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Sensitivity and Tolerance Index of Selected Plant Species as Bioindicators of Air Pollution Stress in Abakaliki, Ebonyi State, Nigeria

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Abstract: Screening of plants for their sensitivity/tolerance level to air pollutants is important because the sensitive plants can serve as bio-indicators and the tolerant plants as sinks for controlling air pollution in urban and industrial areas. In order to evaluate the susceptibility level of plants to air pollutants, four biochemical parameters namely ascorbic acid, chlorophyll, relative water content and leaf extract pH were determined and computed together in a formulation signifying the air pollution tolerance index (APTI) of plants. APTI values of four economically important plant species growing in the residential and commercial urban area of Abakaliki, Nigeria were estimated. The order of tolerance was as follows: *Anacardium occidentale* (11.27) < *Magnifera indica I.* (14.10) < *Psidium guajava* (22.43)<*Terminata catappa I* (30.22). Among the plant species studied, *Terminata catappa I* (% increase in APTI value, 169.10%) is considered as a very tolerant species and *Anacardium occidentale* (% increase in APTI value, 0.99) as most sensitive species to air pollutants. The sensitive *Anacardium occidentale* and tolerant *Terminata catappa I* can be used as a bio-indicator and as a sink for air pollutants, respectively. The technique provides a reliable method for screening sensitive/tolerant plants under field conditions where the air-shed is contaminated by a variety of pollutants.

Key words: Abakaliki · Air Pollution · APTI · Plant Species · Sensitive · Tolerant

INTRODUCTION

Air is a component of the environment which is vital for the maintenance and sustenance of a functional ecosystem. Air pollution is the release of contaminants such as fumes, dust, odour, gas, mist or smoke into the atmosphere in quantities, which is injurious to human, plant or animal life [1]. Emissions of air pollutants result from almost all economic and societal activities and by natural disaster (e.g. particulate matter or gaseous emissions by volcanic activities or forest fires, dust by desert winds, pollen scattering, sea aerosol, etc.). Increase in urbanization and industrialization has resulted in concomitant increase in air pollution in many regions [2, 3]. The composition of pollutants is highly variable with differences observed between rural areas and cities, between individual cities and even between regions within cities. The energy production and the general industrial activities, all types of transport and agriculture are key emission sources of air pollutants. The three basic components of air pollution include; source of pollutants, the transporting medium which is air and the target or receptor which could be man, animal, plant and structural facility.

Air pollution from human activities is attracting global concern due to its role in climate change and invariably, man's health [4]. Road traffic emissions have emerged as the major cause of poor air quality. It has been reported that 60 % of air pollution in city is caused by automobiles alone [5]. The effect of these pollutants (Carbon(iv)oxide (CO_2), carbon(ii)oxide (CO), sulphur oxides (SO_X), nitrogen oxides (NO_X) and particulate matter) is observed at a severe level on sensitive species of plants, animals and human beings. Plants are directly affected by these pollutants through the leaves or indirectly through soil acidification [6]. When most plants are exposed to air pollutants, they experience physiological changes before showing signs of visible damage to leaves [7].

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Leaves of roadside plants act as a sink for air pollutants and through their deposition, these plants show specific morphological, physiological and biochemical responses. Deposition of particulate matter pollutants on a leaf surface starts the process of structural and functional changes [8]. The effects of pollutants in plant's system occur at various scales beginning at the biochemical level and progressing to the landscape level [8]. Urban roadside plants demonstrate a wide range of responses when exposed to pollutants in the form of respiration, enzymatic reactions, photosynthesis, stomatal behaviour, membrane disruption, senescence and ultimately death [8-10]. The injury on plant leaves along with the significant changes in plant anatomy, physiology and biochemistry indicates polluted urban environment [8]. Air pollution tolerance index (APTI) is used by landscapers to select plant species tolerant to air pollution. It measures the level of tolerance of each plant studied at a particular location. This index identifies whether a plant is sensitive or tolerant to pollution using biochemical parameters such as relative water content, chlorophyll content, ascorbic acid content and pH of plant leave extract. According to Palit *et al.* [11] the APTI scale value of 0-1, 1-16, 17-29 and 30-300 indicates most sensitive, sensitive, intermediate and tolerant, respectively. These indices keep everyone aware of our surrounding environment to protect our nature which adds beauty to our health, especially breathe [12]. It also provides ideas on types of plant species to be used in the control of air pollution in residential, commercial or industrial areas.

The impacts of air pollutants on the morphological, biochemical and physiological features of some urban roadside plants have been recorded by several researchers in Nigeria and other countries [13, 14]. However, no systematic study has been carried out at Abakaliki metropolis, Southeast, Nigeria using some the present selected plant species to serve as bioindicator on the impacts of air pollution on urban roadside plants with the aim of identifying sensitive and tolerant species using their air pollution tolerance index. This study determined and compared the APTI values of some selected plant species growing in both residential and commercial areas.

MATERIALS AND METHODS

Study Location: This study was carried out at Abakaliki in May, 2018. It was wet season in this area. Abakaliki is the capital and largest city in Ebonyi State, Southeast, Nigeria. It has the geographical coordinates of 6°20'N and 8°06'E (Fig. 1) with a population of 141, 438 according to 2006 census. The prevailing climate conditions are high precipitation that exceeds evapo -transpiration rates, high temperatures and humidity for more than half the year. Vegetation types are mangrove and freshwater swamp communities, rainforest, forest/savanna mosaic and derived savanna zone.

Sources of Experimental Materials: Four (4) fresh plant leaves samples as shown in Fig. 2 were collected from residential and commercial locations in Abakialiki (Table 1) and put in polythene bags, labelled and taken to the laboratory for determination of biochemical parameters and air pollution tolerance index.

Determination of Biochemical Parameters: Four biochemical parameters of the plant leaves samples were determined. The parameters included; relative water content, total chlorophyll, pH and ascorbic acid content.

Determination of Relative Water Content: Relative water content was determined by the method of Singh [15]. The fresh weights of the leaves were determined using a weighing scale. The leaves were then immersed overnight in water, blotted dry and then weighed to get the turgid weight. The leaves were then dried overnight in an oven at 70°C and reweighed to obtain the dry weight.

$$RWC = (FW - DW) / (TW - DW) \times 100$$

where,

RWC = Relative Water Content in %, FW = Fresh Weight (g), TW = Turgid Weight (g), DW = Dry Weight (g)

Determination of Total Chlorophyll: The total chlorophyll was estimated principally by the method of Arnon [16]. One-gram fresh leaf was macerated with 80% (v/v) chilled acetone and a pinch of magnesium carbonate in a pre-chilled pestle and mortar. The extract was centrifuged at 2500 rpm for 10 minutes. The process was repeated till the extract becomes colourless and the extracts were pooled and the volume was made up to 15mL. All operations were carried out in the ice bath under dark condition. The absorbance was measured at 645, 663 and 750nm using UV-visible spectrophotometer.

$$Tch = 20.2(A_{645}) + 8.02(A_{663}) \times V / (1000 \times W)$$

Table 1: Plant species and their sites of collection in Abakaliki

Plant species	Residential site	Commercial site
Guava (*Psidium guajava*)	Afikpo Street	Ochudo Park
Cashew (*Anacardium occidentale*)	Nkaliki	Afikpo road
Mango (*Magnifera indica I.*)	Nkaliki	Ogoja Road
Almond (*Terminata catappa I.*)	Ogbe Hausa	Spera en deo junction

Table 2: Relative Water Content (%) of plant species

Plant Species	Residential Site	Commercial Site	% (D)
Guava (*Psidium guajava*)	73.70±0.46	54.11±0.20	26.58
Mango (*Magnifera indica I.*)	85.73±0.57	51.70±0.36	39.69
Cashew (*Anacardium occidentale*)	81.13±0.41	52.64±0.60	35.12
Fruit (*Terminata catappa I.*)	88.33±0.38	75.69±0.36	14.31

Table 3: Total Chlorophyll content (mg/g) of plant species

Plant Species	Residential Site	Commercial Site	(%D)
Guava (*Psidium guajava*)	0.91±0.01	0.76±0.01	16.48
Mango (*Magnifera indica I.*)	0.54±0.00	0.74±0.01	-37.04
Cashew (*Anacardium occidentale*)	0.46±0, 00	0.93±0.00	-102.17
Ruit (*Terminata catappa I.*)	0.22±0.00	0.73±0.00	-231.82

Table 4: pH of leaf extract of plant species

Plant Species	Residential Site	Commercial Site	(% D)
Guava (*Psidium guajava*)	5.52±0.01	5.67±0.01	-2.72
Mango (*Magnifera indica I.*)	5.43±0.01	5.55±0.01	-2.21
Cashew (*Anacardium occidentale*)	4.91±0.01	4.81±0.01	2.04
Fruit (*Terminata catappa I.*)	4.11±0.00	4.84±0.01	-17.76

(% D) = percentage decrease

Table 5: Ascorbic Acid Content (mg/g) of plant species

Species	Residential Site	Commercial Site	(%D)
Guava (*Psidium guajava*)	0.44±0.04	2.86±0.09	-242
Mango (*Magnifera indica I.*)	0.03±0.01	1.48±0.01	-145
Cashew (*Anacardium occidentale*)	0.53±0.01	1.06±0.05	-53
Fruit (*Terminata catappa I.*)	0.53±0.01	4.54±0.02	-401

Table 6: Air pollution tolerance index (APTI) of plant species.

Plant Species	Residential Site	Commercial Site	% Increase in APTI
Guava (*Psidium guajava*)	7.7	22.43	191.30
Mango (*Magnifera indica I.*)	9.27	14.10	52.10
Cashew (*Anacardium occidentale*)	11.16	11.27	0.99
Fruit (*Terminata catappa I.*)	11.23	30.22	169.10

where,
Tch = Total chlorophyll in mg/g, A_{645} = Absorbance at 645nm minus the absorbance at 750nm, A_{663}=Absorbance at 663nm minus the absorbance at 750nm, V = Total volume of the extract in mL, W = Weight of the sample in g.

Determination of pH of the Leaf Samples: Five grams of the washed leaves were homogenized in 50 ml de-ionized water solution and passed through a fine filter paper. The pH value of leaf was measured using METTLER TOLEDO Seven Compact pH/Ion meter and Inlab Expert Pro-ISM pH electrode which was dipped in the homogenized solution of the leaf filtrate. The pH electrode was calibrated with buffer solutions of pH of 4, 7 and 10.

Determination of Ascorbic Acid Content: Ascorbic acid content was measured using the spectrophotometric method of Liuand Ding [17]. About 1g of fresh leaf sample was weighed and homogenized with distilled water. To 25 mL of diluted sample, 2.5 mL of 5 % metaphosphoric acid was added and 2 drops of bromine water was added to oxidize ascorbic acid in dihydro form. The solution was centrifuged for 5 minutes and supernatant was collected for estimation of ascorbic acid after incubation at 37°C for 3 h, followed by the addition of concentrated sulphuric acid using spectrophotometer with absorbance at 540 nm was noted.

Determination of Air Pollution Tolerance Index (APTI): The above determined four parameters were used to calculate the air pollution tolerance index (APTI) for each of the plant species. The air pollution tolerance indices were determined following the method of Singh and Rao [18].

$$APTI = AA(TCh+pH) + RWC/10$$

where,

APTI = Air pollution tolerance index, AA = ascorbic acid content in mg/g, TCh = total chlorophyll in mg/g, pH = pH of leaf extract, RWC = relative water content in %

Statistical Analysis: Statistical evaluation of the data obtained in triplicates was done using the IBM-SPSS Statistics software version 23. Descriptive statistics of the obtained biochemical data of the selected plant species were presented in tables as mean and standard deviation (Table 2-6). One Way Analysis of Variance (One-Way ANOVA) was conducted on the data to check whether statistically significant differences exist in the variations observed in the values of plant parameters obtained in residential and commercial areas

RESULTS AND DISCUSSION

APTI gave a practical value for the tolerance level of plants to air pollution. The plants which are continually left out in the open under the atmosphere take in copious amounts of pollutants impacting on their leaf surfaces. In the present investigation the biochemical parameters of plant species growing in the residential and commercial areas were determined and their APTI calculated.

The percentage increment in relative water content, total chlorophyll, pH, ascorbic acid and APTI for the four plant species at both residential and commercial site are shown in Fig. 2-6. The plant species from the commercial sites in Abakaliki metropolis gave significantly ($P<0.05$) higher total chlorophyll content, pH, ascorbic acid and APTI values compared to those obtained from the residential sites.

All plant species samples obtained from commercial sites had significantly lower relative water content (RWC) than their counterparts obtained from residential sites. As shown in Fig. 2, *Terminata catappa I* had the highest RWC of 88.33 and 75.69% for residential and commercial site, respectively while *Psidium guajava* had the least RWC of 73.7% for residential. *Anarcardium occidentale* obtained from commercial site showed the least RWC of 51.7%. For the APTI study, the water available in a leaf relative to its bursting turgidity is called its relative water content. It is a suitable gauge of plant's water status. High water content within plant body helps to maintain its physiological balance under stress conditions which include contact with air pollutants [1]. If this contact with air pollutants occurs when the transpiration rates are high, desiccation may occur. Consequently, maintenance of the desirable water status by the plant affects the relative tolerance of plant species towards air pollution [19]. The high relative water content of *T. catappa I* and *P. guajava* under commercial air pollution stress condition is an indication of their tolerance and sink for air pollution. In the assessment of APTI values of some selected species of plants in two locations, Marimuthu *et al*. [20] reported that RWC was in the range of 19.61 to 87.49% with highest percentage observed in *Ficuscarica*. This is in consonant with the present study, where *T. catappa I* showed RWC of 88.33% which is comparatively higher.

The plant species with the highest chlorophyll content was *Magnifera indica* (0.93 mg/g) followed by *Psidium guajava* (0.76 mg/g) obtained from commercial and residential sites, respectively while *Terminata Catappa I* obtained from the residential sites had the lowest significant chlorophyll content as shown in Fig. 3. The photosynthetic capacity of plant species along with its growth and development is reflected in its chlorophyll content. Achakzai *et al*. [21] reported that the degradation of photosynthetic pigments was widely used as an indicator of pollution stress, hence, chlorophyll content varies with tolerance as well as the plant species' sensitivity. This means that the higher the sensitivity of plant species to pollution stress, the lower the chlorophyll content [10]. The plant species in this study showed higher sensitivity to air pollution in the residential compared to the commercial areas apart from *Psidium guajava*. There was an observed reduction in the chlorophyll content of the plant species particularly in the residential areas. This trend was however different for *Psidium guajava*. This reduction in chlorophyll content could lead to a decrease in photosynthetic capacity which may have been initiated by air pollution impact [22]. Furthermore, this decrease observed in the chlorophyll content could be caused by enzyme inhibition, Mg and Zn and dust deposition on leaves [23].

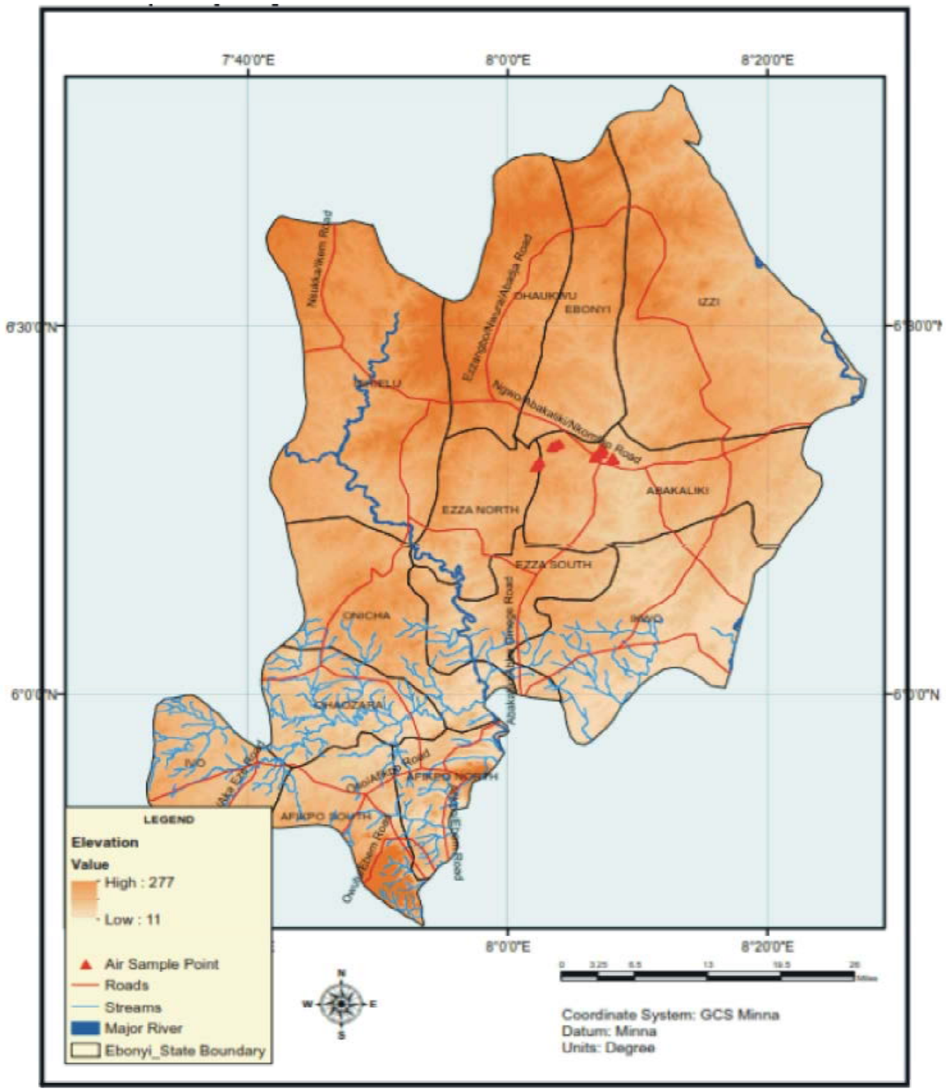

Fig. 1: Map of Ebonyi State, Nigeria, showing sites of collection in Abakaliki

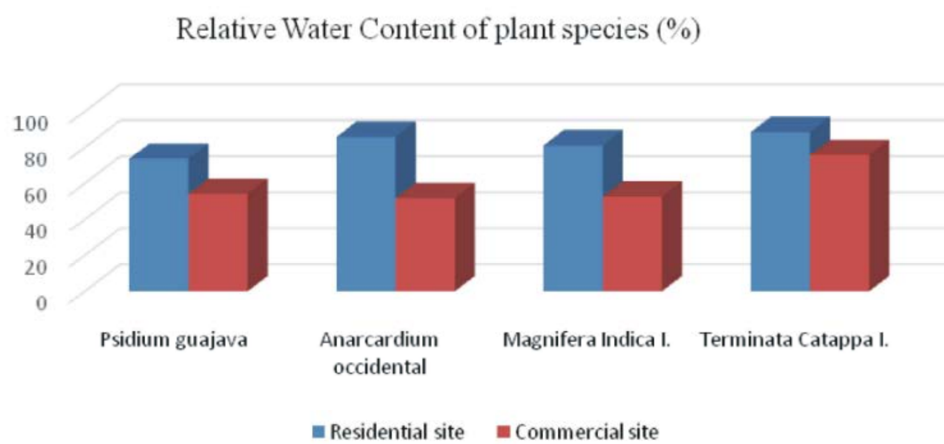

Fig. 2: Relative water content of the plant species in residential and commercial sites

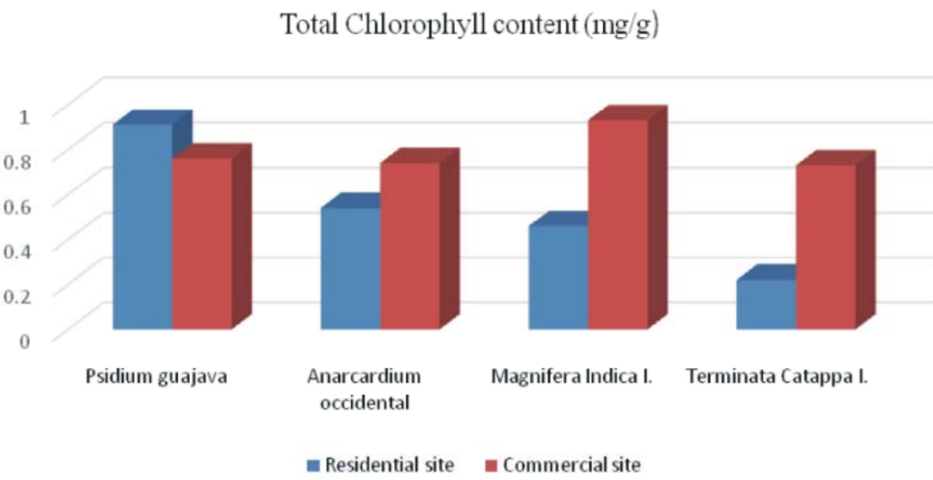

Fig. 3: Total Chlorophyll content of the plant species in residential and commercial sites

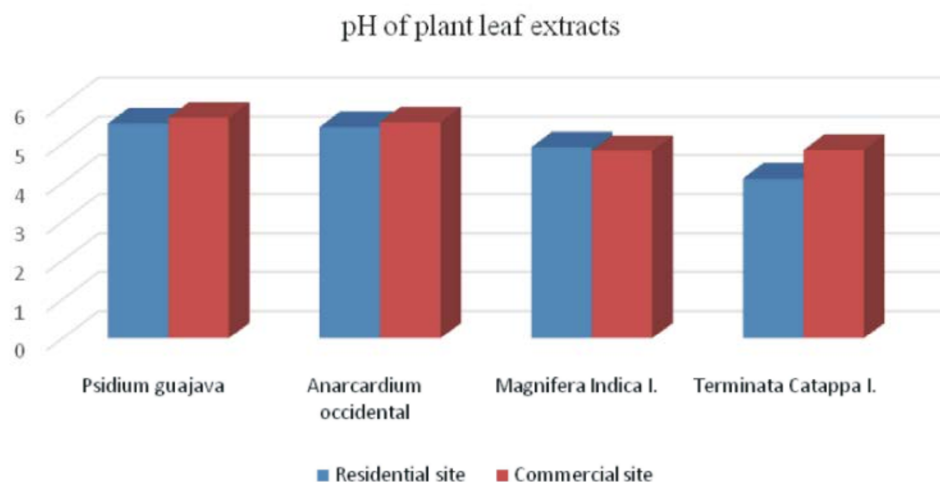

Fig. 4: pH of plant species leaf extracts in residential and commercial sites

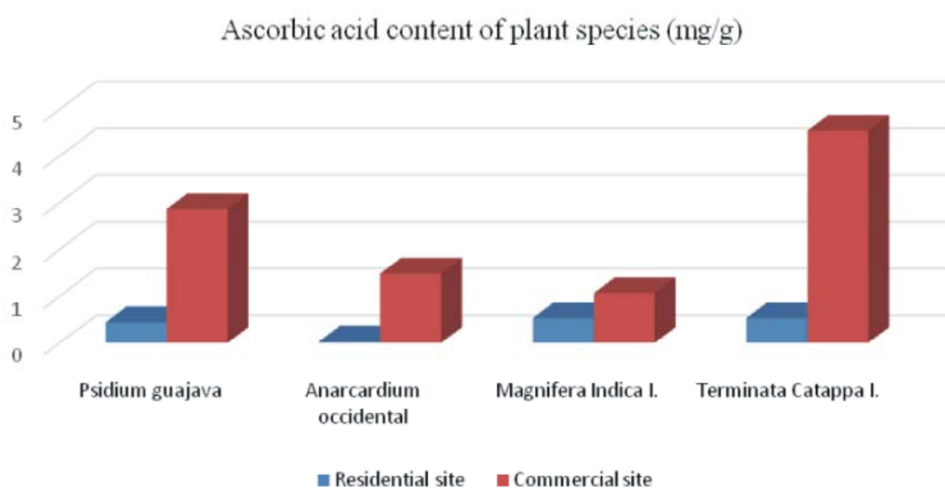

Fig. 5: Ascorbic acid content of plant species in residential and commercial site

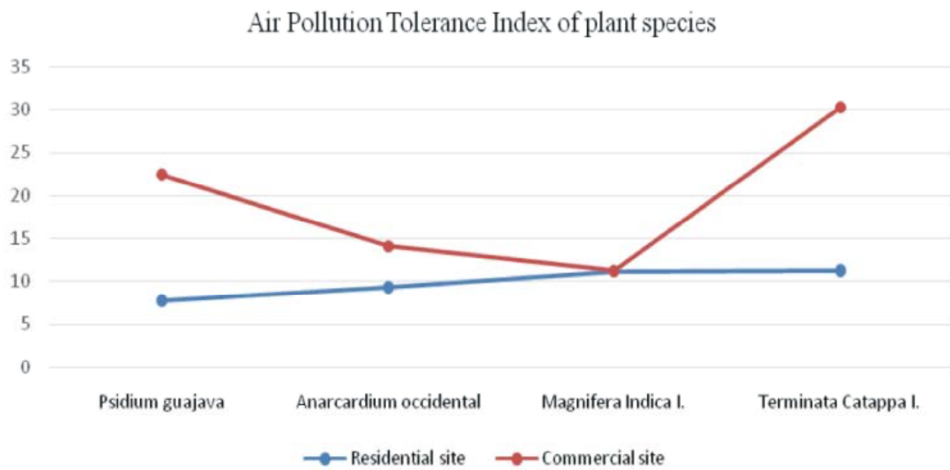

Fig. 6: Air pollution tolerance index of plant species in residential and commercial sites

According to Jyothi and Jaya [24] high levels of automobile pollution decreases chlorophyll content in higher plants near roadsides. In this study, *M. indica I.* obtained from the commercial site had the highest chlorophyll content indicating its ability to withstand air pollution. Assessment of APTI of seven (7) selected plant species in polluted areas by Lohe *et al.* [25] showed that *M. indica I.* had the highest chlorophyll content among others.

For pH, Fig. 4 showed that only *Magnifera indica* from the commercial site was comparatively more acidic (4.81) than its counterpart from the residential sites. However, *Psidium guajava, Anarcardium occidental* and *Terminata catappa I* from the commercial sites were less acidic than those from the residential sites. The pH of plant leaf extract shows its acidic and alkaline nature as a response to a sensitivity of air pollution [18]. Plant species with pH values as high as 7 are more tolerant to air pollutants while plants with low pH values are more susceptible to pollutant attack [26, 27]. In this present study, higher pH was observed from *P. guajava* (5.52 and 5.67) and *A. occidentale* (5.43 and 5.55) in both residential and commercial sites, respectively. The pH range exhibited by the plant species in this study are similar to the results obtained by Agrawal *et al*. [28].

The leaf extract of all the plant species obtained from the commercial sites gave significantly higher quantities of ascorbic acid compared to their counterparts obtained from the residential as observed in Fig. 5. The highest ascorbic acid content of 4.54 and 2.86 mg/g was obtained from *Terminata catappa I* and *Psidium guajava*, respectively in commercial site while the least (0.03 mg/g) was observed from *Anarcardium occidental* in residential site. Ascorbic acid as strong reductant activates many physiological and defense mechanisms in plant species. The reducing power of ascorbic acid is directly proportional to its concentration [29]. Its reducing activity is however pH dependent, being more at higher pH levels because high pH has the tendency of increasing the efficacy of transformation of hexose sugar to ascorbic acid which is related to the plant's tolerance to pollution [17]. High ascorbic acid content was observed from *T. catappa I* and *Psidium guajava* in commercial areas, indicating their tolerance to air pollution.

The results of the APTI (Fig. 6) determined for the four plants obtained from the residential and commercial sites showed that *Terminata catappa I* gave significantly ($P<0.05$) highest APTI value of 30.22, followed by *Psidium guajava* (22.43) in the commercial sites. In the residential area, *Psidium guajava* had the lowest significant ($P<0.05$) APTI value of 7.7. The APTI values of the plants in the commercial areas are higher than the values obtained in the residential area. This could be attributed to higher exposure to air pollutants in the commercial area.

CONCLUSIONS

Urbanization comes with attendant increase in sources of air pollution. This includes industries and road traffic pollution from automobiles. The determination of the APTI of plant species would help in revamping the ecosystem of the urban areas. This study has shown the impact of air pollution in the changes observed in the plant biochemical parameters as determined. The differentiation between tolerant and sensitive plant species have been made with respect to their APTI values. Based on the study (Fig. 6), *T. catappa*, *P.*

guajava, *M. indica* and *A. occidentale* obtained from commercial site can be grouped as tolerant, intermediate, sensitive and very sensitive, respectively. Planting of *T. catappa* and *P. guajava* along roadsides in industrial or commercial areas could help in the control/reduction of air pollution from automobiles and other ill-defined sources of air pollution.

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