context of rapid urbanization and escalating industrialization, the significance of these findings becomes pronounced. The insights gained from APTI assessments hold vital implications for conservation efforts and urban planning. They serve as a proactive guide for devising strategies to mitigate ecological repercussions stemming from air pollution. It could be concluded that APTI values offer valuable contributions to the pursuit of harmonizing urban development with ecological preservation, navigating the complexities of an evolving urban landscape.

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