Research Article

# Sensitivity study of plant species due to traffic emitted air pollutants ($NO_2$ and $PM_{2.5}$) during different seasons in Dhaka, Bangladesh

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**Abstract**

The impact of traffic emitted nitrogen dioxide ($NO_2$) and fine particulate matter ($PM_{2.5}$) on various plant species (*Polyalthia longifolia*, *Swietenia mahagoni*, *Artocarpus heterophyllus*) during different seasons (summer, rainy, and winter) was studied in greater Dhaka city (traffic, residential, and control site), Bangladesh. Air pollution tolerance index (APTI) of these plant species was determined from the measured concentrations of total chlorophyll content (TCC), ascorbic acid (AAC), relative water content (RWC), and pH of the leaf extract. TCC and AAC concentrations in leaves species were determined with UV–visible spectrophotometer. $NO_2$ concentration was determined with Aeroquel (New Zealand), and $PM_{2.5}$ was determined with Aerocet (USA). The measured $NO_2$ and $PM_{2.5}$ concentrations at each sampling location were used to establish a relationship with the determined APTI values. The average value of TCC, AAC, and RWC was found much lower in traffic site compared than that of the control site. High pollution stress on plants was also found in traffic sites showing 30% lower APTI values. The plants become sensitive if the APTI value is smaller than or equal to 12 (APTI ≤ 12). However, the average APTI values in different seasons showed a significant variations and followed the sequence—rainy season (8.10) > summer (7.34) > winter (6.69). The plants had the highest sensitivity towards pollutants during winter time. The average APTI values also varied depending on the locations and plant species with a total average of 7.38 ± 1.17, which indicates the sensitivity of plants towards pollution. On average, the measured concentration of $NO_2$ was 223 ± 0.15 $\mu g\,m^{-3}$ and $PM_{2.5}$ mass was 125.7 ± 0.05 $\mu g\,m^{-3}$. The APTI values showed a strong negative correlation with traffic emitted pollutants $NO_2$ ($R^2 = 0.86$) and $PM_{2.5}$ ($R^2 = 0.70$) indicating threats towards the plants survival.

**Keywords** Air pollution resistivity · Plants sensitivity · Traffic emission · Fine particulate matter · Nitrogen dioxide

## 1 Introduction

Air pollution has severe impact on human health, climate change, and ecosystem. Air quality has been degrading day by day from both natural as well as anthropogenic sources. The air quality of major cities in the world has been deteriorating badly with the increase in traffic and industrial emission, and also reduction in vegetation, e.g. Dhaka [1]. Particulate matter (PM), nitrogen oxides ($NO_x$), carbon monoxide (CO), oxides of sulphur ($SO_x$), toxic trace metals, volatile organic compounds (VOCs), and polyaromatic hydrocarbons (PAHs) are the major components of air pollutants nowadays [2, 3]. Effect of these pollutants on human health could be reduced by proper planning of green belt, a natural way of reducing pollution by plants [4]. According to World Health Organization (WHO) [5], 30% of particulate matter (PM) emission has occurred from road transportation. The main source of $NO_x$ is the combustion of fossil fuels (coal, gas, oil), especially fuels in the cars. $NO_x$ reduce plant growth, affect vegetation, and also cause acid rain. Quinqian and Zunling [6] showed that $NO_2$ exposure affects chlorophyll concentration of the plants through the interaction with their functional groups. They also contribute to the formation and modification of other

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air pollutants as a precursor in the atmosphere. $NO_x$ leads the accumulation of nitrites and cell acidification, along with the generation of reactive oxygen species (ROS). These pollutants enter in the plant stomata through wet and dry deposition and reduce light interceptions [7].

To determine the air quality of the environment, biomonitoring might be a most effective technique [8]. It uses the response of plants and/or animal organisms with changing the air quality. In these processes, plants can be widely used as bio-indicator. Absorption and accumulation of pollutants on the large surface of plant leaves reduce air pollution [9]. Plants serve as initial receptors of air pollution, and many air-borne particulates and pollutants are taken up by tree leaf [10]. These cause some severe damages like an injury in leaf, stomatal damage, the decrease in the photosynthetic process, distract membrane permeability, growth reduction, and yield of sensitive plants [11]. Plant productivity gets affected directly due to absorption of sulphur dioxide, oxides of nitrogen, carbon dioxide, and suspended particulate matter on the leaves that cause a diminution in the concentration of the photosynthetic pigments, e.g. chlorophyll and carotenoids [11] and affect plant productivity.

However, a biological parameter (air pollution tolerance index—APTI) has great significance to evaluate the effect of air quality in plants. It denotes the inherent quality of plants how much it can counter air pollution effects. Plants having high indices are generally tolerant to air pollution. They can survive on polluted air. Plants with low indices show sensitivity to air pollution. Based on APTI value, plants are classified as sensitive (≤ 12), intermediate (13–20), and tolerant (≥ 20) [12]. Chlorophyll concentration, ascorbic acid concentration, relative water content, and pH of the leaf extracts are measured and combined to find APTI using a formula $\mathrm{APTI} = \frac{([A(T+P)]+R)}{10}$ [8, 13–16]. Along with these biological parameters, visible foliar injury, leaf conductance, membrane permeability of the leaf extract was determined previously for APTI calculation (e.g. [1, 14]. However, our aim is to evaluate the impact of traffic emitted $NO_2$ and $PM_{2.5}$ on APTI values. Correlations of biochemical parameters with the $NO_2$ and $PM_{2.5}$ in each sampling location will help to find the reason behind the low/high APTI. The APTI values of different plant species growing in different traffic and residential areas in Dhaka region was also determined, and compared the values with a control site to show the difference of plant resistivity depending on pollution load. Recent years, Bangladesh is facing many problems regarding pollutions and many researches have been done on human health effects [17]. Unfortunately, despite of plants being a very fundamental part of nature, very less attention has been given to it. There is very limited information regarding the effect of pollution on plants in Bangladesh, except the determination of APTI value of the mango tree in Dhaka [18].

Therefore, we have focused on the air pollution resistance capability and the impact of traffic emitted $NO_2$ and $PM_{2.5}$ on plant species growing in the greater Dhaka city, Bangladesh. Air pollution tolerance index (APTI) was determined for the selected plant species (*Polyalthia longifolia*, *Swietenia mahagoni*, *Artocarpus heterophyllus*) based on ascorbic acid concentration (AAC), total chlorophyll content (TCC), relative water content (RWC), and pH of leaf extract in five locations in Dhaka city. The concentrations of $NO_2$ and $PM_{2.5}$ were measured at traffic, residential sites, and also a control site. The influences of $NO_2$ and $PM_{2.5}$ on the plant resistivity based APTI values were also studied. The findings of this study might be helpful in choosing plants for green belt in Dhaka city and also save the pollution-sensitive plants from being extinct.

## 2 Materials and methods

### 2.1 Sampling sites

The megacity, Dhaka, lies between 23°42′N latitude and 90°24′E longitude. Dhaka, the centre of commerce and industries of the country facing a serious air pollution problem, has been selected as a study area. The fresh matured leaf samples of *Polyalthia longifolia*, *Swietenia mahagoni*, and *Artocarpus heterophyllus* were collected from tall trees (about 9–15 m tall and 2–20 m wide), mostly planted by Dhaka city authorities. These are the most common trees found in Dhaka city both at roadside and residential areas. *Swietenia mahagoni* is semi-deciduous and semi-evergreen. *Polyalthia longifolia* and *Artocarpus heterophyllus* are evergreen. *Polyalthia longifolia* is widely planted in roadside as it is very effective in minimizing noise pollution and decorative purpose. *Swietenia mahagoni* and *Artocarpus heterophyllus* have very ancient uses in structural and furniture making. These species were chosen based on plant abundance of the selected areas and their ecological significance. Leaf samples were collected from two traffic sites (Farmgate, T1 and Gulistan, T2), two residential areas (Uttara, R1 and Dhanmondi, R2) and one control site, C (botanical garden, Mirpur). The places surrounded by a busy bus stoppage and running vehicles had mentioned as traffic samples (T). Residential areas (R) are mentioned based on their low count of vehicles and most of the lands used where housing predominates. A control site (C) was chosen where pollution is assumed to be very low. It is the national botanical garden of Bangladesh, about 850,000 square meters of area containing approximately 56,000 individual trees. All the sites are shown in Fig. 1.

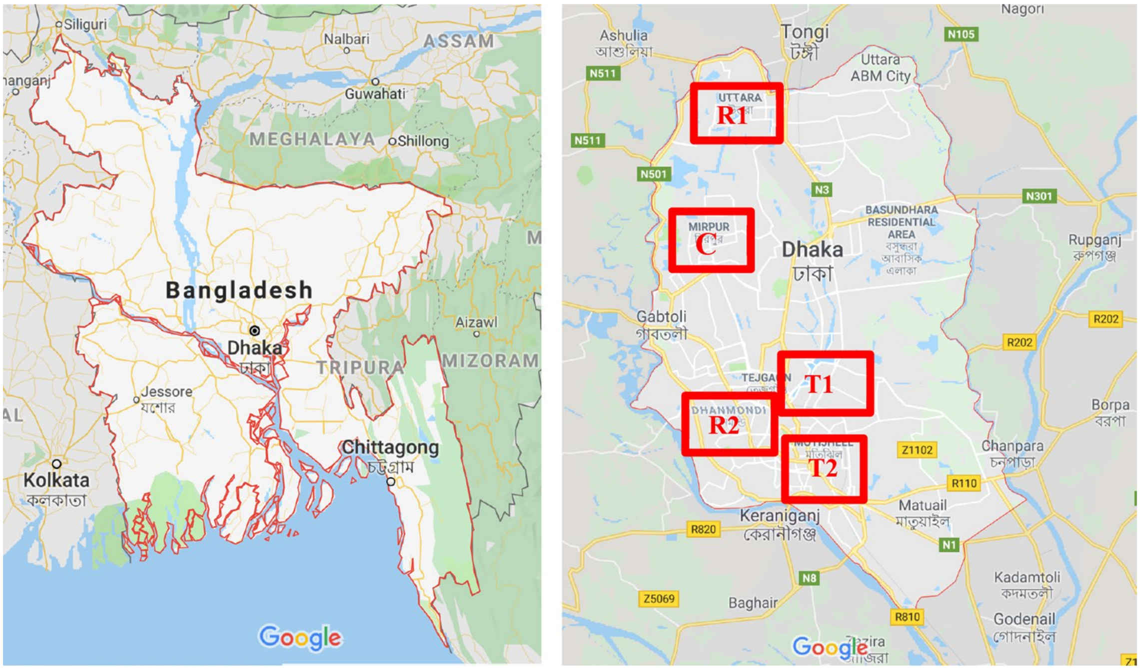



**Fig. 1** [Left panel] Map of Bangladesh; [Right panel] showing the sampling locations in Dhaka City (T1 = Farmgate, T2 = Gulistan, R1 = Uttara, R2 = Dhanmondi, C = Mirpur) [*source*: Google]

## 2.2 Meteorology of Dhaka, Bangladesh

Generally, the climate of Bangladesh is humid with high temperature. There are four seasons: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February). The average winter temperature is 4 °C to 25 °C, and in summer it varies between 24 and 36 °C. July is known for the highest relative humidity (99%), and the lowest occurs in December (36%). The wind direction follows the trend of the west and south-west direction at pre-monsoon and north and north-west at winter [16]. Similar light, water, and soil conditions are maintained for the plants used for the study at all sites.

## 2.3 Collection of samples

About 30–25 leaves of each species were taken manually by tearing off from the bottom of the tree crown at about the height of 2.0.–3.0 m from ground level. Three replicates were done per each analysis. For three individual analyses, leaves were collected from three different plants of the same species. All the species were collected from the similar ecological condition. Moreover, for some trials and error, 15–20 leaves of each species were taken for the experiments. This collection was conducted in all the three seasons; summer (March–May), rainy (June–September) and winter (November–February). Utmost care of the leaves was taken to keep them free from any types of visible diseases of leaf and fungal attack. The fresh leaf samples had analysed as early as possible. The rest was refrigerated in polythene bag for further analysis.

## 2.4 Biochemical parameters measurement

To compute air pollution tolerance index (APTI), different biochemical parameters such as relative water content (in %), total chlorophyll content (in mg $g^{-1}$), pH, ascorbic acid content (in mg $g^{-1}$) were measured by the processes as follows.

### 2.4.1 Total chlorophyll content determination (TCC)

500.0 mg of fresh leaves sample was taken for TCC determination. It was grounded with mortar and pestle in 10.0 mL of 80% acetone. The absorbance of the leaf extract was measured with a UV–visible spectrophotometer (Model UV-1800, Shimadzu, Japan) at 645 nm and 663 nm. TCC was determined following the method given by Singh et al. [7] using the formula:

$$\mathrm{TCC}\left(\frac{\mathrm{mg}}{\mathrm{g}}\right) = (20.2 \times A_{645} + 8.02 \times A_{663}) \times \frac{V}{1000 \times W} \quad (1)$$

where $A_{645}$ = absorbance at 645 nm, $A_{663}$ = absorbance at 663 nm, $V$ = total volume of the extract in millilitre (mL), $W$ = weight of leaf materials in gram.

#### 2.4.2 Ascorbic acid concentration (AAC)

500.0 mg of fresh leaf samples were taken for AAC determination following the method of [19] and then homogenized in 20 mL of extracting solution (500.0 mg oxalic acid and 75.0 mg EDTA in 100 mL of distilled water). 2,6-dichlorophenolindophenol (DCPIP) (3.0 mg in 100 mL distilled water) was added to 1.0 mL of the filtered sample solution after measuring the absorbance of the mixture at 520 nm ($E_s$), few drops of ascorbic acid were added to the mixture to bleach the pink colour. Then, the absorbance was recorded again at the same wavelength ($E_t$). The absorbance of DCPIP solution is also measured at 520 nm ($E_o$). The AAC of leaf samples were calculated with the following formula:

$$\text{Ascorbic acid}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\left[E_0 - \left(E_s - E_t\right)\right] \times V}{W \times V1 \times 1000} \tag{2}$$

where $W$ = weight of the fresh leaf taken (g), $V_1$ = volume of the supernatant solution (mL), $V$ = total volume of the solution (mL). The value of $[E_o - (E_s - E_t)]$ was determined using a calibration curve. The calibration curve was prepared by using a different known concentration of ascorbic acid solutions following the above method.

#### 2.4.3 Relative water content (RWC) determination

Following the method of Sivakumaran and Hall [20], RWC was determined. Individual leaf was excised and weighed immediately (initial weight) with an analytical balance (Model XB 120A, Precisa Gravimetric AG, Dietikon, Switzerland). Leaves were then soaked into the water in a beaker for about 6.0 h. Then, the leaves were weighed (saturated weight) after blotting and dried at 80 °C for 16.0 h. The dry weight was again recorded. The RWC was calculated using the following equation:

$$\text{RWC}(\%) = \frac{\text{Initial weight} - \text{Dry weight}}{\text{Saturated weight} - \text{Dry weight}} \tag{3}$$

#### 2.4.4 pH determination

The pH of leaf extract was taken from 1.0 g samples homogenized with 10.0 mL of deionized water. A digital pH meter of Model pH 211, Hanna Instrument, Germany, was used to measure the pH of the suspension.

#### 2.4.5 Air pollution tolerance index (APTI) determination

APTI of the leaf samples was calculated by combining the above biochemical parameters using the following equation [13]:

$$\text{APTI} = \frac{[A(T + P)] + R}{10} \tag{4}$$

where $A$ is the ascorbic acid content in the leaf in mg g$^{-1}$ dry weight, $T$ is total chlorophyll content of leaf in mg g$^{-1}$ dry weight, $P$ is the pH of the leaf extract, and $R$ is the percentage (%) RWC of the leaf.

### 2.5 Measurement of $NO_2$ concentration

$NO_2$ concentration has been measured using gas sensor Aeroqual (Model series 500, New Zealand) with a flow rate of 0.5 L/min. Using a different sensor, it can measure $CO_2$, CO, $SO_2$, VOC, $NO_x$, and $O_3$ directly from the environment. As we focused on the $NO_2$, we used $NO_2$ sensor (GSE sensor) and measured its concentration on each sampling locations.

### 2.6 Measurement of $PM_{2.5}$

$PM_{2.5}$ concentration in the air of the sampling sites was measured by Aerocet (Model 531S, USA) with a flow rate of 2.83 L/min, a battery operated, handheld mass monitor or particle counter. This unit provides particle counts or particulate mass measurements as stored data-logged values, real-time networked data, or printed results. Similar procedure was also followed in the previous study [18].

### 2.7 Statistical analysis

For each plant species, measured biochemical parameters were calculated as their average of triplicate samples. These mean values are presented with standard deviation in Table 1. Using one-way ANOVA (Microsoft excel 2016), variance ($p$ value) was calculated for each parameter with respect to $NO_2$ and $PM_{2.5}$ concentrations, sampling sites, seasonal variation, and plant species. Statistical correlations are shown in Table 1.

## 3 Results and discussion

The measured biochemical parameters show a variation from species to species and vary with different seasons. In different sampling sites, these parameters also vary depending on the pollution level. The average TCC, AAC,

**Table 1** Result of one-way ANOVA signifying variation in studied parameters with plant species and seasons in different sampling sites

| Variable | Sampling site | Season | $PM_{2.5}$ | $NO_2$ |
|---|---|---|---|---|
| APTI | 0.000* | 0.000* | 0.123 | 0.003* |
| $PM_{2.5}$ | 0.010* | – | 0.010* | 0.001* |
| TCC | 0.002* | 0.370 | Plant species 0.006* | |
| AAC | 0.000* | 0.001* | 0.000* | |
| pH | 0.001* | 0.000* | 0.003* | |
| RWC | 0.402 | 0.010* | 0.000* | |
| Plant species | Biochemical parameters 0.005* | APTI 0.001* | | |

*Shows significant level of $p < 0.05$

RWC and APTI values were found 76%, 43%, 11%, and 19% lower compared to the control site, respectively (calculated from the average values of Table 2).

The highest average TCC was found in the rainy season (0.376 mg $g^{-1}$) and lowest for winter (0.202 mg $g^{-1}$), though the relation with seasonal variation was not significant ($p > 0.05$). However, *Polyalthia longifolia* showed the highest TCC (0.465 mg $g^{-1}$) and *Swietenia mahagoni* has the lowest (0.092 mg $g^{-1}$). Depending on sampling sites, TCC varied as high TCC in lower polluted site and high pollution stress decreases TCC with great significance ($p < 0.05$). An increasing amount of $PM_{2.5}$ and $NO_2$ might be responsible for the decrease in TCC. $PM_{2.5}$ blocks the opening or closing of stomata which decreases the photosynthesis rate. From reactions with $SO_2$, $NO_2$, and $O_3$, oxyradicals are produced which damaged chlorophyll and the membrane of the leaf [21]. $SO_2$ which is potential bleaching and strong reducing agent produces sulphurous acid in water. $H^+$ is formed in acid ionization process and removes $Mg^{2+}$ from chlorophyll a and convert it to pheophytin a. Thus, the destruction of the structure is an indication of chlorophyll content decrease [18]. The reduction in chlorophyll content might also be due to the increase in chlorophyllase enzyme activities, which in turn may cause yellowing of leaves in combination with leaf injury. Similar mechanism (e.g. $SO_2$) may also be possible for traffic emitted $NO_2$ to damage the chlorophyll content in the leaves. Oxidative pollutants penetrate the leaves and produce cytotoxic radicals. Ascorbic acid is consumed during the removal of cytotoxic radicals when the oxidative pollutants penetrate the leaf surface [22]. Due to the defence mechanism of the respective plant, increased level of ascorbic acid content assists pollution tolerance. At the biochemical level, oxidation of sulfhydryl and fatty acid double bonds by ozone increases membrane permeability, lowers foliar sugar and polysaccharide levels, and disrupts membrane-bound photosynthetic systems. At the physiological level, net photosynthesis, conductance in stomata and efficiency of water use are reduced, dark respiration is affected, fruit set is delayed, leaf senescence is accelerated, foliar visible injuries and leaching are increased, and carbon allocation is changed. Exposure to $SO_2$ reduces starch content. Polyhydric sugars remove free radicals. This mechanism helps to cope with increasing $SO_2$ pollution. Enzymes and metabolites that are involved in organic acid metabolism are affected by sulphur dioxide exposure. Any changes in their metabolism would affect ascorbic acid concentration. Ascorbic acid concentration varied in three seasons as rainy (1.529 mg $g^{-1}$) > summer (1.191 mg $g^{-1}$) > winter (0.928 mg $g^{-1}$) showing a good significance ($p < 0.05$). In case of sample species, the AAC was *Swietenia mahagoni* (1.538 mg $g^{-1}$)> *Polyalthia longifolia* (1.241 mg $g^{-1}$)> *Artocarpus heterophyllus* (0.870 mg $g^{-1}$) ($p < 0.05$).

pH (6.01–7.88) was found in three seasons and all the species (6.56—on average) with a less variation. These pH values varied significantly with season, sampling sites and plant species ($p < 0.05$). Acidic pH points out the presence of $SO_x$ and $NO_x$ in the air [23]. $NO_2$ influences the plant cellular pH by diffusion through stomata that dissolve in water to form nitrites and nitrates and other ionic species with the generation of protons. Plants with a pH around 7.0 are tolerant [24]. The sensitivity of stomata towards air pollutants increases with the lowering of pH. However, higher pH helps in conversion of hexose sugar to ascorbic acid [25, 26]. The photosynthetic activity also gets reduced in low pH condition [10].

In our study, plants showed their highest values of relative water content during the rainy season. Significant variation ($p < 0.05$) was found in RWC with seasonal variation. On that season, relative water contents were *Polyalthia longifolia* (68.18%) > *Artocarpus heterophyllus* (64.33%) > *Swietenia mahagoni* (62.02%) with significance ($p < 0.05$). Highly polluted traffic sites showed lower values of water content (60.85%) than the residential sites (65.84%) in comparison to control site (70.83%) though the significance was not good ($p > 0.05$). Plants with high RWC are tolerant of polluted environments. Under the stressed condition, the transpiration rate is lower with the lower water content. Air pollutants increase cell permeability. Consequently, loss of water and dissolved nutrients from plant tissue occurred.

Among the three species, *Polyalthia longifolia* had the highest tolerance (7.69) than others with the highest water content (68.18%) and highest total chlorophyll concentration (0.465 mg $g^{-1}$) value. However, *Swietenia mahagoni* showed the highest value of ascorbic acid concentration (1.538 mg $g^{-1}$) and pH value (6.58) on average in all the

**Table 2** Seasonal variation of determined biochemical parameters of some plant species

| Parameter | | TTC (mg $g^{-1}$) | | | AAC (mg $g^{-1}$) | | | RWC (%) | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | | S | R | W | S | R | W | S | R | W | S | R | W |
| S1 | Control | 0.997 ± 0.020 | 1.190 ± 0.351 | 0.871 ± 0.129 | 1.695 ± 0.234 | 2.124 ± 0.436 | 1.180 ± 0.029 | 70.660 ± 0.025 | 86.670 ± 1.301 | 67.890 ± 0.489 | 6.210 ± 0.020 | 6.560 ± 0.060 | 5.980 ± 0.010 |
| | R1 | 0.432 ± 0.014 | 0.639 ± 0.083 | 0.297 ± 0.005 | 1.459 ± 0.185 | 1.921 ± 0.095 | 1.198 ± 0.155 | 70.910 ± 0.051 | 80.290 ± 0.857 | 62.540 ± 0.153 | 6.80 ± 0.110 | 6.690 ± 0.020 | 6.090 ± 0.030 |
| | R2 | 0.380 ± 0.129 | 0.460 ± 0.0198 | 0.199 ± 0.073 | 1.068 ± 0.087 | 1.588 ± 0.073 | 0.966 ± 0.357 | 69.530 ± 0.039 | 76.560 ± 0.492 | 57.560 ± 0.367 | 6.540 ± 0.090 | 6.730 ± 0.030 | 6.010 ± 0.020 |
| | T1 | 0.215 ± 0.046 | 0.339 ± 0.027 | 0.089 ± 0.037 | 0.953 ± 0.020 | 1.175 ± 0.048 | 0.667 ± 0.101 | 65.170 ± 0.019 | 77.460 ± 0.020 | 57.470 ± 0.378 | 6.590 ± 0.050 | 6.880 ± 0.010 | 6.230 ± 0.050 |
| | T2 | 0.361 ± 0.006 | 0.414 ± 0.044 | 0.097 ± 0.017 | 0.827 ± 0.049 | 1.099 ± 0.063 | 0.679 ± 0.051 | 56.160 ± 0.011 | 74.060 ± 0.395 | 49.740 ± 0.185 | 7.650 ± 0.070 | 6.910 ± 0.050 | 6.440 ± 0.020 |
| S2 | Control | 0.124 ± 0.031 | 0.197 ± 0.025 | 0.087 ± 0.007 | 2.160 ± 0.439 | 3.057 ± 0.239 | 1.973 ± 0.196 | 64.130 ± 0.091 | 79.140 ± 0.531 | 60.630 ± 0.582 | 6.300 ± 0.020 | 6.810 ± 0.080 | 6.040 ± 0.040 |
| | R1 | 0.095 ± 0.019 | 0.106 ± 0.031 | 0.079 ± 0.001 | 1.987 ± 0.057 | 2.230 ± 0.341 | 1.117 ± 0.046 | 60.940 ± 0.163 | 75.960 ± 0.922 | 54.050 ± 0.021 | 6.400 ± 0.010 | 6.870 ± 0.010 | 6.190 ± 0.020 |
| | R2 | 0.088 ± 0.003 | 0.112 ± 0.022 | 0.042 ± 0.004 | 1.554 ± 0.184 | 1.709 ± 0.053 | 1.242 ± 0.029 | 58.970 ± 0.052 | 71.320 ± 0.169 | 45.230 ± 0.011 | 6.370 ± 0.030 | 6.940 ± 0.020 | 6.260 ± 0.050 |
| | T1 | 0.069 ± 0.009 | 0.082 ± 0.009 | 0.051 ± 0.008 | 1.028 ± 0.113 | 1.355 ± 0.174 | 0.792 ± 0.004 | 55.430 ± 0.020 | 72.940 ± 0.643 | 52.380 ± 0.169 | 6.530 ± 0.020 | 6.770 ± 0.020 | 6.250 ± 0.020 |
| | T2 | 0.068 ± 0.001 | 0.070 ± 0.003 | 0.836 ± 0.023 | 0.876 ± 0.069 | 1.246 ± 0.089 | 0.739 ± 0.011 | 58.190 ± 0.051 | 74.380 ± 0.749 | 46.580 ± 0.740 | 7.730 ± 0.040 | 6.890 ± 0.030 | 6.320 ± 0.009 |
| S3 | Control | 0.945 ± 0.178 | 1.288 ± 0.026 | 0.099 ± 0.004 | 1.444 ± 0.129 | 1.696 ± 0.070 | 1.288 ± 0.037 | 72.70 ± 0.051 | 81.350 ± 0.198 | 54.290 ± 0.187 | 6.480 ± 0.120 | 6.790 ± 0.010 | 6.210 ± 0.060 |
| | R1 | 0.182 ± 0.064 | 0.464 ± 0.011 | 0.082 ± 0.002 | 0.858 ± 0.044 | 0.972 ± 0.004 | 0.797 ± 0.021 | 65.460 ± 0.086 | 77.830 ± 0.179 | 51.860 ± 0.029 | 6.080 ± 0.260 | 6.680 ± 0.040 | 6.320 ± 0.010 |
| | R2 | 0.095 ± 0.006 | 0.121 ± 0.009 | 0.025 ± 0.001 | 0.992 ± 0.016 | 1.084 ± 0.023 | 0.858 ± 0.017 | 68.540 ± 0.008 | 70.800 ± 0.022 | 66.780 ± 0.486 | 6.240 ± 0.060 | 6.350 ± 0.020 | 6.510 ± 0.020 |
| | T1 | 0.035 ± 0.007 | 0.068 ± 0.003 | 0.062 ± 0.003 | 0.619 ± 0.010 | 0.893 ± 0.007 | 0.217 ± 0.010 | 65.440 ± 0.023 | 64.250 ± 0.011 | 51.410 ± 0.295 | 6.660 ± 0.040 | 6.250 ± 0.010 | 6.710 ± 0.130 |
| | T2 | 0.077 ± 0.004 | 0.099 ± 0.008 | 0.872 ± 0.025 | 0.344 ± 0.051 | 0.783 ± 0.012 | 0.194 ± 0.009 | 62.170 ± 0.016 | 57.680 ± 0.009 | 54.360 ± 0.009 | 7.880 ± 0.170 | 6.110 ± 0.030 | 6.890 ± 0.220 |

S1 = *Polyalthia longifolia*, S2 = *Swietenia mahagoni*, S3 = *Artocarpus heterophyllus*, R1 = Residential site 1, R2 = Residential site 2, T1 = Traffic site 1, T2 = Traffic site 2, S = Summer, R = Rainy W = Winter

*TTC* total chlorophyll content, *ACC* ascorbic acid concentration, *RWC* relative water content

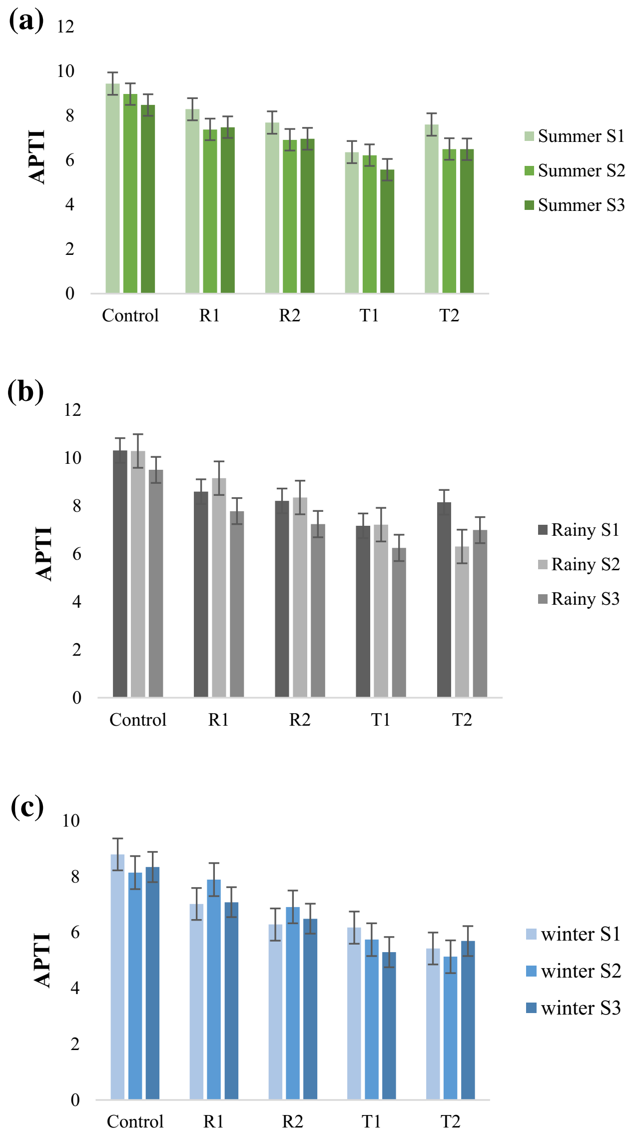



**Fig. 2** Seasonal variation of air pollution tolerance index (APTI) of the leaf samples in different sites. **a** Summer season, **b** rainy season, **c** winter season (S1 = *Polyalthia longifolia*, S2 = *Swietenia mahagoni*, S3 = *Artocarpus heterophyllus*, R1 = Residential site 1, R2 = Residential site 2, T1 = Traffic site 1, T2 = Traffic site 2)

seasons with an average APTI of 7.41. *Artocarpus heterophyllus* had the lowest in all the parameters showing the highest sensitivity towards pollution.

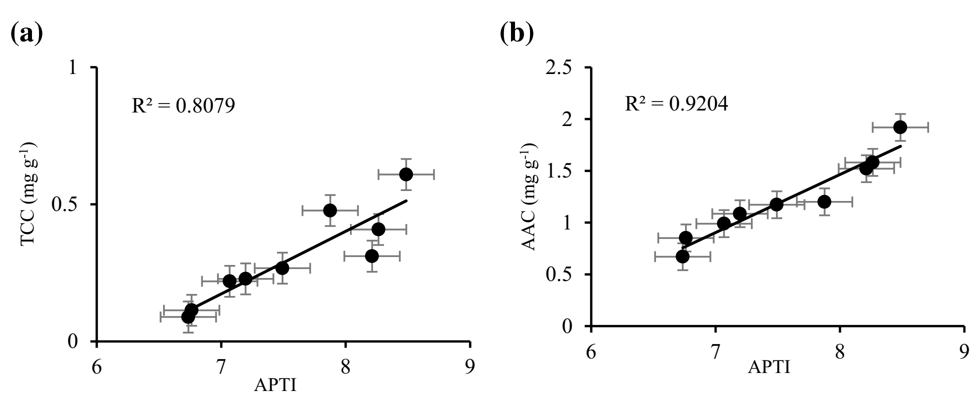
However, the rainy season had the highest values of chlorophyll concentrations (0.465 mg $g^{-1}$), ascorbic acid (1.66 mg $g^{-1}$), pH (6.69), and water content (74.71%) with the highest APTI value (8.42). Overall, the changes in APTI were control (9.14) > residential (7.54) > traffic (6.69). On average, the rainy season has the highest APTI (8.10) than the summer (7.36) and winter (6.98) season (Fig. 2). For all the parameters, the values were found as rainy > summer > winter and in case of sampling sites; control > residential > traffic. Significant ($p < 0.05$) variations were observed between seasons and also within the sampling sites. This indicates the variation of sampling sites and seasons affect the APTI, subsequently the sensitivity of the plants. The overall results are presented in Table 2.

APTI values of the plant species varied due to the variation of the biochemical parameters. Unfortunately, all of them were found as sensitive to air pollution. These indicate that the pollution stress in this city has increased so high that plants had lost their tolerance. Among the four parameters, AAC ($R^2 = 0.9204$) and TCC ($R^2 = 0.8079$) were found strongly correlated with APTI value (Fig. 3) with great significant value ($p < 0.05$).

These indicate that when the pollution level gets higher, AAC and TCC also get increased to defeat the pollution stress in the plant body. Subsequently, keep the plant species tolerant towards pollution. Several studies had also reported a similar correlation between APTI and these biochemical parameters [27–29].

Traffic emission along with brick kiln, long-range transport, and construction activities may have a significant contribution to the elevated concentrations of air pollutants in Dhaka city. The emissions from brick kilns are also expected to be contributed to the high-level pollution during this winter sampling period as brick kilns are operating only during winter. Unplanned urbanization and uncontrolled traffic making the city ventured for not only the humans but also the plants.

**Fig. 3** Correlation between **a** total chlorophyll content (TCC) in mg $g^{-1}$ and APTI values **b** ascorbic acid concentration (AAC) in mg $g^{-1}$ and APTI values



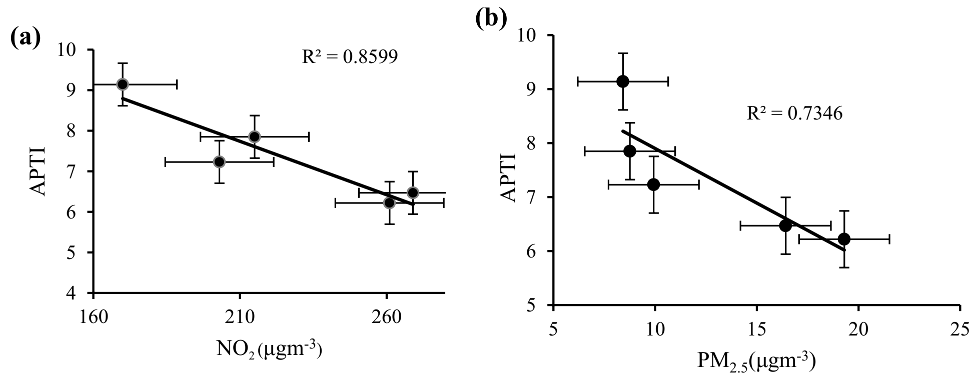



**Fig. 4** Correlation of determined APTI with **a** traffic pollutant $NO_2$, **b** particulate matter ($PM_{2.5}$)

It was seen that the air pollution tolerance index values vary with the $PM_{2.5}$ and $NO_2$ values of the experimental sites (Fig. 4). APTI values showed a strong negative correlation with $NO_2$ ($R^2=0.8599$) and $PM_{2.5}$ ($R^2=0.7346$). A good significant variation was found between $NO_2$ and APTI implying great effect of $NO_2$ on APTI ($p<0.05$) though it was not much significant for $PM_{2.5}$ and APTI ($p>0.05$). $PM_{2.5}$ blocks the stomata and decreases the photosynthetic process [30, 31], subsequently affects the chlorophyll concentration and other physiological activity which decreases the APTI values. $NO_2$ acts as acidic pollutants and deteriorates the chlorophyll concentration along with leaf pH and other physiological activities. These affect the plants in their fertility and tolerance in stress condition. In the last few years, Dhaka is developing rapidly along with the increased rate of motor vehicles. It has been highlighted for its worse traffic jam condition nowadays. Burning of fossil fuels in these vehicles are contributing to the $NO_2$ concentration through the vehicular exhaust. Hence, civilization and modernization of city dwellers are deteriorating the air quality. More the traffic emitted $NO_2$ increases, higher the sensitivity of the plant life occurs and make them to the verge of extinction.

## 4 Conclusion

Plants are continuously exposed to the air pollutants leading to an accumulation in their system. It alters the nature of the leaves and makes them more sensitive to the pollutants. Pollutants from traffic emission are creating a threat to plant life by making them sensitive. This sensitivity had measured by air pollution tolerance index (APTI) based on some biochemical parameters measurements. However, the susceptibility levels of different plant species growing in the traffic and residential areas in Dhaka city had evaluated based on their APTI values and compared with a control site at different seasons. All the parameters in winter seasons were less than other two seasons (summer and monsoon) indicating the higher pollution in winter than the rainy season as deposition of air pollutants might occur by rain. All the sampling species were found in the sensitive range towards air pollution. APTI determinations are important because, with increased industrialization, there is increasing danger of deforestation due to air pollution. The strong negative correlations of APTI with traffic emitted $NO_2$ and $PM_{2.5}$ indicate their great contribution in decreasing the plant's tolerance level towards pollution. Controlling and improving traffic emission might help to decrease these pollutants and extricate the plants. The results of such studies are therefore handy for future planning and may be helpful to bring out possible control measures.

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### Compliance with ethical standard

**Conflict of interest** Authors declare that there is no conflict of interest regarding the publication of this paper.

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