Assessment of Air Pollution Tolerance Index (APTI) and Expected Performance Index (EPI) of Plants along Nsukka, Enugu Road, Nigeria

ABSTRACT

Air pollution is a worldwide ecological problem that threatens human health through harmful emissions as vehicular exhaust emission. There is a need to examine ecological role of plants growing around major roads to identify their susceptibility and resistance towards air pollutants. Air Pollution Tolerance Index (APTI) and Expected Performance Index (EPI) of some plants growing along Nsukka - Enugu road in Enugu State, Nigeria were estimated to explore plants' ability to absorb air pollutants. Twenty-eight plant species comprising herbs, shrubs and tree species were sampled and determination of APTI used combined biochemical parameters measurements. The APTI results showed that herbs are sensitive with APTI range of < 7 to 11.91, shrubs are mostly moderate tolerant with range of 9.38 to ≤ 17.43 while trees species are tolerant that ranged from ≥ 10.58 to ≥ 23.26 at $t \leq 1.51$, $p>0.05$ in the experimental and control sites respectively. Based on APTI grades, *Rauvolfia. vomitoria* (11.91) had highest sensitive index and *Erigeron canadensis* (6.45) had the least, *Persea americana* (16.11) had highest moderate tolerant index and *Ricinus. communis* had the least while *Terminalia. catappa* (23.26) produced the highest tolerant index and *Gmelina arborea* (17.50) had the least in the experimental site. The EPI revealed that plants can be categorized as fit, very fit and unfit for plantation and those under 'excellent to best' performer category can be highly recommended as 'very fit' for plantation to control air pollution. *Dacryodes edulis* (94.74%) was in the 'Best' performer category and the best recommended species for plantation planting to monitor and control air pollutants.

Keywords: Air pollution; Air Pollution Tolerance Index (APTI), Biochemical, Expected Performance Index (EPI), Plant species

INTRODUCTION

Air pollution is a major environmental problem which is as a result of man's activities such as industrialization, wood or fossil fuel combustion or natural processes such as volcanic eruption and forest fire (Odilara *et al.*, 2006). Air pollution is defined as the introduction of biological materials, chemical materials, and particulate matter into the atmosphere either by anthropogenic or natural activities which cause environmental hazards to man, animals, plants and the environment (Chou, 2014; Zahid et al., 2023). The continuous increase in industries and automobile numbers constantly increase the level of air pollution because combustion of fuel in vehicles or industries emits soot particles, carbon monoxide, nitrogen oxide, sulphur oxides, organic molecules and radioactive isotopes (Agbaire and Esiefarienrhe, 2009). Nwadinigwe (2014) also stated that air pollutants can be produced through the use of fossil fuels such as petroleum hydrocarbons or coal for transport and for generation of light in industries and homes.

Some air pollutants have direct and indirect impact in the environment, for example, carbon dioxide, methane, nitrous oxide, hydrofluorocarbon, sulphur, hexafluoride and perfluorocarbon which are greenhouse gases cause global warming which results to climate change (Nwadinigwe, 2014). In plants it disrupts normal physiological system while in animals and man it alters the respiratory mechanisms, morphological characteristics and biochemical characteristics (Govindaraju *et al*., 2011; Hamraz *et al*., 2014). Plants are very important in the ecosystem because they have the ability to monitor and maintain ecological balance (Escobedo *et al.*, 2008). Panigrahi *et al.* (2014) stated that plants have the ability to take in air pollutants in form of particulate or gaseous particles through the leaves. Plants also serve as sink for air pollutants (Vyankatesh and Arjun, 2014). Determination of plants that can absorb air pollutants or act as phytoremediator is achieved through the use of air pollution tolerance index (APTI) (Bala *et al*., 2022).

Air pollution tolerance index is a reliable environmental friendly venture method useful in evaluating the capabilities of plants to withstand the effect of air pollution (Nwaogwugwu*et al*., 2017) and absorb air pollutants. It classifies plants into tolerant and sensitive categories. The sensitive plant species are plants with low APTI and they are utilized as biological indicators while the tolerant plant species are plants with high APTI which serve as sinks for air pollutants (Nwadinigwe, 2014; Sabri *et al*., 2015). APTI is determined by carrying out biochemical analysis of total chlorophyll content, ascorbic acid content, relative water content and pH of the leaf extracts (Sabri *et al*., 2015). Chlorophyll measures productivity of the plants, photosynthetic activity, development and growth. Its level is a direct measure of leaf damage by pollution. Chlorophyll plays an important role in plant metabolism and reduction in chlorophyll content is directly proportional to reduction in plant growth (Joshi and Swami, 2009). When plants are subjected to stress of air pollution, physiological balance is maintained by the relative water content of the tissues (Swami *et al*., 2004). Since air pollution interacts with rain water to form mixtures and solutions with varying pH depending on the type of pollutant, the pH of the plant tissue is also related to the degree of air pollution (Singh and Verma, 2007). Plants are able to detect drought conditions and air pollution by building up reactive oxygen species and respond by reducing the amount of water that escape through leaves. Ascorbic acid protects the plants against oxidative damage emanating from aerobic metabolism, different pollutants and photosynthesis. It helps in cell wall synthesis, defense and cell division (Lima *et al*., 2000).

This study will provide basic information on APTI to reveal levels of tolerance or sensitive ability of plants to air pollution in the study area. Also, the combined assessment of the APTI, socio-economic and biochemical parameters values resulting in Expected Performance Index (EPI) of the plants will provide information on plants that are fit or unfit for plantation in designing pollution tolerant Green Belts along major roads and urban areas. It will also serve as a base on which new researchers will build on. This study will help industry owners and landscapers to identify, select and grow plants that can absorb emitted air pollutants around polluted areas. Hence the objectives of this study are to determine the APTI and EPI of some plants growing along Nsukka-Enugu road. The tolerance and sensitivity of the plants will provide information on their phyto remediating and phyto-indicating abilities, respectively.

MATERIAL AND METHODS

Study Area

Nsukka is a town in Nsukka Local Government Area in Enugu State, Nigeria and covers a land area of approximately 1810 Km^2, with an estimated population of 417,770 million of people residing in the area in 2010 (Ezeh and Ugwu, 2010). It falls within the coordinates of longitude 7° 8' 0''E and 7° 32' 0'' E, and latitude 6° 44' 0''N and 7° 0' 0''N, sitting at an elevation of 434 m above sea level (Plate 1). Nsukka records maximum average temperature of 35°C, 60% humidity and a total rainfall of 1550 mm per annum (Akamigbo and Asadu, 1983). Though, surrounding temperature is largely influenced by harmattan (the cool dry wind that blow through the Sahara region) (Oparaku *et al.*, 2021). The climate is hot-humid type and peaks between March and November (Andong *et al.*, 2023). Rain and dry seasons occur throughout the year with eight months rainy season (April - Nov) and four months dry season (Dec - March) (Asadu *et al.*, 2018; Amujiri *et al*., 2022). The topography is characterized as undulating and the vegetation type is derived savannah. The soils in the area is a mixture of different types, including ferrallitic soils, also known as red earth or acid sands and hydromorphic soils on the floodplains (Anon, 2003), which contribute to dust pollution. The Nsukka-Enugu road is the major road that connects villages within and outside of the Nsukka Local Government Area, thus promotes vehicular movement as well as dust pollution. The climatic elements such as air temperature, relative humidity, rainfall, wind speed and air pressure of Nsukka town from 2022 to 2023 were obtained from Centre for Atmospheric Research, National Space Research and Development Agency (CAR-NASRDA) and Nigerian Meteorological Agency (NiMet). Prior to biological analysis of plants for determination of APTI and EPI, a local survey was carried out for site and plant selection. Selected experimental site was Nsukka-Enugu road from Total Filling Station to Ede-Oballa where there is heavy traffic (Plate 1). The control site was the New Botanical Garden of University of Nigeria, Nsukka campus because of absence of vehicular movement in that area.

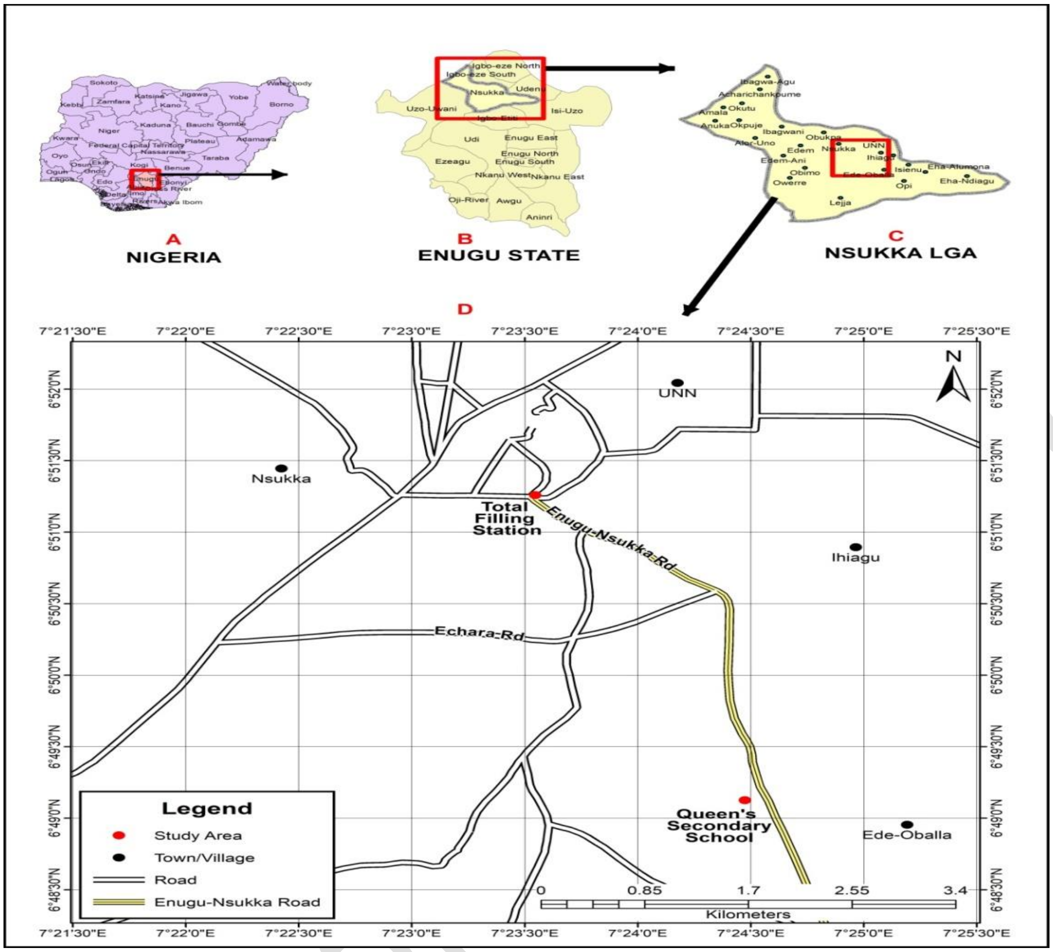

Plate 1: Map showing the study location A: Map of Nigeria, showing South-East States, B: Map of Enugu state showing Nsukka local government area, C: Map of Nsukka local government area showing Nsukka-Enugu road, D: Map of Nsukka-Enugu road showing the study site (Total filling station to Queen of Holy Rosary Secondary School, Ede Oballa) (Source: Department of Soil Science, University of Nigeria Nsukka)

Sample collection

Twenty-eight plants were randomly sampled based on the availability and commonly identified plants growing along Nsukka-Enugu road and control sites. This study used belt transect sampling method because of the obvious environmental gradients at the experimental site. Then, five exposed mature leaves of the plants in close proximity to the roads (10 meters from the road edge) were collected in triplicates from three plants of each species in the morning between 9 am and 11am when dust pollution was at its peak. The biological collections were conducted for four months from January to April in 2022 and 2023 and collected samples were transported to laboratory in a heat proof container for analysis immediately. A total of 45 samples for every species in each site were analyzed. Some samples of the leaves were also preserved using plant press and deposited at the Herbarium of Plant Science and Biotechnology, University of Nigeria, as voucher specimens.

Biochemical analysis

The biochemical properties determined includes: pH of leaf extractis calculated using five grams of ground fresh leaves, filtered after homogenized in 10 ml of distilled water. The pH reading was taken with calibrated Elico-112 pH meter (Shannigrahi *et al*., 2004). Relative water content (RWC) was determined with gravimetric analysis by weighing leaves and calculating with the formula below (Sabri *et al*., 2015).

$$\text{RWC (\%)} = \frac{(\text{FW}) - (\text{DW})}{(\text{TW}) - (\text{DW})} \text{ x } 100$$

Where: FW = fresh weight, DW = dry weight and TW = turgid weight.

Ascorbic Acid was determined by reading the absorbance of the extracted and homogenized fresh leaves with UV digital spectrophotometer (S-22BOECO Germany) at 760 mm as explained by (Ogbonna *et al.* 2014). Total Chlorophyll (TCC) was determined with the help of (Gogoi and Basumatary, 2018) method by reading the absorbance of the extracted supernatant at 645 nm and 663 nm using UV digital spectrophotometer and was calculated with below formula

$$\text{Total chlorophyll (mg/g)} = \frac{20.2(\text{A } 645) + 8.02(\text{A } 663) \text{ x V}}{1000 \text{ x W}}$$

Where A = absorbance at 645 nm and 663 nm, V = final volume of chlorophyll extract in 80% acetone, W = fresh weight of tissue extracted.

Air pollution tolerance index (APTI) was determined according to Rai *et al*. (2013) with the formula:

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

Where A = ascorbic acid (mg/g), T = total chlorophyll (mg/g),
P = pH of the leaf extract, R = relative water content (%).

Moreover, APTI values of plants were conveniently classified by using the following gradation criteria: 1–11 as sensitive (S), 12–16 as moderately tolerant (MT) and ≥ 17 as APTI tolerant (T) plants.

Plant socio-economic characters and morphological parameters like habit, crown structure, and type of plant, laminar structure and economic value were noted qualitatively. Then, the Expected Performance Index (EPI) of each plant was determined by combining the APTI values of the plant species along with its socio-economic values and biological parameters according to grading description of Sahu *et al.*, (2020) calculated with below formula:

$$Expected\ Performance\ Index(EPI) = \frac{No. of\ (+)\ obtained}{Total\ no. of\ (+)} \times 100$$

The "Plus" signs were used to indicate the features which are helpful against air pollution, to assess the EPI of selected plants. Assessments category of plants on the basis of their Expected Performance Index (EPI) scores were graded as from "Not Recommended to Best" to select best in designing pollution tolerance Green Belt and Urban Forest.

Statistical Analysis:

The data collected were subjected to analysis of variance (ANOVA) to test the variability in the meteorological features of the environment across the different month of evaluation and T-test was used to test the variation in the parameters across the two study locatios (experimental and control sites) using IBM SPSS version 27.

RESULTS

Several plants were encountered in the study sites and the photograph of the preserved herbarium samples presented on Fig 1. Evaluation of the physiological features of the twenty-eight sampled plants showed that the plants consisted of herbs, shrubs and trees species which belong to nineteen families (Table 1). Among the Families, Asteraceae was the highest in number and was followed by Euphorbiaceae (which were all shrubs). The herbs had seven plants belonging to five families with highest being the Asteraceae. Shrubs were eight plants in six families and Euphorbiaceae was the highest, whereas the treespecies had thirteen plants found in eleven families with Anacardiaceae and Fabaceae being the highest.

***Amaranthus hybridus* L.**

***Ageratum conyzoides*L.**

***Emilia sonchifolia*(L) DC. Ex Wight.**

***Erigeron canadensis* L.**

***Sida acuta* Burm F.**

***Rauvolfia vomitoria* Afzel.**

***Chromolaena odorata* L.**

***Vernonia amygdalina* Delile.**

***Newbouldia laevis* P. Beauv. Seem**

***Carica papaya* L.**

***Alchornea cordifolia* Mull. Arg.**

***Ricinus communis* L.**

***Urena lobata* L.**

***Psidium guajava* L.**

***Anacardium occidentale* L.**

Mangifera indica L.

Polyalthia longifolia (Sonn). Thwaites

Plumeria obtuse L.

Dracaena arborea. Vand. Ex L.

Dacryodes edulis H.J. Lam.

 ***Terminalia catappa*L.**	 ***Baphia nitida* Lodd.**	 ***Pentaclethra macrophylla* Benth.**	 *Gmelina arborea* Roxb
 ***Persea americana* Mill.**			

Figure 1: Photographs of some plant press leaf samples.

Table 1: The physiological features of the sampled plants

S/N	Species Scientific name	Common name	Family
1.	*Amaranthus hybridus* L	Smooth pigweed.	Amaranthaceae
2.	*Ageratum conyzoides*L.	Goat weed	Asteraceae
3.	*Emilia sonchifolia*(L) DC. Ex Wight.	cupid's shaving brush	Asteraceae
4.	*Erigeron Canadensis* L.	Horse weed	Asteraceae
5.	*Sida acuta* Burn F.	Wire weed	Malvaceae
6.	*Panicum maximum* Jacq.	Guinea grass	Poaceae
7.	*Rauvolfia vomitoria* Afzel.	Devil pepper	Apocynaceae
8.	*Chromolaena odorata* L.	Siam weed or Bitter	Asteraceae
9.	*Vernonia amygdalina* Delile	Bitter leaf	Asteraceae
10.	*Newbouldia laevis* P. Beauv. Seem	Tree of life or fertility tree	Bignoniaceae
11.	*Alchornea cordifolia* Mull. Arg.	Christmas bush	Euphorbiaceae
12.	*Ricinus communis* L.	Castor oil plant	Euphorbiaceae
13.	*Urena lobate* L.	Caesarweed	Malvaceae
14.	*Psidium guajava* L.	Guava	Myrtaceae
15.	*Lantana camara* L.	Tickberry plant	Verbenaceae
16.	*Anacardium occidentale* L.	Cashew tree	Anacardiaceae
17.	*Mangifera indica* L.	Mango	Anacardiaceae
18.	*Polyalthia longifolia* (Sonn) Thwaites	Asoka tree or mast tree	Annonaceae
19.	*Plumeria obtuse* L.	Plumeria or Khmer	Apocynaceae
20.	*Dracaena arborea* Vand. Ex L.	Dracaena	Asparagaceae
21.	*Dacryodes edulis* H.J. Lam.	Native pear, African plum	Burseraceae
22.	*Terminalia catappa*L.	Tropical almond or fruit	Combretaceae
23.	*Baphia nitida* Lodd.	Barwood or Camwood	Fabaceae
24.	*Pentaclethra macrophylla* Benth.	Oil bean tree	Fabaceae
25.	*Gmelina arborea* Roxb.	Gmelina	Lamiaceae
26.	*Persea Americana* Mill.	Avocado	Lauraceae
27.	*Pycnanthus angolensis* (Welw) Warb.	African nutmeg	Myristicaceae
28.	*Carica papaya* L.	Pawpaw	Carcicaeae

Climatic parameters data of the study area

The average climatic data of Nsukka during 2022–2023 was evident that air temperature was 29.28±0.3°C, the relative humidity was 54.07±1.9%, windspeed was 3.15 ± 0.5 m/s, air pressure was 92.9 ± 02 kpa, while average amount of rainfall was 1.96 ± 1.0 mm respectively in Nsukka. Results observed significant monthly variations ($p<0.05$) in climatic parameters except air pressure (Table 2).

Table 2: Average Climatic data of Nsukka town in Nigeria during 2022 – 23.

Months	Air Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Wind Speed (m/s)	Air Pressure (kpa)
Jan	27.9 ± 0.3^{c}	34.15 ± 1.9^{c}	0.0 ± 0.0^{c}	3.4 ± 0.6^{a}	93.8 ± 0.2^{ns}
Feb	29.3 ± 0.3^{b}	55.0 ± 2.9^{b}	0.3 ± 0.2^{c}	3.2 ± 0.6^{a}	93.05 ± 0.2^{ns}
Mar	30.6 ± 0.2^{a}	58.75 ± 1.8^{a}	3.3 ± 1.9^{b}	2.9 ± 0.5^{b}	92.15 ± 0.2^{ns}
April	29.4 ± 0.4^{b}	68.35 ± 1.0^{a}	4.3 ± 2.1^{a}	3.1 ± 0.5^{a}	92.8 ± 0.2^{ns}

APTI of the studied plants

Results obtained across biochemical parameters (ascorbic acid (AA), leaf extract pH, total chlorophyll content (TCC) and relative water content, RWC) and Air Pollution Tolerance Index (APTI)) in experimental site plants compared to their control counterparts showed variation in plant properties (Table 3). The results showed that the leaf extract pH and TCC values were more acidic in experimental plants than in the control sites. The mean TCC concentrations were higher in experimental plants, with the highest concentration in *E. sonchifolia*. The RWC and AA values were also higher in experimental plants, with the highest in *R. cummunis* and the lowest in *A. cordifolia*. Ascorbic acid levels were highest in *P. guajava* and lowest in *U. lobata*. The APTI of shrubs in the experimental sites showed a decreasing order, with *A. cordifolia >N. laevia>U. lobata >R. communis >L.* camara > *C. odorata >V. amygdalina >P. guajava*. The study found that experimental trees produced mostly non-significant pH compared to the controls, with the highest pH in *C. papaya* and lowest in *P. angolensis*. TCC was highest in *T. catappa*, followed by *P. obtuse* and *P. angolensis*. RWC and AA were highest in *T. catappa* and *P. angolensis*, respectively. The APTI of tree species ranged from 10.76 in *P. angolensis* to 23.26 in *T. catappa*, with a decreasing order. All herb plants were sensitive to air pollution, while shrubs were mostly moderately tolerant and tree species showed a tolerant index. The control site had the highest sensitive, moderately tolerant, and tolerant plants.

Table 3: Variation in biochemical properties and APTI

Plant name	Sites	AA mg/g)	pH	TCC mg/g	RWC %	APTI	Grade
				Plants with Herb habits			

A. hybridus	Experimental	3.32±0.01	5.53±0.18	1.62±0.02	64.51±0.01*	8.82±0.02	S
	Control	3.12±0.02	4.23±0.15	1.55±0.02	59.68±0.02	7.71±0.03	S
A. conyzoides	Experimental	0.97±0.01	4.83±0.12	1.98±0.01	60.23±0.06	6.68±0.02	S
	Control	0.80±0.02	4.70±0.17	1.69±0.02	59.74±0.02	6.49±0.04	S
E. sonchifolia	Experimental	0.98±0.02	5.57±0.15	0.64±0.02	64.86±0.01	7.09±0.02	S
	Control	1.16±0.01	6.43±0.20	1.74±0.01	62.95±0.01	7.24±0.02	S
E.canadensis	Experimental	0.92±0.01	4.37±0.26	1.32±0.02	59.22±0.0	6.45±0.03	S
	Control	0.84±0.69	5.47±0.15	1.27±0.01	61.00±0.01	6.67±0.02	S
S.acuta	Experimental	2.27±0.01	6.50±0.17	1.32±0.02	73.16±0.02	9.09±0.03	S
	Control	2.15±0.01	6.30±0.17	1.25±0.01	72.44±0.02	8.87±0.02	S
P. maximum	Experimental	0.95±0.02	6.47±0.21	2.06±0.01*	61.50±0.01	6.96±0.05	S
	Control	0.69±0.02	6.40±0.15	1.76±0.02	60.17±0.01	6.58±0.04	S
R. vomitoria	Experimental	5.27±0.02	5.47±0.15	2.77±0.01*	75.69±5.36*	11.91±0.53*	S
	Control	4.18±0.01	5.30±0.17	1.92±0.01	70.76±0.02	10.09±0.02	S
				Plants with shrub habits			
C. odorata	Experimental	6.27±1.19	6.43±0.09	2.47±0.03	75.42±0.02*	13.12±0.02	MT
	Control	5.90±1.15	5.75±0.12	2.36±0.02	72.85±0.08	12.07±0.06	MT
V. amygdalina	Experimental	8.58±0.01	5.57±0.20	2.26±0.02	78.09±0.02*	14.53±0.02*	MT
	Control	7.34±0.02	5.51±0.26	2.24±0.02	74.48±0.01	13.14±0.03	MT
N. laevis	Experimental	5.69±0.02	5.47±0.12	1.85±0.02	71.51±0.86	11.32±0.01	S
	Control	4.95±0.01	5.40±0.17	1.83±0.02	69.95±0.03	10.57±0.03	S
A. cordifolia	Experimental	6.25±1.18	5.57±0.12	2.46±0.02	54.95±0.02*	10.51±0.36	S
	Control	6.10±1.29	4.47±0.18	2.44±0.02	51.69±0.01	9.38±0. 12	S
R. communis	Experimental	6.11±1.04	4.60±0.17	1.83±0.02	83.22±0.02*	12.27±0.03*	MT
	Control	5.21±1.15	4.50±0.17	1.75±0.02	75.01±0.02	10.76±0.02	S
U. lobata	Experimental	5.38±0.33	5.40±0.17	2.25±0.13	76.95±0.02*	11.81±0.21*	S
	Control	5.23±0.03	4.47±0.26	2.15±0.02	68.40±0.02	10.30±0.06	S
P. guajava	Experimental	9.85±0.02	5.67±0.15	3.95±0.02	79.53±0.02*	17.43±1.86*	T
	Control	8.05±0.03	5.30±0.12	2.84±0.02	75.55±0.02	14.11±0.03	MT
L. camara	Experimental	6.14±0.02	5.37±0.18	2.53±0.02	80.43±0.01*	12.89±0.01	MT
	Control	6.24±0.03	6.77±0.09	3.66±0.02	85.23±0.01	15.03±0.02*	MT
				Plants with tree habits			
A. occidentale	Experimental	10.89±0.02	6.63±0.12	3.20±0.01	86.10±0.01*	19.31±0.03*	T
	Control	10.35±0.02	6.52±0.23	2.88±0.01	78.93±0.02	17.62±0.02	T
M.indica	Experimental	11.28±0.01	5.73±0.49	3.28±0.02	89.67±0.01*	19.09±0.07*	T
	Control	10.24±0.02	5.68±0.38	3.50±0.02	81.68±0.01	17.57±0.06	T
P. longifolia	Experimental	13.24±0.02*	6.60±0.12	2.83±0.02	81.30±0.01	20.62±0.03*	T
	Control	11.03±0.01	5.50±0.21	2.18±0.02	86.22±0.02*	17.09±0.02	T
P. obtuse	Experimental	11.34±0.01	6.47±0.15	3.50±0.01	80.64±0.03	19.37±0.03*	T
	Control	9.37±0.01	5.43±0.12	2.52±0.02	84.35±0.02*	15.89±0.01	MT
D.arborea	Experimental	9.97±0.01	5.47±0.12	2.16±0.02	75.65±0.01	15.07±0.02	MT
	Control	8.95±0.02	5.20±0.15	2.04±0.02	74.31±0.02	13.91±0.01	MT
D.edulis	Experimental	12.35±0.01	5.43±0.15	2.96±0.01	77.69±0.02*	18.13±0.03*	T
	Control	11.25±0.02	5.77±0.23	2.83±0.01	69.40±0.02	16.61±0.03	MT
T. catappa	Experimental	14.24±0.02	6.37±0.09	3.66±0.02	89.76±0.02	23.26±0.01*	T
	Control	13.45±0.02	6.90±0.12	3.59±0.03	88.42±0.02	21.61±0.06	T

B. nitida	Experimental	8.22±0.18	5.80±0.17	2.57±0.02	69.64±0.02*	13.84±0.02	MT
	Control	7.96±0.03	5.77±0.20	2.37±0.01	65.09±0.02	12.99±0.02	MT
P. macrophylla	Experimental	9.90±0.01	6.78±0.12	3.25±0.02	82.79±0.02*	18.20±0.27*	T
	Control	8.19±0.02	6.60±0.17	2.54±0.03	79.08±0.02	15.39±0.03	MT
G. arborea	Experimental	10.45±0.01	6.40±0.17	3.32±0.32	73.44±0.02	17.50±0.03	T
	Control	10.09±0.11	6.27±0.20	3.20±0.02	75.06±0.02	17.06±0.03	T
P. americana	Experimental	7.21±0.01	6.17±0.09	2.73±0.02	76.94±0.02	16.11±0.02	MT
	Control	9.88±0.01*	6.70±0.15	3.59±0.03	77.01±0.02	17.87±0.01*	T
P. angolensis	Experimental	4.15±0.01	5.33±0.19	1.94±0.01	77.45±0.02*	10.76±0.02	S
	Control	4.20±0.02	5.30±0.15	2.00±0.32	75.12±0.01	10.58±0.40	S
C. papaya	Experimental	9.76±0.02 *	6.98±0.18	3.24±0.03	77.25±0.05	17.70±0.01*	T
	Control	7.26±0.01	6.57±0.15	1.32±0.03	82.88±0.02*	14.16±0.03	MT

***-significant variation between the experimental and the control site**

Relationship between the climatic conditions, biochemical properties and APTI

It is evident that among the climatic parameters, the air temperature, showed significant negative correlation with wind speed and air pressure, (r = −0.985 and -0.989, p< 0.05 respectively). More so, most of the climatic data (air temperature, relative humidity and rainfall) correlated negatively with AA, leaf extract pH, RWC and APTI but rainfall showed significant negative correlation with ascorbic acid content (r = −0.990, p<0.01) while relative humidity showed significant negative correlation with APTI (r = −0.956, p<0.05). Based on the results, AA correlated negatively with leaf extract pH and showed significant positive correlation with RWC (r = 0.705, p>0.01) and APTI (r = 0.937, p>0.01). The RWC also had significant positive correlation with APTI(r = .897, p>0.01) (Table 4).

Table 4: Correlations of the various climatic and biochemical parameters of the leaves of plants in control and experimental sites of Nsukka town in Nigeria

	Air Temp. (°C)	R. Humidity (%)	Rainfall (mm)	Wind speed (m/s)	Air pressure (kpa)	AA mg/g)	pH	TCC mg/g	RWC %	APTI
Air Temp.	1	0.748	0.664	-0.985*	-0.989*	-0.738	-0.567	0.752	-0.791	-0.851
R. Humidity		1	0.830	-0.757	-0.780	-0.807	-0.704	0.321	-0.922	-.956*
Rainfall			1	-0.763	-0.763	-.990**	-0.196	0.621	-0.578	-0.923
Wind speed				1	.999**	0.833	0.451	-0.822	0.734	0.889
Air pressure					1	0.829	0.490	-0.796	0.764	0.900
AA						1	-0.109	0.501	.705**	.937**
pH							1	0.007	0.399	0.151
TCC								1	0.214	0.475
RWC									1	.897**
APTI										1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Expected Performance Index (EPI)

The Expected Performance Index (EPI) of different plant species in experimental site of Nsukka town during 2022 –2023 are provided in Table 5. It was observed that *D. edulis* with an EPI grade of 18 (94.74%) was in the 'Best' performance category; *A. occidentale*, *P. guajava, M. indica, T. catappa, P. macrophylla, G. arborea* and *P. americana* with 16 (84.21%) were under 'Excellent' performer category while *P. longifolia* 15 (78.95%) and *C. papaya* 14 (73.68%) were in 'Very Good' performer category. Again, *R. communis* 12 (63.16 %), *B. nitida*, *P. obtuse* and *P. angolensis* 13 (68.42 %) were 'Good' performers; *D. arborea* and *V. amygdalin* 11 (57.89) together with *N. laevi* and *A. cordifolia* 10 (52.63 %) were under 'Moderate' performers; *C. odorata* 8 (42.11 %), *L. camara* and *R. vomitoria* 9 (47.37 %) were in 'Poor' performer category while the other plants were under 'Not recommended' EPI grading category. The trend of the EPI scoring of different plant species in the experimental sites on the basis of the assessed performer categories had a decreasing order as follow: *D. edulis*>*A. occidentale, P. guajava, M. indica, T. catappa, P. macrophylla, G. arborea* and *P. americana*>*P. longifolia* and *C. papaya* > *R. communis, P. obtuse, B. nitida* and *P. angolensis*> *D. arborea,V. amygdalina, N. laevi* and *A. cordifolia*> *C. odorata, L. camara, R. vomitoria* and *U. lobate* >*A. hybridus, A. conyzoides, E. sonchifolia, E. canadensis, S. acuta* and *P. maximum*.

Table 5: Expected Performance Index (EPI) of different plant species in experimental site of Nsukka town during 2022 –2023.

Plant species	APTI	PH	CT	CH	Ls	Tx	Hd	EV	Total (+)	% EPI Score	EPI grade
A. hybridus	++	-	-	-	-	+	-	-	3	15.79	NR
A. conyzoides	+	-	-	-	-	+	-	-	2	10.53	NR
E. sonchifolia	++	-	-	-	-	++	-	-	4	21.05	NR
E. canadensis	+	-	-	-	-	++	-	-	3	15.79	NR
S. acuta	+++	-	-	-	-	++	-	-	5	26.32	NR
P. maximum	+	-	-	-	-	+	+	-	3	15.79	NR
R. vomitoria	++++	-	+	-	++	+	+	-	9	47.37	P
C. odorata	+++++	+	-	-	+	+	-	-	8	42.11	P
V. amygdalina	+++++	+	+	+	+	+	-	+	11	57.89	M
N. laevis	++++	+	+	-	++	+	+	-	10	52.63	M
A. cordifolia	+++	+	+	-	++	+	+	+	10	52.63	M
R. communis	++++	+	++	+	+	++	-	+	12	63.16	G
U. lobate	++++	+	+	-	-	+	-	++	9	47.37	P
P. guajava	+++++++	+	+	++	-	++	+	++	16	84.21	E
L. camara	++++	+	+	+	-	+	+	-	9	47.37	P

A. occidentale	+++++++	++	+	++	-	+	+	++	16	84.21	E
M. indica	+++++++	++	+	++	+	+	+	+	16	84.21	E
P. longifolia	+++++++	++	+	-	++	++	+	-	15	78.95	VG
P. obtuse	+++++++	++	+	+	-	+	+	-	13	68.42	G
D. arborea	+++++	++	++	-	-	+	+	-	11	57.89	M
D. edulis	+++++++	++	+	++	++	+	+	+	18	94.74	B
T. catappa	+++++++	++	++	++	-	+	+	+	16	84.21	E
B. nitida	+++++	++	+	+	++	+	+	-	13	68.42	G
P. macrophylla	+++++++	++	+	++	-	+	+	++	16	84.21	E
G. arborea	+++++++	++	+	++	+	+	-	++	16	84.21	E
P. americana	++++++	++	+	++	+	+	+	++	16	84.21	E
P. angolensis	++++++	++	+	++	-	++	+	-	13	68.42	G
C. papaya	+++++++	++	+	+	+	+	-	+	14	73.68	VG

Key: PH = Plant Habit, CT = Crown Type, CH = Crown Habit,Ls = Lamina size, Tx = Texture, Hd = Hardness, E.V = Economic value, B = Best, E = Excellent, VG = Very good, G = Good, M = Moderate, P = Poor, NR = Not Recommended.APTI (< 7: +; 7 – 8.9:++; 9 – 10.9: +++; 11–12.9: ++++; 13 – 14.9: +++++; 15 – 17: ++++++; ≥ 17: +++++++); Habits-Type (Herbs (small): +; Shrubs(medium): ++; Trees (large): +++); Canopy Type (Irregular: -; Spread crown: +; Dense canopy: ++); Crown Habits (Deciduous: -; Semi-deciduous: +; Evergreen: ++); Leaf LaminaSize (Small: -; Medium: +; Large: ++); Texture (Glabrous: +; Pubescent: ++); Hardiness (Soft: -; Hard: +); Economic featuredFrequency Uses (< 3: -; 3 – 4: +; ≥ 4: ++); EPI grading (Up to 30: Not recommended; 31-40: Very Poor; 41-50: Poor; 51-60: Moderate; 61-70: Good; 71-80: Very Good; 81-90: Excellent; 91-100: Best)

DISCUSSION

Plants differ in their response to air pollution because of environmental variation, type of species and physiological factors of the plants. However, combination of biochemical parameters (pH, total chlorophyll, relative water content and ascorbic acid) for determining the ability of plants to absorb or detect air pollution in a polluted area, makes APTI result more reliable. The pH is an important leaf parameter because water forms the basic need of physiological processes in plant. Presence pH increases conversion of hexose sugar to ascorbic acid during pollution stress (Escobedo *et al.* 2008; Satpute and Bhalerao, 2017). Majority of the pH values of the plants from the experimental site were lower which implies more acidic than the pH values of plants at the control site.This aligned with the report of Satpute and Bhalerao, 2017 that the higher the air pollution, the lower the pH. Udeagbala *et al.* (2017) also reported that plants at the experimental site recorded lower pH values than its counterpart in the control site and this could be as a result of acidification of cytoplasm due to exposure of plants to pollutants. Lower pH in leaf extract is caused by the presence of sulphur oxide (SO_4) and nitrogen oxide (NO_2) pollutants whose reactions form sulphates and nitrates which affectsplants adversely when finally converted to Sulphuric and Nitric acid (Bharti *et al.* 2017; Satpute and Bhalerao, 2017).

Increase in relative water content of plants helps in maintaining physiological balance when exposed to air pollution or any other stress condition (Nwadinigwe, 2014). High relative water content helps plants survive drought effect. Normal biological process is maintained by high relative water content (Meerabai *et al.,* 2012). Tolerance ability of plants towards air pollution is increased by high relative water content which is dependent on protoplasmic permeability (Paulsamy *et al.*, 2000; Satpute and Bhalerao, 2017). Reduction in relative water content may occur as a result of effect of air pollution on transpiration rate in leaves (Larcher, 1995; Swami *et al*., 2004). In the present study the relative water content was significantly ($P< 0.05$) higher at the experimental site plants than at the control site. This was similar with the works of, Nwadinigwe (2014) and Nwaogwugwu (2017) who reported higher relative water content in the experimental plants than in the control plants. This study attributed the high relative water content to high relative humidity in air similar to high moisture content in soil reported by Sahu *et al.* (2020). The higher relative water content in the experimental site plants suggests that its availability in the polluted areas can resist plants from pollution stress as it aids in controlling of stomatal opening in leaves.This finding was supported with the positive correlation of RWC with the APTI values in the experimental site plants.

Ascorbic acid is important in cell wall synthesis, cell division and may prevent adverse effects of pollutants on plant tissues because ascorbic acid is a natural detoxicant (Krishnaveni and Kumar, 2017). It provides growing plants with resistance from various stress conditions because it is an anti-oxidant and it prevents the formation of dangerous free radicals that cause disturbance in biochemical and physiological activities of plants (Agbaire and Esiefarienrhe, 2009). In this study, high ascorbic acid was found more in tolerant plants from both study sites compared to the moderately tolerant and sensitive counterparts. This study revealed that 28.56 % tolerant plants obtained resulted from increased ascorbic acid in the plants and attributed the improvement in the plants tolerance ability against air pollution to enhanced ascorbic acid. This agrees with the work of Lima *et al*. (2000), Satpute and Bhalerao (2017) and Sahu *et al.* (2020) who reported that tolerance level in plants increases with increase in ascorbic acid content since more ascorbic acidshelp plants to combat against air pollution. Das and Prasad (2010) added that higher levels of ascorbic acid protect chloroplasts against Sulphur dioxide (SO_2), induced Hydrogen peroxide

(H_2O_2) and Hydroxide (OH) accumulation in stressed conditions. Das and Prasad (2010) discovered that the amount of Ozone that penetrates the cell wall to gain entrance into the plasmalemma, can be reduced by ascorbic acid. Singh and Verma (2007) reported that ascorbic acid takes part in light reaction during photosynthesis.

Mean Total chlorophyll contents (TCC) were not directly related to air pollution levels in the present study but to the productivity ability of plants. Jyothi and Jaya, 2010; Ninavae *et al.* (2001) and Agbaire and Esiefarienrhe (2009) reported that presence of TCC is an indication of the rate of photosynthetic activity, growth, development and biomass productivity. Also, reduction in TCC is as a result of increase in chlorophyllase enzyme activities which might cause yellowing of leaves (Prajapatic, 2012). This suggests that in this research, sensitive plants, the herbs with low TCC are indicators of air pollutions as dust blocks their stomata and lowered their productive ability as well. This finding corroborates with the report of Nwaogwugwu *et al.* (2017) that chlorophyll is an important stress metabolite and increase in plants TCC can increase its tolerance to air pollutant and decrease serves as indicators.

Level of increase in APTI of plants determine their defense ability against air pollution. According to Udeagbala *et al.* (2017) APTI determines the capability of plants to monitor, tolerate and bioaccumulate air pollutants. Present study observed that various plants had high (28.56 %) and low (30.35 %) APTI values and the highest APTI value was in *T. catappa* (L.) 23.26 and 21.61 and least was in *A. conyzoides* (L.) 6.68 and 6.45 at experimental and control sites, respectively. The variations in high APTI were attributed to prolonged exposure of plants to vehicular emissions and industrial wastes. Previous reports of Jyothi and Jaya, (2010); and Sahu *et al.*, (2020) described plants exposed to air pollutions with high APTI values 'as tolerant plants with pollution sink abilities' while those exposed with low APTI values are 'the sensitive plants with pollution indicator or monitor abilities'. Sahu *et al.*, (2020), as well suggested utilization of APTI grading idea in identification of suitable plants for plantation. Based on the APTI classification categories, it can be inferred from this study that *T. catappa* was the most tolerant and *A. conyzoides* was the most sensitive.

The combined assessment of APTI, socio-economic and biochemical parameters in form of EPI showed that of the total plant species, 35.71 % were under 'very poor to poor' performer category which implies unfit for plantation. Also, 35.71 % were under 'moderate to very good' performer category that implies fit for plantation, while 28.57 % plants were under 'excellent to best' performer category and implied 'very fit' for plantation. Based on the EPI assessed performer categories, *D. edulis, A. occidentale*, *P. guajava*, *M. indica*, *T. catappa*, *P. macrophylla, G. arborea* and *P. americana* had 'very fit' for plantation potential; *P. longifolia*, *C. papaya*,*R. communis*, *P. obtuse*, *B. nitida*, *P. angolensis*, *D. arborea*,*V. amygdalina*, *N. laevi* and *A. cordifolia* had 'fit' for plantation potential; while *C. odorata*, *L. camara*, *R. vomitoria*, *U. lobate*, *S. acuta*, *E. sonchifolia*, *A. hybridus*, *E. canadensis*, *P. maximum* and *A. conyzoides* had 'unfit' for plantation potential. Therefore, plants under 'excellent to best' performer category can be highly recommended as very fit for plantation to control air pollution, though *D. edulis was* the best for plantation as per EPI assessed categories.

CONCLUSION

Air pollution tolerance index (APTI) is one of the natural ways of assessing suitable plants useful in reducing air pollution in an environment. Ecologists utilize air pollution index assessment to examine plant susceptibility and resistance towards air pollution. This study used APTI parameters (i.e. ascorbic acid, leaf extract pH, total chlorophyll and relative water content) in combination and revealed that plants with high APTI are tolerant to air pollution and serve as pollutant absorbers and bioremediators, whereas those with low APTI are sensitive to air pollution and they serve as pollutant indicators as well as biomonitors to detect air pollution. *T. catappa* was the most tolerant and *E. canadensis*was themost sensitive plant.

In combined assessment of APTI, socio-economic and biochemical parameters values, the EPI revealed plant species that are fit, very fit and unfit for plantation. Therefore, *P. guajava*, *A. occidentale, M. indica, T. catappa, P. macrophylla, G. arborea, P. americana,* and *D. edulis*, under 'excellent to best' performer category can be highly recommended as 'very fit' for plantation potential plants which can control air pollution, though *D. edulis* recorded the best for plantation.

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