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AIR POLLUTION TOLERANCE INDEX IN SELECTED PLANT SPECIES AT DIFFERENT SITES IN MUZAFFARPUR CITY

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ABSTRACT

Urban growth, industrial development, to higher $PM_{2.5}$ concentrations compared to recommended level, all contribute to a major risk of air pollution in cities. Plants can be an aid in removal of contaminants. The PM pollution is caused by majority of residential energy use, transportation, and industrial sources. Addition of greenery along roads and highways can greatly reduce PM levels. Four sites with in Muzaffarpur city were selected to conduct the study, based on the sources of pollution, level of pollution, the amount of greenery, the use of the land, and the traffic congestion. The sequence of the locations' was Akharaghat (AKG)> Bela Industrial Area (BIA)> Amgola Road (AMG)> Babasaheb Bhimrao Ambedkar Bihar University (BRABU). The focus of this study is to evaluate the air pollution tolerance index (APTI) of 12 locally grown roadside plants such as *Dalbergia sissoo*, *Mangifera indica*, *Syzygium cumini*, *Psidium guajava*, *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Cassia fistula*, *Litchi chinensis*, *Morus alba*, *Terminalia arjuna*, *Nerium oleander* and *Polyalthia longifolia* were selected. At AKG site, a significant amount of dust load was recorded due to heavy traffic. The highest dust deposition was observed in *Psidium guajava* (0.97 mg/cm^2) in AKG, the most polluted site and the lowest on *Nerium oleander* (0.32 mg/cm^2) in BRABU. Based on APTI, the tolerant species identified were *Mangifera indica*, *Syzygium cumini*, *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Cassia fistula*, *Polyalthia longifolia*, *Litchi chinensis*, and *Psidium guajava*, while the sensitive species included *Morus alba*, *Terminalia arjuna*, *Nerium oleander* and *Dalbergia sissoo*. The findings thus suggest that *Cassia fistula*, *Syzygium cumini*, *Psidium guajava*, *Polyalthia longifolia*, *Hibiscus rosa-sinensis*, *Litchi chinensis*, and *Mangifera indica* have a high APTI, and could be planted in urban regions to help prevent or minimize vehicular air pollution.

KEY WORDS: Air pollution; Particulate matter; Plants; APTI; Dust load; Muzaffarpur

1. INTRODUCTION

In order to exist life on Earth, the dynamic atmosphere of complex gaseous system must be maintained. The poor quality of air in urban areas has become a serious hazard due to the rapid industrial growth and urban expansion as well as the rise in vehicular traffic. The most pernicious type of air pollution, which has a severe negative impact on living being, among the numerous categories is caused by vehicular emission (Deepalakshmi *et al.*, 2013). With 1.4 billion people, India has the fastest-growing economy on the planet (Singh *et al.*, 2019). The majority of people living in Indian subcontinent are subjected to ambient particulate matter (PM) pollution concentrations that are substantially higher than recommended by the World Health Organization (WHO) (Dey *et al.*, 2012; Goel *et al.*, 2015). According to a recent study, India's toxic air, which includes household air pollution and particle matter, resulted in 1.24 million fatalities in 2017 (Chatterjee, 2009). According to reports, Delhi had the highest annual mean pollution levels [particulate matter (PM) having diameter < 2.5 μm] in 2017, followed by the northern Indian states including Uttar Pradesh, Bihar, and Haryana, having mean PM value more than 125 μg/m^3 (Chatterjee, 2009). Van Donkelaar *et al.* (2016) examined global trends in $PM_{2.5}$ concentrations from 2001 to 2015 using remote sensing data, and they reported notable improvements in North

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America and Europe's air quality, with some locations experiencing a 30% reduction in $PM_{2.5}$ concentrations. The study did discover reduction, however, $PM_{2.5}$ concentration still rising over most of Asia, including China and India having some of the highest levels on the planet. African cities in particular are at risk from PM pollution. According to a study by Amegah and Agyei-Mensah (2017), Accra, Ghana's $PM_{2.5}$ levels were higher than those recommended by the WHO. The authors postulated that household energy usage, transportation, and industrial sources account for the majority of the PM pollution in Africa. According to Brook *et al.* (2010), $PM_{2.5}$ levels in the United States reduced by 38% between 1980 and 2000, and since then remained steady. They suggested, transportation, power generation, and industrial sources are the main contributors to PM pollution in the US. No mechanical or chemical method/device can entirely stop the discharge of pollutants at the source however, plants may provide some hope of clearing up pollutants once they are released into the atmosphere, because they can take up the chemicals and metabolise them. Consequently, in recent years, the importance of plants in reducing air pollution has gained momentum (Woo & Je 2006; Hoque *et al.*, 2007; Rai 2013; Rai & Panda, 2014). Xu *et al.* (2018) reported that *Pinus orientalis* and *P. armandi*, two evergreen conifer species, have the highest PM accumulation on their leaves and the deposition of PM was less successful with *Fraxinus pennsylvanica*, *Pinus tomentosa*, *Alianthus altissima*, and *Squatina japonica*. There were only three species out of seventeen that collected more than 50% of the total insoluble PM being *P. tomentosa*, *P. orientalis*, and *P. armandi* (Xu *et al.*, 2018). Computations based on the complex roof areas of the various Montreal businesses obtained through Google Earth Pro that 88% of the roof coverage of *P. mugho* var. pumilio can annually remove 92.37 kg of PM_{10}, of which 35.10 kg is $PM_{2.5}$. The removal rates are 4.00 g/m^2 and 1.52 g/m^2 for PM_{10} and $PM_{2.5}$, respectively (Gourdji, 2018). The effectiveness of urban trees for trapping $PM_{2.5}$ and PM_{10} has been investigated in the past, and it has been shown that the amount of PM accumulated on plant species' leaves varies greatly (Xu *et al.*, 2018; Przybysz *et al.*, 2014). According to Wang *et al.* (2006), particles mostly settle on the adaxial leaf surfaces, where their collected masses are approximately six times greater than those on the abaxial leaf surfaces. Studies in US, demonstrated that planting vegetation roads and highways can considerably lower PM levels in the vicinity (Nowak *et al.*, 2006). According to Abedesfahani *et al.* (2013), the APTI determination offers a trustworthy way for screening a number of plants with regard to their susceptibility to air pollution. By computing the plant's Air Pollution Tolerance Index (APTI) using factors like relative water content (RWC), total chlorophyll, ascorbic acid content (AA), and pH, it is possible to assess the vulnerability and tolerance of plants to air pollution (Singh & Rao, 1983; Chauhan, 2010; Das & Prasad, 2010; Kuddus *et al.*, 2011). Plant species have been ranked according to how well they tolerate air pollution using APTI (Raza & Murthy, 1988; Singh & Rao, 1983). Various environmental contaminants, notably PM, and their impacts on forest and urban plants have been the subject of extensive research (morphological, biochemical, physiological, and molecular). Additionally, several researchers have already noted the detrimental effects of PM on urban vegetation, including modifications to its morphological, physiological, and genetic stability as well as changes in the leaf's appearance (Cox, 2003; Chandawat *et al.*, 2011; Rai & Panda, 2014; Sicard *et al.*, 2016; Gomez-Arroyo *et al.*, 2018; Rai, 2020). In reaction to stress from air and PM pollution, chlorophyll concentration drastically decreased in commercially significant plant leaves (Rai, 2020). Thus, the present study focused on the effect of pollution on biochemical parameters such as photosynthetic pigments, non-enzymatic antioxidants, reactive oxygen species, leaf extract pH, and relative water content (Chlorophyll a, Chlorophyll b, total chlorophyll, carotenoid, ascorbic acid, proline, lipid peroxidation, membrane stability index, and relative water content) in 12 locally grown roadside plants at four study sites (BRABU, AMG, AKG, BIA). This research analyses the trends or variabilities observed in the biochemical and physiochemical parameters of plants with an increase in particulate matter concentration.

Table 1: Description of the selected sites

Site	Coordinates	Land use	Green area	Air Pollution Source
BRABU	26.11ºN, 85.37ºE	Residential/ Educational	High	Vehicular pollution
AMG	26.11ºN, 85.38ºE	Commercial/Residential	Low	Vehicular pollution, combustion and construction activities
BIA	26.09ºN, 85.40ºE	Industrial	Low	Vehicular pollution, Fuel burning, Combustion and Industrial emission
AKG	26.13ºN, 85.39ºE	Commercial area connected to Highway	Medium	Vehicular pollution with heavy traffic congestion, Biomass burning, Dust

2. MATERIALS AND METHODS

2.1. Study Area

Muzaffarpur is located at 26°07'N and 85°24'E in North Bihar. The city's average height meters sea level (MSL) ranges from 53 to 57 (187 Ft). Muzaffarpur experiences a humid subtropical climate. The town is situated over Himalayan sand and silt that have been transported by the glacier-fed and rain-fed meandering rivers of the Himalayas to the vast Indo-Gangetic plains of Bihar. It is the fourth-most populous city in Bihar. Compared to other areas of Bihar, Muzaffarpur city receives less rainfall. Based on the pollution sources, degree of pollution, greenery, land use and traffic load, four sites were selected within the Muzaffarpur city at different locations (out of which one is the control site) to carry out the study. Amgola Road (AMG) dotted with residential and commercial area was selected as the residential site, Bela Industrial Area (BIA) harbours small scale industries selected as the industrial site, Akharaghat (AKG) facing the heavy traffic load during the peak hours as traffic congested site and Babasaheb Bhimrao Ambedkar Bihar University Campus (BRABU) served as the reference site or control site which is an academic centre having buildings and green area. The pollution load of sites was in the order AKG>BIA>AMG>BRABU. The detailed description of all the four sites has been provided in Table 1.

2.2. Sampling Method

Twelve locally grown plant species that were often exposed to air pollution, were identified for the present study after a thorough field investigation of the area (Table 2). Plant leaf samples of the 12 selected trees were collected for biochemical analysis and dust deposition. The selection was made based on their common occurrence at all the study sites, availability and abundance throughout the year. The biochemical analysis was conducted during winter season of the year 2021. The higher TSP concentrations during winter seasons may be attributed to favourable meteorological factors for particulate matter accumulation and condensation, such as temperature inversion, low temperatures, and reduced wind speed, higher emissions due to an increase in combustion activities, such as burning wood and coal, crop residue, and biomass, and higher vehicle loads during the season (Tiwari *et al.*, 2015; Gogikar & Tyagi 2016). Between 0700 to 1000 hr in the morning, the sampling (15 to 30 leaf samples) was carried out at a height of 1.5 m to 4 m above the ground level from the selected trees. With the aid of forceps and scissors, leaves from chosen plants were picked and placed in zipper bags to avoid any damage. The leaf samples carrying bags were stored in the icebox and were taken to the lab immediately after the collection for further investigations.

2.3. Dust Deposition

For analysing the dust deposition and biochemical analyses, 12 commonly found plant species such as *Dalbergia sissoo*, *Mangifera indica*, *Syzygium cumini*, *Psidium guajava*, *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Cassia fistula*, *Litchi chinensis*, *Morus alba*, *Terminalia arjuna*, *Nerium oleander* and *Polyalthia*

Table 2: Characteristics and list of plant species selected for biochemical analysis

Tree species	Common name	Family	Nature	Leaf shape	Plant height (cm)
Dalbergia sissoo	Shisham	Pappilionaceae	Deciduous	Elliptic Oval	Large (25-30)
Polyalthia longifolia	Ashoka	Annonaceae	Evergreen	Lanceolate	Small (9)
Mangifera indica	Mango	Anacardiaceae	Evergreen	Oblong elliptic to lanceolate	Large (30)
Syzygium cumini	Jamun	Myrtaceae	Evergreen	Elliptic to Oblong or Ovate	Large (30)
Psidium guajava	Guava	Myrtaceae	Evergreen	Elliptic to Oblong	Medium (3-10)
Terminalia arjuna	Arjuna	Combretaceae	Evergreen, Deciduous	Oblong conical	Large (20-25)
Hibiscus rosa-sinensis	Chinese Hibiscus	Malvaceae	Evergreen	Ovate to Lanceolate	Small (1.5-3)
Nerium oleander	Nerium	Apocynaceae	Evergreen	Narrow lanceolate	Small (2-6)
Morus alba	Shahtoot	Moraceae	Evergreen	Oval	Medium (10-20)
Azadirachta indica	Neem	Meliaceae	Semi-Evergreen	Elongated to Oblong	Medium (15-20)
Cassia fistula	Amaltas	Fabaceae	Fabaceae	Ovate to lanceolate	Medium (10-20)
Litchi Chinensis	Litchi	Sapindaceae	Evergreen	Elliptic oblong to lanceolate, pointed	Medium (15)

longifolia growing alongside the roads were chosen (Table 2). Within 24 hours after their harvest, three replicates of each species' completely grown leaves were randomly taken from the lower branches (at a height of 2-4 m) in the early morning and transported to the lab in a polythene bag preserved in an ice box for further examination. The initial and end weights of the beaker used to wash the leaf samples were used to calculate the amount of dust employing the following formula:

$$W = \frac{(W2 - W1)}{A}$$

Where W = Dust content (mg/cm^2)

W1 = weight of clean leaf without dust

W2 = weight of total leaf with dust

A = Total area of leaf in square centimetre

2.4. Biochemical Analysis

For biochemical analysis, the parameters were pH, ascorbic acid, chlorophyll content, reactive oxygen species (ROS), leaf water content (RWC) and membrane stability.

2.4.1. Photosynthetic Pigments : The modified method described by Porra *et al.* (1989) and Doong *et al.* (1993) was used to quantify the total carotenoid concentration and the photosynthetic pigment chlorophyll (Chl a, Chl b, Chl a/Chl b, Total Chl/Carotenoid) by smashing 100 mg of leaf samples with 1 ml of 80% acetone (v/v), centrifuging for 10 minutes at 5000 rpm, and measuring the absorbance using UV-visible spectrophotometer at wavelengths of 470, 645, and 663 nm.

2.4.2. Non-enzymatic Antioxidants : Estimates of antioxidant activity were calculated to provide a general overview of the defence mechanisms used by plants under stress from particulate matter. Ascorbic acid (AsA) content in leaf extract was calculated using Keller and Schwazer (1968) methodology. Oxalic acid and EDTA were used in a 10 mL solution to extract AsA at a rate of 0.75% and 0.05%, respectively. For proline estimation 0.5 g of leaf tissue samples were obtained, and 5 ml of 3% sulphosalycylic acid was used to homogenise the samples using a pre-washed mortar and pestle according to the methodology of Bates *et al.* (1973).

2.4.3. Reactive Oxygen Species Generation (ROS) : According to Able (2003) method, reactive oxygen species generation was calculated by monitoring the XTT reduction.

2.4.4. Lipid Peroxidation (LPO) and Membrane Stability Index (MSI) : Lipid peroxidation was assessed as MDA content following the Heath and Packer (1968) methodology. Procedure of Bates *et al.* (1973) was used to quantify membrane stability index (MSI). The formula used to compute the membrane stability index percentage is given below:

$$MSI\ \% = \{E2\text{-}(E1/E2)\} \times 100$$

2.5. Leaf Extract PH

Approximately 0.5g leaf sample was crushed and homogenised in 50 ml deionized water, and the mixture was then centrifuged. The supernatant was collected, and the pH of mixture was determined using a pH meter.

2.6. Relative Water Content (RWC)

Employing the Li *et al.* (2009) approach, the relative water content (RWC) was determined by comparing the fresh weight (FW), turgid weight (TW), and dried weight (DW) of the leaf sample. The sample's RWC was determined using the following formula:

$$RWC\ (\%) = \frac{(W2 - W1)}{A} \times 100$$

The variations in different biochemical parameters (Chlorophyll a, Chlorophyll b, Carotenoid, Total Chlorophyll, Chlorophyll a/Chlorophyll b, Total Chlorophyll/ Carotenoid, Ascorbic acid, Proline, Leaf extract pH, Relative Water Content, Lipid Peroxidation and Membrane Stability Index) of different plant species studied at the selected study area are shown in Table 3.

2.7 Air Pollution Tolerance Index (APTI)

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

$$APTI = A\ (T+P) + R/10$$

Where: A=Ascorbic Acid (mg g^{-1})

T=Total Chlorophyll (mg g^{-1} fresh weight)

P=pH of the leaf extract

R=Relative water content of leaf (%)

2.7. Statistical Analysis

The data obtained were subjected to one way analysis of variance (ANOVA) applying Tukey's test as post hoc for assessing the significance of tested parameters site wise for the selected plant species.

3. RESULT AND DISCUSSION

Air pollution is a menace especially in cities which show industrial developments and urbanization with heavy vehicular pollution load and shrinkage of green areas. The urban regions of Muzaffarpur is located in Tirhut Division of the state of Bihar. Muzaffarpur City is the most significant hub for trade and business activity for the entire northern region of Bihar. According to report (WHO, 2018), the average $PM_{2.5}$ concentration in this city was 120 µg/ m^3. The presence of manufacturing companies, open waste burning, and brick factories are the main contributors to deteriorating air quality. The WHO (2019) reported that

Table 3: Biochemical parameters of plants selected at different study sites

Index: (Chlorophyll a (Chla), Chlorophyll b (Chlb), Carotenoid (Car), Total Chlorophyll (TChl), Chla/Chlb, TChl/Car, Ascorbic acid (AsA), Leaf extract pH (pH), Relative Water Content (RWC), Lipid Peroxidation (LPO), Membrane Stability Index (MSI)

Dalbergia sissoo	BRABU	AMG	BIA	AKG
Chl a	1.62±0.08^{b}	1.85±0.10^{b}	2.21±0.11^{ab}	2.69±0.14^{a}
Chl b	0.49±0.02^{c}	0.84±0.05^{b}	1.09±0.05^{ab}	1.27±0.06^{a}
Car	1.22±0.06^{b}	1.63±0.09^{b}	1.92±0.09^{ab}	2.05±0.11^{a}
TChl	2.05±0.12^{b}	2.69±0.14^{ab}	3.30±0.27^{ab}	3.96±0.26^{a}
Chla/Chlb	3.31±0.15^{a}	2.2±0.11^{b}	2.03±0.11^{b}	2.12±0.16^{b}
TChl/Car	1.73±0.09^{a}	1.65±0.09^{a}	1.72±0.09^{a}	1.93±0.12^{a}
AsA	0.27±0.01^{c}	0.57±0.03^{bc}	0.75±0.04^{b}	0.88±0.04^{a}
Proline	9.01±0.46^{c}	16.42±0.76^{b}	21.07±1.16^{b}	28.17±1.42^{a}
pH	6.86±0.29^{a}	6.53±0.31^{a}	6.12±0.34^{a}	6.01±0.30^{a}
RWC	75.09±3.90^{a}	68.97±3.39^{a}	60.17±3.13^{a}	57.17±2.81^{a}
LPO	1.13±0.05^{d}	4.72±0.24^{c}	9.36±0.49^{b}	12.45±0.62^{a}
MSI	78.00±3.60^{a}	58.00±3.11^{a}	35.00±1.74^{b}	21.00±1.07^{c}
Polyalthia longifolia	BRABU	AMG	BIA	AKG
Chl a	1.69±0.10^{a}	1.57±0.08^{a}	1.43±0.07^{a}	1.33±0.07^{a}
Chl b	0.69±0.03^{a}	0.58±0.03^{a}	0.42±0.02^{b}	0.33±0.02^{b}
car	0.97±0.05^{a}	0.87±0.05^{a}	0.81±0.04^{a}	0.72±0.04^{a}
TChl	2.38±0.13^{a}	2.15±0.12^{ab}	1.85±0.10^{ab}	1.66±0.08^{b}
Chla/Chlb	2.45±0.12^{c}	2.71±0.13^{bc}	3.40±0.19^{ab}	4.03±3.40^{a}
TChl/Car	2.45±0.14^{a}	2.47±0.13^{a}	2.28±0.12^{a}	2.31±0.11^{a}
AsA	4.13±0.21^{b}	4.58±0.24^{ab}	5.01±0.28^{ab}	5.77±0.27^{a}
Proline	10.63±0.56^{b}	13.64±0.73^{a}	14.16±0.80^{a}	18.99±0.88^{a}
pH	6.76±0.35^{a}	6.17±0.28^{ab}	5.62±0.28^{ab}	5.03±0.28^{b}
RWC	88.23±4.66^{a}	90.87±5.09^{a}	94.56±5.35^{a}	98.26±5.34^{a}
LPO	2.37±0.13^{c}	5.12±0.29^{b}	11.27±0.61^{a}	14.65±0.80^{a}
MSI	86.00±4.67^{a}	64.00±3.10^{b}	51.00±2.86^{b}	23.00±1.16^{c}
Mangifera indica	BRABU	AMG	BIA	AKG
Chl a	1.52±0.08^{b}	1.97±0.11^{a}	2.06±0.11^{a}	2.83±0.14^{a}
Chl b	0.25±0.01^{d}	0.43±0.02^{c}	0.61±0.03^{b}	0.86±0.04^{a}
Car	0.73±0.04^{b}	0.89±0.04^{ab}	0.96±0.05^{ab}	1.07±0.05^{a}
TChl	1.77±0.10^{c}	2.40±0.13^{b}	2.67±0.14^{ab}	3.69±0.17^{a}
Chla/Chlb	6.08±0.31^{a}	4.58±0.25^{a}	3.38±0.18^{a}	3.29±0.16^{b}
TChl/Car	2.42±0.00^{b}	2.70±0.14^{ab}	2.78±0.14^{a}	3.45±0.16^{a}
AsA	2.06±0.10^{c}	2.21±0.12^{bc}	2.97±0.16^{ab}	3.15±0.17^{a}
Proline	4.96±0.23^{c}	6.08±0.30^{b}	7.55±0.35^{a}	9.61±0.46^{a}
pH	6.08±0.32^{a}	5.87±0.31^{a}	5.37±0.26^{a}	5.02±0.23^{a}
RWC	78.09±4.35^{a}	89.16±4.43^{a}	90.42±4.82^{a}	96.37±5.14^{a}
LPO	2.67±0.15^{c}	3.47±0.19^{b}	4.81±0.24^{a}	6.08±0.30^{a}
MSI	52.00±2.78^{a}	41.00±2.06^{b}	39.00±2.15^{bc}	23.00±1.07^{c}
Syzygium cumini	BRABU	AMG	BIA	AKG
Chl a	0.49±0.03^{c}	0.74±0.04^{bc}	0.94±0.05^{b}	1.07±0.05^{a}
Chl b	0.26±0.01^{c}	0.48±0.02^{c}	0.76±0.04^{b}	0.80±0.04^{a}
Car	2.21±0.11^{b}	4.81±0.24^{b}	5.31±0.26^{b}	5.65±0.31^{a}
TChl	0.75±0.04^{c}	1.22±0.06^{c}	1.70±0.09^{b}	1.87±0.10^{a}
Chla/Chlb	1.88±0.10^{a}	1.54±0.08^{a}	1.24±0.07^{ab}	1.34±0.07^{b}
TChl/Car	0.34±0.02^{b}	0.25±0.01^{ab}	0.32±0.02^{ab}	0.33±0.02^{a}
AsA	4.37±0.22^{c}	6.12±0.35^{b}	6.25±0.34^{a}	8.68±0.47^{a}

Proline	0.46±0.02^{a}	0.37±0.02^{b}	0.29±0.01^{bc}	0.12±0.01^{c}
pH	7.06±0.37^{a}	6.72±0.31^{a}	6.07±0.31^{a}	5.63±0.28^{a}
RWC	75.15±4.07^{a}	76.61±4.31^{a}	82.31±4.51^{a}	88.37±4.97^{a}
LPO	3.41±0.17^{d}	6.12±0.31^{c}	8.61±0.48^{b}	11.63±0.54^{a}
MSI	62.00±3.19^{a}	52.00±2.72^{b}	39.00±2.07^{bc}	23.00±1.16^{c}
Psidium guajava	BRABU	AMG	BIA	AKG
Chl a	0.11±0.01^{b}	0.19±0.01^{b}	0.35±0.02^{a}	0.42±0.02^{a}
Chl b	0.12±0.01^{d}	0.21±0.01^{c}	0.37±0.01^{b}	0.52±0.03^{a}
Car	0.11±0.01^{b}	0.17±0.01^{b}	0.25±0.01^{a}	0.30±0.02^{a}
TChl	0.23±0.01^{c}	0.40±0.02^{b}	0.72±0.04^{a}	0.94±0.05^{a}
Chla/Chlb	0.92±0.05^{a}	0.90±0.05^{a}	0.95±0.05^{a}	0.81±0.04^{a}
TChl/Car	2.09±0.11^{c}	2.35±0.12^{bc}	2.88±0.14^{ab}	3.13±0.17^{a}
AsA	3.61±0.17^{b}	4.07±0.20^{b}	7.13±0.35^{a}	8.47±0.46^{a}
Proline	12.09±0.59^{c}	17.62±0.81^{b}	26.71±1.37^{a}	35.27±1.78^{a}
pH	6.91±0.35^{a}	6.28±0.32^{a}	6.01±0.30^{a}	5.81±0.29^{a}
RWC	58.10±3.07^{c}	60.41±3.20^{bc}	80.30±4.39^{ab}	87.61±4.67^{a}
LPO	4.96±0.26^{c}	11.38±0.61^{b}	18.72±2.60^{b}	25.64±1.37^{a}
MSI	67.00±3.44^{a}	52.00±2.45^{ab}	48.00±2.54^{b}	34.00±1.90^{c}
Azadirachta indica	BRABU	AMG	BIA	AKG
Chl a	1.47±0.08^{a}	1.51±0.07^{a}	1.63±0.09^{a}	1.77±0.08^{a}
Chl b	0.47±0.02^{c}	0.56±0.03^{bc}	0.68±0.03^{ab}	0.83±0.05^{a}
Car	0.75±0.04^{b}	0.83±0.05^{ab}	0.92±0.05^{ab}	1.03±0.06^{a}
TChl	1.94±0.11^{b}	2.07±0.10^{ab}	2.31±0.11^{ab}	2.60±0.13^{a}
Chla/Chlb	3.13±0.17^{a}	2.70±0.15^{ab}	2.40±0.12^{ab}	2.13±0.11^{b}
TChl/Car	2.59±0.14^{a}	2.49±0.14^{a}	2.51±0.12^{a}	2.52±0.14^{a}
AsA	1.42±0.08^{b}	1.78±0.10^{ab}	1.93±0.11^{a}	2.38±0.13^{a}
Proline	16.73±0.87^{c}	27.52±1.57^{bc}	33.09±1.81^{b}	42.16±2.31^{a}
pH	6.23±0.32^{a}	5.08±0.28^{ab}	4.18±0.22^{bc}	3.27±0.16^{c}
RWC	76.87±3.71^{a}	83.03±4.51^{a}	91.25±4.21^{a}	97.53±5.30^{a}
LPO	3.87±0.18^{d}	7.82±0.42^{c}	13.25±0.72^{b}	17.54±0.95^{a}
MSI	54.00±2.9^{a}	43.00±2.28^{b}	37.00±1.71^{bc}	21.00±1.11^{c}
Hibiscus rosa-sinensis	BRABU	AMG	BIA	AKG
Chl a	1.07±0.06^{a}	1.17±0.06^{a}	1.26±0.07^{a}	2.23±0.12^{b}
Chl b	1.05±0.06^{a}	1.16±0.06^{a}	1.21±0.07^{a}	1.28±0.06^{a}
Car	0.47±0.02^{a}	0.50±0.03^{a}	0.78±0.04^{b}	0.83±0.05^{b}
TChl	2.12±0.11^{a}	2.33±0.13^{a}	2.47±0.14^{a}	3.51±0.19^{b}
Chla/Chlb	1.02±0.05^{a}	1.01±0.06^{a}	1.04±0.05^{a}	1.74±0.09^{b}
TChl/Car	4.51±0.24^{ab}	4.66±0.24^{a}	3.17±0.16^{b}	4.23±0.21^{b}
AsA	2.18±0.12^{c}	3.21±0.17^{b}	3.83±0.19^{ab}	5.83±0.30^{a}
Proline	7.02±0.38^{a}	7.35±0.38^{a}	8.16±0.47^{a}	8.67±0.45^{a}
pH	6.13±0.33^{a}	5.34±0.26^{a}	5.03±0.24^{a}	4.83±0.25^{a}
RWC	63.56±3.32^{a}	71.18±3.81^{a}	79.49±4.30^{a}	84.37±4.57^{a}
LPO	5.19±0.27^{c}	9.47±0.44^{b}	11.72±0.55^{b}	18.47±1.00^{a}
MSI	70.00±3.23^{a}	68.00±3.44^{ab}	53.00±2.55^{bc}	42.00±2.11^{c}
Nerium oleander	BRABU	AMG	BIA	AKG
Chl a	1.21±0.07^{a}	1.14±0.06^{a}	1.04±0.06^{a}	0.93±0.05^{a}
Chl b	1.08±0.06^{a}	0.92±0.05^{ab}	0.84±0.04^{ab}	0.67±0.03^{b}
Car	0.34±0.01^{a}	0.23±0.01^{ab}	0.17±0.01^{b}	0.11±0.01^{c}
TChl	2.29±0.12^{a}	2.06±0.11^{ab}	1.88±0.10^{ab}	1.60±0.09^{b}
Chla/Chlb	1.12±0.06^{a}	1.24±0.06^{a}	1.24±0.06^{a}	1.39±0.07^{a}
TChl/Car	6.74±0.36^{c}	8.96±0.45^{b}	11.06±0.54^{ab}	14.55±0.73^{a}
AsA	0.83±0.04^{c}	1.07±0.06^{b}	1.78±0.09^{a}	2.73±0.13^{a}
Proline	0.53±0.03^{b}	0.98±0.05^{b}	1.05±0.06^{b}	1.26±0.07^{a}
pH	7.69±0.39^{a}	7.11±0.37^{a}	6.56±0.34^{a}	6.23±0.35^{a}
RWC	90.17±4.83^{a}	93.71±4.96^{a}	95.71±4.67^{a}	96.47±4.62^{a}
LPO	6.35±0.31^{c}	10.23±0.53^{b}	14.71±0.82^{a}	24.61±1.18^{a}
MSI	74.00±3.49^{a}	63.00±3.45^{ab}	58.00±2.80^{b}	42.00±1.94^{b}

Terminalia arjuna	BRABU	AMG	BIA	AKG
Chl a	1.83±0.10^{a}	1.69±0.09^{a}	1.52±0.08^{a}	1.41±0.07^{a}
Chl b	0.72±0.04^{a}	0.68±0.04^{ab}	0.61±0.03^{ab}	0.53±0.03^{b}
Car	0.73±0.04^{a}	0.62±0.04^{ab}	0.58±0.03^{ab}	0.47±0.02^{b}
TChl	2.55±0.14^{a}	2.37±0.12^{a}	2.13±0.12^{a}	1.94±0.10^{a}
Chla/Chlb	2.54±0.13^{a}	2.49±0.13^{a}	2.49±0.13^{a}	2.66±0.14^{a}
TChl/Car	3.49±0.19^{a}	3.82±0.169^{a}	3.67±0.19^{a}	4.13±0.20^{a}
AsA	0.53±0.03^{c}	0.76±0.04^{b}	0.93±0.05^{ab}	1.19±0.06^{a}
Proline	0.64±0.03^{c}	0.78±0.04^{bc}	0.94±0.05^{ab}	1.13±0.06^{a}
pH	6.31±0.35^{a}	5.81±0.31^{a}	5.02±0.27^{a}	4.83±0.27^{a}
RWC	77.06±4.02^{a}	84.58±4.41^{a}	90.32±5.06^{a}	97.02±5.32^{a}
LPO	2.08±0.10^{d}	6.17±0.31^{c}	12.57±0.69^{b}	18.62±1.02^{a}
MSI	23.00±1.24^{c}	47.00±2.23^{bc}	52.00±2.62^{b}	64.00±3.59^{a}
Morus alba	BRABU	AMG	BIA	AKG
Chl a	1.26±0.07^{a}	1.13±0.06^{a}	1.04±0.05^{a}	0.95±0.05^{a}
Chl b	1.53±0.08^{a}	1.41±0.07^{ab}	1.27±0.06^{ab}	1.09±0.05^{b}
Car	1.93±0.10^{a}	1.75±0.10^{ab}	1.43±0.07^{bc}	1.26±0.06^{c}
TChl	2.79±0.15^{a}	2.54±0.13^{ab}	2.31±0.12^{ab}	2.04±0.12^{b}
Chla/Chlb	0.82±0.04^{a}	0.80±0.04^{a}	0.82±0.04^{a}	0.87±0.05^{a}
TChl/Car	1.45±0.08^{a}	1.45±0.07^{a}	1.62±0.08^{a}	1.62±0.08^{a}
AsA	1.14±0.06^{c}	1.38±0.07^{bc}	1.87±0.10^{ab}	2.31±0.11^{a}
Proline	3.58±0.20^{b}	4.21±0.22^{ab}	4.86±0.27^{a}	5.97±0.33^{a}
pH	8.53±0.44^{a}	7.45±0.41^{a}	7.02±0.39^{a}	6.82±0.37^{a}
RWC	70.81±3.55^{a}	78.34±4.03^{a}	82.36±4.46^{a}	89.21±4.64^{a}
LPO	3.84±0.19^{d}	8.36±0.43^{c}	13.72±0.67^{b}	19.56±1.02^{a}
MSI	72.00±3.62^{a}	63.00±3.57^{b}	47.00±2.63^{bc}	29.00±1.42^{c}
Cassia fistula	BRABU	AMG	BIA	AKG
Chl a	1.02±0.05^{b}	1.94±0.11^{b}	2.07±0.10^{b}	2.31±0.11^{a}
Chl b	0.61±0.03^{c}	0.96±0.05^{b}	1.07±0.06^{b}	1.83±0.09^{a}
Car	1.15±0.06^{b}	1.46±0.08^{bc}	1.79±0.07^{ab}	1.93±0.09^{a}
TChl	1.63±0.09^{c}	2.90±0.11^{b}	3.14±0.17^{b}	4.14±0.20^{a}
Chla/Chlb	1.67±0.08^{b}	2.02±0.10^{a}	1.93±0.11^{ab}	1.26±0.06^{b}
TChl/Car	1.42±0.08^{b}	1.99±0.10^{ab}	1.75±0.09^{b}	2.15±0.10^{a}
AsA	10.32±0.54^{a}	11.17±0.61^{a}	12.03±0.61^{a}	12.91±0.71^{a}
Proline	4.23±0.21^{c}	9.56±0.52^{b}	12.39±0.69^{b}	18.27±0.88^{a}
pH	8.31±0.42^{a}	7.04±0.38^{ab}	6.43±0.35^{ab}	5.75±0.31^{b}
RWC	78.12±4.06^{a}	83.21±4.45^{a}	90.14±4.68^{a}	98.53±5.23^{a}
LPO	2.74±0.15^{d}	7.89±0.43^{c}	11.58±0.57^{b}	15.89±0.84^{a}
MSI	69.00±3.47^{a}	53.00±2.73^{b}	45.00±2.47^{b}	24.00±1.18^{c}
Litchi chinensis	BRABU	AMG	BIA	AKG
Chl a	0.96±0.05^{b}	1.27±0.07^{b}	1.86±0.10^{a}	2.06±0.10^{a}
Chl b	0.52±0.03^{c}	0.78±0.04^{b}	0.93±0.04^{b}	1.18±0.05^{a}
Car	0.38±0.02^{c}	0.62±0.03^{b}	0.74±0.04^{b}	0.96±0.04^{a}
TChl	1.48±0.08^{b}	2.05±0.10^{b}	2.79±0.16^{a}	3.24±0.16^{a}
Chla/Chlb	1.85±0.10^{a}	1.63±0.08^{a}	2.00±0.11^{a}	1.75±0.08^{a}
TChl/Car	3.89±0.20^{a}	3.31±0.16^{a}	3.77±0.21^{a}	3.38±0.16^{a}
AsA	2.42±0.12^{c}	3.71±0.20^{bc}	4.83±0.24^{b}	5.74±0.29^{a}
Proline	9.53±0.49^{b}	10.06±0.52^{ab}	11.92±0.60^{a}	13.26±0.67^{a}
pH	6.24±0.31^{a}	5.37±0.27^{ab}	4.86±0.24^{b}	3.68±0.18^{b}
RWC	54.13±2.81^{c}	62.53±2.97^{bc}	78.31±3.75^{ab}	93.26±4.31^{a}
LPO	3.86±0.21^{d}	7.95±0.38^{c}	13.75±0.69^{b}	17.43±0.81^{a}
MSI	78.00±4.05^{a}	62.00±3.36^{ab}	52.00±2.61^{bc}	43.00±2.16^{c}

Values are mean ± SE. Each value represents the mean value of three biological replications. Superscripted letters above the values within a row indicates significant difference among the treatments according to Tukey's test at $p<0.05$

Muzaffarpur is one of the top 10 most polluted cities in the world. High concentration of dust load was seen at AKG site because of the heavy vehicular load, burning of tress in open and less greenery at this site. In areas with high traffic, the concentration of TSP increased by 64% between 2002 and 2012 (Pandey *et al.*, 1992; Trivedi & Agrawal, 2003; Mukherjee & Agrawal, 2016). Least concentration of dust load was seen at BRABU site because of restricted construction activities, low vehicle load, more greenery and trees. The PM deposition was observed in the order AKG>BIA>AMG>BRABU. AMG is the residential and commercial area having construction and other developmental activities, thus manifesting PM deposition more than BRABU. BIA is an industrial area, where blackish dust was observed possibly due to the industrial influences. At a polluted site, the dust deposition was recorded highest in *Psidium guajava* (0.97 mg/cm^2) followed by *Mangifera indica* (0.96 mg/cm^2), and *Syzygium cumini* (0.91 mg/cm^2), while the lowest level was found in *Nerium oleander* (0.63 mg/cm^2) followed by *Azadirachta indica* (0.68 mg/cm^2), and *Cassia fistula* (0.68 mg/cm^2) (Figure 1). The Chlorophyll a (Chl a), Chlorophyll b (Chl b), Carotenoid (Car) and total chlorophyll (TChl) of *Dalbergia sisso*, *Mangifera indica*, *Syzygium cumini*, *Psidium guajava*, *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Cassia fistula*, *Litchi chinensis* was highest in the most polluted site i.e., AKG and minimum in the least polluted site i.e., BRABU followed by AMG (Table 3). With increase in pollution level, the Chl a, Chl b and carotenoid content of these eight trees increased. Tolerant plant species have evolved to sustain the rate of photosynthesis under stress by increasing the concentration of pigments, whereas sensitive plant species loose pigments as the first sign of stress induction (Singh *et al.,* 1991; Mukherjee & Agrawal, 2016). While the Chlorophyll a, Chlorophyll b, Carotenoid and total Chlorophyll of *Morus alba*, *Terminalia arjuna*, *Nerium oleander*, *Polyalthia longifolia* was highest at the least polluted site (BRABU) and minimum in the highly polluted site (AKG and BIA). All the three sites (AKG, BIA, AMG) shows less Chl a, Chl b, Carotenoid, total chlorophyll concentration from control site (BRABU), i.e., with increase in pollution level, the Chl a, Chl b, Car, TChl content of these four trees decreased. The site wise significance level for the 12 plant species for all the parameters have been provided in Table 3. In tolerant plant species, higher pigment concentrations with increased stress were an adaptation to maintain the rate of photosynthetic activity, whereas in sensitive plant species, pigment loss was the first sign of stress induction (Tripathi & Gautam, 2007; Jyothi & Jaya, 2010). Verma & Singh (2006), observed the reduction in Car content in *Ficus religiosa*. Chl a, Chl b, Car and total chlorophyll concentrations and chlorophyll a/chlorophyll b ratios, as well as total

Table 4: It shows APTI of all the 12 plant species at four selected sites (BRABU, AMG, AKG, BIA) along with the values of the four parameters required to calculate APTI

Plant	Site	pH	Relative Water Content (%)	Total Chloro-phyll (mg/g)	Ascor-bic acid (mg/g)	Air Pollution Tolerance Index (APTI)
Dalbergia sissoo	BRABU	6.86	75.09	2.11	0.27	7.75
	AMG	6.53	68.97	2.69	0.57	7.42
	BIA	6.12	60.17	3.3	0.75	6.72
	AKG	6.01	57.17	3.96	0.88	6.59
Polyalthia longifolia	BRABU	6.76	88.23	2.38	4.13	12.60
	AMG	6.17	90.87	2.15	4.58	12.90
	BIA	5.62	94.56	1.85	5.01	13.20
	AKG	5.03	98.26	1.66	5.77	13.69
Mangifera indica	BRABU	6.08	78.09	1.77	2.06	9.43
	AMG	5.87	89.16	2.4	2.21	10.74
	BIA	5.37	90.42	2.67	2.97	11.43
	AKG	5.02	96.37	3.69	3.15	12.38
Syzygium-cumini	BRABU	7.06	75.15	0.75	4.37	10.93
	AMG	6.72	76.61	1.22	6.12	12.52
	BIA	6.07	82.31	1.7	6.25	13.09
	AKG	5.63	88.37	1.87	8.68	15.35
Psidium guajava	BRABU	6.91	58.10	0.23	3.61	8.39
	AMG	6.28	60.41	0.4	4.07	8.76
	BIA	6.01	80.30	0.72	7.13	12.83
	AKG	5.81	87.61	0.94	8.47	14.48
Terminalia arjuna	BRABU	6.31	77.06	2.55	0.53	8.18
	AMG	5.81	84.58	2.37	0.76	9.08
	BIA	5.02	90.32	2.13	0.93	9.70
	AKG	4.83	97.02	1.94	1.19	10.51
Hibiscus rosa-sinensis	BRABU	6.13	63.56	2.12	2.18	8.15
	AMG	5.34	71.18	2.33	3.21	9.58
	BIA	5.03	79.49	2.47	3.83	10.82
	AKG	4.83	84.37	3.51	5.83	13.30
Nerium oleander	BRABU	7.69	90.17	2.29	0.83	9.85
	AMG	7.11	93.71	2.06	1.07	10.35
	BIA	6.56	95.71	1.88	1.78	11.07
	AKG	6.23	96.47	1.6	2.73	11.78
Morus alba	BRABU	8.53	70.81	2.79	1.14	8.37
	AMG	7.45	78.34	2.54	1.38	9.21
	BIA	7.02	82.36	2.31	1.87	9.98
	AKG	6.82	89.21	2.04	2.31	10.97
Azadi-rachta indica	BRABU	6.23	76.87	1.94	1.42	8.85
	AMG	5.08	83.03	2.07	1.78	9.58
	BIA	4.18	91.25	2.31	1.93	10.38
	AKG	3.27	97.53	2.6	2.38	11.15
Cassia fistula	BRABU	8.31	78.12	1.63	10.32	18.07
	AMG	7.04	83.21	2.9	11.17	19.42
	BIA	6.43	90.14	3.14	12.03	20.53
	AKG	5.75	98.53	4.14	12.91	22.62
Litchi chinensis	BRABU	6.24	54.13	1.48	2.42	7.28
	AMG	5.37	62.53	2.05	3.71	9.01
	BIA	4.86	78.31	2.79	4.83	11.53
	AKG	3.68	93.26	3.24	5.74	13.30

chlorophyll to carotenoids, are good markers of plant stress responses (Tripathi & Gautam, 2007). The amount of chlorophyll in a plant indicates both its ability to photosynthesize and the expansion and development of its biomass. The amount of chlorophyll in plants varies depending on the species as well as the pollution level (Rai & Panda, 2014). A prominent sign of early stress in plants is a decreasing trend in the TChl/Car ratio (Lichtenthaler & Babani, 2004). Higher Chl degradation relative to carotenoids under stress conditions may be the cause of the lower ratio found in the current investigation for some trees at the more polluted site. Additionally, Mukherjee & Agrawal (2016) found that *Psidium guajava*'s pollution response score increased most when the pollution load increased.

The ascorbic acid and proline content of *Dalbergia sissoo*, *Polyalthia longifolia*, *Mangifera indica*, *Syzygium cumini*, *Psidium guajava*, *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Nerium oleander*, *Terminalia arjuna*, *Morus alba*, *Cassia fistula* and *Litchi chinensis* showed highest value at AKG which is the most polluted site and least at BRABU (control or least polluted site), except the proline content in *S. cumini* which showed the opposite trend i.e., BRABU>AKG>BIA>AMG (Table 3). The first line of defence against reactive oxygen species is an increase in AsA concentration with increasing pollution loads (Conklin & Barth, 2004; Mukherjee & Agrawal, 2016). In Gandhinagar, Chaudhary & Rathore (2018) reported an increase in AsA content in seven tropical tree species complying with an increase in pollution load, which is similar to the findings of the current study. In the urban environment of Tehran, Iran, Sanaeirad *et al.* (2017) also noted an increase in proline content in tree and shrub species with increasing air pollution load.

All the 12 plants showed high pH at BRABU (least polluted site) and low pH at AKG (most polluted site).

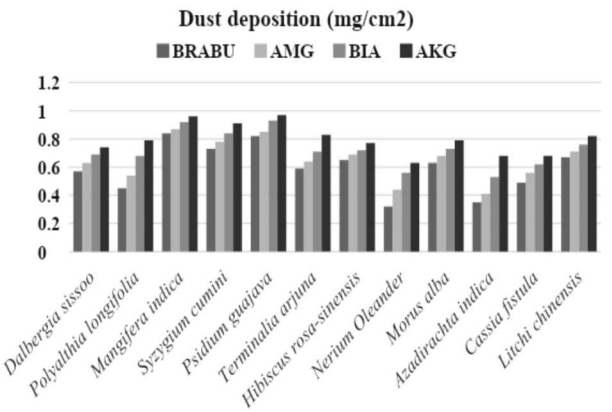

Fig. 1: Dust accumulation of 12 selected plant species at 4 different sites

Alkaline pH dust could directly harm the leaf tissue (Vardak *et al.*, 1995). A comparison of APTI in plants from the polluted and unpolluted areas of Bengaluru city was conducted by Manjunath *et al.* (2019). *Ricinus communis* from the polluted and unpolluted areas displayed different water retention capacities, according to their study. Plants from the contaminated area have less relative water than those from the unpolluted environment. A potential influence was found in the chlorophyll content of *R. communis* from the polluted site as compared to the non-polluted site, along with other biochemical parameters including pH and stomata index suggesting a modest variation between plants of polluted and non-polluted species. The amount of chlorophyll is a significant biological element that influences photosynthetic activity, which affects plant development. Chauhan *et al.* (2012) noted a shift in the pH (5.20 to 5.25) of the leaf extract from *Dalbergia sissoo*. All the selected plant species except *D. sisso* showed highest Relative Water Content (RWC) value at most polluted site and low RWC at least polluted site reflecting that *D. sisso* showed completely opposite trend (Table 3). The RWC decreased under greater pollution loads, according to Arena *et al.* (2014). Four tree species were found to exhibit an increase in RWC with increasing pollution loads as reported by Mukherjee and Agrawal (2016). Plants that encounter early stress have less water retention in them. Lipid peroxidation of the entire 12 plant species showed maximum concentration at most polluted site (AKG) and minimum at least polluted site (BRABU). Membrane stability for all the 12 plant species showed maximum value at least polluted site (BRABU) and minimum value at most polluted site (AKG) except *Terminalia arjuna* which manifested an opposite trend (Table 3).

The APTI at highly polluted site (AKG) was found to be as follows; *Cassia fistula* (22.62)> *Syzygium cumini* (15.35)>*Psidium guajava* (14.48)>*Polyalthia longifolia* (13.69)>*Hibiscus Rosa-sinensis=Litchi chinensis* (13.30)>*Mangifera indica* (12.38)>*Nerium oleander* (11.78)> *Azadirachta indica* (11.15)> *Morus alba* (10.97)> *Terminalia arjuna* (10.51)> *Dalbergia sissoo* (6.59) (Table 4). Singh and Rao (1983) have documented that compared to plants with lower index values, those with higher index values are more tolerant to air pollution. Therefore, right species can be chosen for plantation in polluted areas once the APTI is known. However, it should also be considered that according to Raza *et al.* (1985), a plant species that is known to be sensitive or tolerant in one location might act differently in another region. The results of the present study, that plants like *C. fistula*, *S. cumini*, *Psidium guajava*, *Polyalthia longifolia*, *H. rosa-sinensis*, *L. chinensis*, and *M. indica* could be planted in

contaminated urban regions in the future to minimize and help in preventing air pollution.

4. CONCLUSIONS

Air pollution is a major problem that the World is facing today. Air pollutants can lead to severe damage to human and plant health. However, certain species of plants can show higher tolerance to air pollutants and their leaves can capture and store or detoxify the contaminants. In the present investigation, twelve plant species that commonly grow in the urban regions of Muzaffarpur were examined for their air pollution tolerance index (APTI) in both severely and less polluted locations. In accordance with APTI, the best-suited varieties for planting along the roadside of the polluted areas were determined to be *C. fistula*, *S. cumini*, *Psidium guajava*, *Polyalthia longifolia*, *H. rosa-sinensis*, *L. chinensis*, and *M. indica*. The evaluation of the aforementioned indexes revealed that plants with higher APTIs can be used as indicator to pollution reducers. The present study suggests that *C. fistula* has the strongest resilience to air pollution compared to other species since it has the highest APTI at all polluted sites. Thus, the tolerant species included *D. sisso*, *M. indica*, *S. cumini*, *Azadirachta indica*, *H. rosa-sinensis*, *C. fistula*, *L. chinensis*, and *Psidium guajava*, whereas the sensitive species included *Morus alba*, *T. arjuna*, *N. oleander*, and *Polyalthia longifolia*.

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