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Air pollution tolerance indices of some plants around Ama industrial complex in Enugu State, Nigeria

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Green house gases pollute the atmosphere and cause global warming which has become a worldwide environmental problem. In order to evaluate the ability of plants to absorb such gases, the air pollution tolerance indices (APTI) of some plants around an industrial complex in Nigeria, were determined. The total chlorophyll, ascorbic acid, pH, and relative water content of the leaf extracts of *Mangifera indica*, *Delonix regia*, *Bougainvillea spectabilis*, *Ixora coccinea*, *Anacardium occidentale* and *Duranta erecta* were used to determine the APTI. *Delonix regia* gave significantly ($p<0.05$) highest APTI (5.308 ± 0.090), followed by *Bougainvillea spectabilis* (4.904 ± 0.001) and *Duranta erecta* (4.577 ± 0.166). *Anacardium occidentale* had the lowest (3.470 ± 0.001). *Delonix regia* was comparatively the most tolerant to air pollution. It is suggested that plants with high APTI values should be grown near pollution - prone areas to absorb and thus, screen off certain harmful gaseous pollutants which contribute to green house effect, global warming and climate change.

Key words: Air pollution tolerance index, ascorbic acid, chlorophyll, pH, water, plants.

INTRODUCTION

Emission of green house gases is one of the major problems arising from human population explosion and industrialization. The use of fossil fuels such as petroleum hydrocarbons and coal for transport, electricity generation for industries and households; land clearing, deforestation, agriculture and land use, produce large quantities of oxides of carbon, nitrogen and sulphur, as well as methane, aerosol particulates, etc. These pollute the environment; destroy the atmospheric ozone shield that protects organisms from high levels of ultraviolet radiation, resulting in global warming and climate change (IPCC, 2007).

Many workers like Chauhan (2010), Singh et al. (1991), Abida and Harikrishna (2010) and Sirajuddin and Ravichandran (2010) used ascorbic acid, chlorophyll, relative water content and leaf extract pH to evaluate the susceptibility of some plants to air pollutants by computing these four physiological parameters together in a formation signifying their air pollution tolerance index (APTI). Plants with higher APTI values are more tolerant to air pollution than those with low APTI values. Those with low APTI values are sensitive plants and may act as bio-indicators of pollution (Chandawat et al., 2011, Shannigrahi et al., 2004). Hence, on the basis of their indices, different plants may be categorized into tolerant, moderately tolerant, intermediate and sensitive plants (Chandawat et al., 2011). Ascorbic acid is an antioxidant, which contributes in protecting the plants against oxidative

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damage resulting from aerobic metabolism, photosynthesis and a range of pollutants (Lima et al., 2000). Reactive oxygen species are produced in plants after exposure to environmental conditions like drought, cold or air pollution. Plants sense drought conditions and air pollution by building up reactive oxygen species and then respond by reducing the amount of water that escapes from their leaves (Gallie and Chen, 2004). The water content of the plant tissues helps to maintain the physiological balance of the plant when subjected to the stress of air pollution. Hence, the water content is related to the degree of pollution. The pH of the plant tissue is also related to the degree of air pollution since air pollutants interact with rainwater to form mixtures and solutions with varying pH, depending on the type of pollutant. Chlorophyll is involved in the productivity of the plants and its level is a direct measure of leaf damage by pollution (Bayon et al., 1989; Heath, 1989). Its measurement is an important tool for evaluating the effects of air pollutants on plants since it plays an essential role in plant metabolism and any reduction in chlorophyll content corresponds directly to plant growth (Joshi and Swami, 2009).

The objective of this work is to determine the air pollution tolerance index (APTI) of some plants so as to identify those that may be planted around polluted areas in order to attenuate the adverse effects of pollutants on man and other organisms. The screening of plants globally or in Nigeria for their APTI values has not been exhausted. So there is the need to carry out more work on numerous plants so as to help mitigate the effects of air pollution globally since air pollution has no political boundaries.

The experimental plant species used for this work were collected from Ama industrial complex, 9th mile corner, Ngwo, Udi Local Government Area (L.G.A.), Enugu State, Nigeria. 9th mile corner is a small fast growing city that is located about nine miles before Enugu, the capital of Enugu State, Nigeria. Industries such as bottling companies, breweries, table water purifying industries, hospitals, vehicle mechanic sites, as well as small and medium scale industries are located in it. It is often used as a stop-over town for heavy duty vehicles, tankers, trailers, etc. that ply from the Northern part of Nigeria to the South. Consequently, gaseous emissions and particulate matter are often released by the industrial plants, vehicles and refuse dumps and these pollute the atmosphere around the area.

MATERIALS AND METHODS

Plant collection

Leaves of *Mangifera indica* L. (Family Anacardiaceae), *Delonix regia* (Hook.) Raf. (Family Leguminosae - Caesalpiniodeae), *Bougainvillea spectabilis* Comm. ex Juss. (Family Nyctaginaceae), *Ixora coccinea* L. (Family Rubiaceae), *Anacardium occidentale* L. (Family Anacardiaceae) and *Duranta erecta* L. (Family Verbenaceae) were collected from around some industries in Ama, 9th mile corner, Ngwo, Udi L.G.A., Enugu State, Nigeria (06°.26N and 007°.23E), in the morning between 9 am and 11 am local time. The plants selected were those available at the experimental site and they have similar light, water and soil conditions. Control plants were collected from a non-industrialized area, namely, Botanical Garden, University of Nigeria, Nsukka. The plants were identified by a taxonomist, Mr. Alfred Ozioko. Samples were transported to the laboratory in a water proof container and the fresh weights of the leaves were taken immediately. Some were dried, pulverized and preserved at 4°C for further analysis.

pH determination

pH determination was carried out according to the method of Shannigrahi et al. (2004).

Ascorbic acid determination

Spectrophotometric method was used to determine the ascorbic acid content of the leaves (Abida and Harikrishna, 2010). 1 g of ground fresh leaves was homogenized in 4 ml oxalic acid - ethylenediaminetetraacetic acid (EDTA) extracting solution, for 30 s. 1 ml of orthophosphoric acid and 1 ml 5% tetraoxosulphate (vi) acid were added. 2 ml of ammonium molybdate and 3 ml of water were also added. The solution was left to stand for 15 min. The absorbance was read off with a CE 234 31D digital spectrophotometer at 760 nm. The concentration of the ascorbic acid was determined from a standard ascorbic acid regression curve.

Total chlorophyll determination

For the total chlorophyll determination, 3 g of fresh, ground leaves were extracted with 10 ml of 80% acetone and left to stand for 15 min. It was filtered and centrifuged at 2,500 rpm for 3 min. The absorbance of the supernatant was read at 645 nm (D_{645}) and 663 nm (D_{663}) using a CE 234 31D digital spectrophotometer. The optical density of the total chlorophyll (OT) is the sum of chlorophyll a (D_{645}) density and chlorophyll b (D_{663}) density, thus:

$$OT = 20.2\ (D_{645}) + 8.02\ (D_{663})$$

Total chlorophyll (mg/g DW) = 0.1 OT × (leaf DW ÷ leaf fresh weight) (Liu and Ding, 2008).

Relative leaf water content

The relative leaf water content was obtained by the method of Liu and Ding (2008) and Gharge and Menon (2012).

Determination of air pollution tolerance index (APTI)

Using these four parameters, the air pollution tolerance index (APTI) for each of the plant species was determined using the following mathematical formula:

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

Where, A = Ascorbic acid (mg/g), T = Total chlorophyll (mg/g), P = pH of the leaf extract, R = relative water content (%) (Rai et al., 2013).

Table 1. Air pollution tolerance index (APTI) of some plant species around some industries in Ama, Enugu State, Nigeria.

Plant specie	Site	Total chlorophyll (mg/g)	Ascorbic acid (mg/g)	pH	Relative water content (%)	APTI
Mangifera indica	Exp.	1.495 ± 0.000^{f}	0.042 ± 0.002^{b}	6.3 ± 0.000	4.181 ± 0.066^{a,b}	4.508 ± 0.002^{b}
	Cont	0.058 ± 0.002^{a}	0.012 ± 0.001^{a}	5.1 ± 0.000	3.261 ± 0.007^{d}	3.323 ± 0.002^{f}
Delonix regia	Exp.	0.901 ± 0.000^{e}	0.044 ± 0.001^{b}	5.7 ± 0.000	5.190 ± 0.002^{c}	5.308 ± 0.090^{e}
	Cont	0.093 ± 0.002^{b}	0.015 ± 0.002^{a}	7.1 ± 0.000	3.765 ± 0.002^{e}	3.873 ± 0.002^{g}
Bougainvillea spectabilis	Exp.	2.274 ± 0.002^{i}	0.028 ± 0.002^{e}	4.3 ± 0.000	4.219 ± 6.67^{a,b}	4. 904 ± 0.001^{d}
	Cont	0.900 ± 0.001^{e}	0.012 ± 0.001^{a}	7.6 ± 0.000	3.121 ± 0.004^{f}	3.223 ± 0.001^{h}
Ixora coccinea	Exp.	0.216 ± 0.001^{h}	0.044 ± 0.003^{b}	4.8 ± 0.000	3.507 ± 0.037^{a}	3.728 ± 0.004^{a}
	Cont	0.080 ± 0.013^{b}	0.034 ± 0.001^{d}	5.1 ± 0.000	3.411 ± 0.003^{g}	3.587 ± 0.002^{j}
Anacardium occidentale	Exp.	1.066 ± 0.000^{g}	0.051 ± 0.002^{c}	4.6 ± 0.000	3.441 ± 0.004^{g}	3.470 ± 0.001^{i}
	Cont	0.379 ± 0.003^{d}	0.038 ± 0.001^{d}	4.5 ± 0.000	3.170 ± 0.003^{f}	3.355 ± 0.000^{f}
Duranta erecta	Exp.	0.347 ± 0.000^{j}	0.053 ± 0.003^{c}	5.3 ± 0.000	4.547 ± 1.667^{b,c}	4.577 ± 0.166^{c}
	Cont	0.199 ± 0.001^{c}	0.042 ± 0.001^{b}	5.8 ± 0.000	3.831 ± 0.002^{h}	4.083 ± 0.000^{k}

Exp. = Experimental plants, Cont = Control plants. Values represent means ± standard error. Means followed by the same letters in the same column are not significant at $p<0.05$.

The tolerant plants were calculated as those with APTI more than the mean APTI + SD (standard deviation). The sensitive plants were those with APTI less than mean APTI - SD, while the moderately tolerant plants have intermediate values between that of the tolerant and sensitive plant species (Liu and Ding, 2008). Three replicate samples were taken.

Statistical analysis

The data were subjected to analysis of variance (ANOVA). Multiple comparisons were made between treatment means using Duncan's multiple range tests at $p<0.05$ confidence level (Edafiogho, 2006). t - Tests were carried out between the experimental data and their controls.

RESULTS

The results of the air pollution tolerance index (APTI) determined for the six plants showed that *Delonix regia* gave significantly ($p<0.05$) highest APTI value of 5.308 ± 0.090, followed by *Bougainvillea spectabilis* (4.904 ± 0.001) (Table 1). The plant with significantly ($p<0.05$) lowest APTI value was *Anacardium occidentale* (3.470 ± 0.001). The plant species from the polluted area in Ama Industrial Complex gave consistently and significantly ($p<0.05$) higher APTI values, total chlorophyll, ascorbic acid and relative water content than plants from relatively unpolluted (control) site. For pH, *D. regia, B. spectabilis, I. coccinea* and *D*. erecta from the polluted site were comparatively more acidic than their counterparts from the control site. However, *M. indica* and *A. occidentale* from the polluted site were less acidic than those from the control site. *D. regia* and *B. spectabilis* from the control site were slightly alkaline. Among the experimental plants, *B. spectabilis* had the highest chlorophyll content, followed by *M. indica*, while *I. coccinea* had the lowest chlorophyll content ($p<0.05$ significance). Among the test plants, the leaf extract of *D. erecta* gave the highest quantity of ascorbic acid, followed by that of *A. occidentale*, while *B. spectabilis* gave the lowest ($p<0.05$ significance). Among the experimental plants, *D. regia* had the highest percentage (%) relative water content, while *A. occidentale* had the lowest ($p<0.05$ significance).

DISCUSSION

The results demonstrate that different plant species respond in different ways to air pollution and the same plant species growing in different environments may respond differently, depending on the level of air pollution in the habitat. Hence, plants possess different pollution tolerance capabilities depending on the species and the environmental factors affecting them. In the present work, the variation in the APTI values could be attributed to the different responses of the plants to the four physiological factors, namely, ascorbic acid, total chlorophyll, pH of the leaf extract and the relative water content of the leaf. These physiological factors, in turn, are affected by variation in the level of air pollution in the environment. *D. regia* was the most tolerant plant. Moderately tolerant plants were *B. spectabilis, D. erecta* and *M. indica*. Sensitive ones were *I. coccinea* and *A. occidentale*, in the present investigation. Rai et al. (2013) reported that

Mangifera indica and *Bougainvillea spectabilis* were tolerant for both industrial and non industrial sites in India. Gharge and Menon (2012) showed a decreasing order of tolerance to air pollution as: *Alternanthera sessilis* > *Amaranthus spinosus* > *Chenopodium album* and *Eclipta alba*. Chandawat et al. (2011) also reported that *Ficus benghalensis* gave the highest APTI in Ahmedabad city, India, followed by *Ficus religiosa* ≥ *Ficus glomerata*, followed by *Azadiracta indica* ≥ *Polyalthia longifolia*. They emphasized that plants with high APTI can serve as tolerant plants, while those with low APTI can serve as sensitive ones. Agbaire and Esiefarienrhe (2009) reported that *Emilia sonchifolia, Manihot esculenta* and *Elaeis guineensis* were the more tolerant species around Otorogun gas plant in Delta State, Nigeria. Liu and Ding (2008) found a number of tolerant to moderately tolerant plants near a Beijing steel factory, China and these included *Cotinus coggygria, Periploca sepium, Lespedeza floribunda* and *Grewia biloba*. The comparatively high APTI values recorded for *Delonix regia, Bougainvillea spectabilis, Duranta erecta* and *Mangifera indica* in the present work, is in agreement with the report of Shannigrahi et al. (2004) who found high APTI values for *Mangifera indica, Moringa pterydosperma, Cassia renigera* and *Ailanthus excelsa*. Plants with higher APTI (tolerant plants) can trap and contain dust particles or smog, absorb pollutants, heat, other gaseous emissions and improve the ambient air quality. Such plant species should be grown in polluted cities, along roads and around industrial areas to create a sort of "curtain" that will absorb pollutants and screen the environment from their harmful effects. The plant species from Ama Industrial complex showed significantly ($p<0.05$) higher values of APTI than the plant species from comparatively less polluted area (control), in the present investigation. Nwadinigwe (2009), Gharge and Menon (2012) and Rai et al. (2013) reported an increase of APTI values of plants at the experimental site when compared with those at the control site. This may be due to constant exposure of these plants to emissions of gaseous and particulate matter from industries operating where they were collected, as well as emissions from vehicle exhausts.

The plant species from the polluted site gave higher values for ascorbic acid, total chlorophyll and relative water content than the control plants. Perhaps the plants exposed to air pollution are naturally adjusting to these gaseous pollutants by increasing these physiological parameters in an attempt to contend with the environmental pollution. Dohmen et al. (1990) observed that when exposed to air- borne pollutants, most plants experience physiological changes before exhibiting visible damage to the leaves. The ascorbic acid from plants in the polluted site was higher than that from the control plants, in this present work. This agrees with the reports of Chandawat et al. (2011), Meerabai et al. (2012) and Rai et al. (2013) who found higher levels of ascorbic acid in the leaves of the most tolerant plants and those at the polluted sites and this suggests their tolerance to the air pollutants. The lower ascorbic acid in the leaves of the sensitive ones supports the sensitive nature of the plants to the pollutants. Ascorbic acid is important in cell wall synthesis, defence and cell division (Conklin, 2001). It is a strong reductant and it activates many physiological and defence mechanisms. It plays an important role in photosynthetic carbon fixation (Pasqualini et al., 2001). Due to its importance, it is used as a multiplication factor in the formula used in deriving APTI (Liu and Ding, 2008).

In the present work, the total chlorophyll of the test plants was higher than those of the control plants. Agbaire and Esiefarienrhe (2009) reported similar results in their work around Otorogun gas plant. Jyothi and Jaya (2010) observed higher levels of total chlorophyll in *Ficus benghalensis* and this may be due to the tolerant nature of the plant. On the other hand, Gharge and Menon (2012) and Rai et al. (2013) reported lower chlorophyll content of plants from experimental site when compared with those from the control. Certain pollutants increase the total chlorophyll content while others decrease it (Allen et al., 1987). Chandawat et al. (2011) observed that the chlorophyll content of all plants they tested varied with the pollution status of the area, as well as the tolerance and sensitivity of the plant species. The total chlorophyll is related to ascorbic acid productivity since the ascorbic acid is concentrated mainly in the chloroplasts (Liu and Ding, 2008).

In the present investigation, the relative water content of the leaves from the polluted area was higher than those from the control plants. It is similar to the report of Agbaire and Esiefarienhe (2009), Gharge and Menon (2012) and Rai et al. (2013), who found higher relative water content in the experimental plants than in the control plants. A high water content in a plant's body helps to maintain its physiological balance in stress conditions such as exposure to air pollution (Verma, 2003), when the transpiration rates are usually high. High relative water content contributes to the normal functioning of biological processes (Meerabai et al., 2012) and favors drought and pollution resistance in plants.

The result of pH of the leaf extract was variable, in the present investigation. High pH may increase the efficiency of conversion from hexose sugar to ascorbic acid (Escobedo et al., 2008), while low leaf extract pH showed good correlation with sensitivity to air pollution (Yan-Ju and Hui, 2008). This agrees with the present investigation, where *I. coccinea* and *A. ocidentale* that were found to be sensitive plants, had comparatively low leaf extract pH. Similarly, *D. regia, B. spectabilis, I. coccinea* and *D*. erecta from the polluted site were comparatively more acidic than their counterparts from the control site, in the present work. Rai et al. (2013) found that plants from the industrial site had a pH towards the acidic side, whereas those from the non industrial site showed neutral to slightly alkaline range.

Combining a number of physiological parameters in the determination of APTI gives a more reliable result than depending on a single biochemical or physiological factor (Liu and Ding, 2008). Air pollution tolerance is affected by natural climatic conditions such as rainfall, temperature, soil type, relative humidity, etc. and these were not taken into consideration in this work, since all the experimental plants were collected from the same climatic environment. The same applies to the control. The variation in the APTI values could be attributed to the different responses of the plants to the physiological factors and these receive most impact from the pollution load in the environment. APTI is an inherent quality of plants to encounter air pollution stress (Rai et al., 2013). These physiological factors help plants to adjust to stresses in the environment, especially pollution, drought, fire, etc. and the major stress observed in the environment was that of pollution.

Conclusion

Tolerance of plants to air pollution may be specific to the site depending on the level of pollution. Plants growing in the industrialized area have higher APTI than those at the non industrial site. Plant species (such as *Delonix regia, Bougainvillea spectabilis, Duranta erecta* and *Mangifera indica*) that are tolerant to air pollution can absorb air pollutants, particulate matter and other emissions, thereby improving the air quality which man and other organisms are exposed to. Such plants should be grown on sites exposed to air pollutants, industrial areas, cities and along the roads. Sensitive plants (such as *I. coccinea* and *A. occidentale*) are more useful as bioindicators (Agrawal et al., 1991). Therefore, more work should be carried out on the APTI determination of many more plants globally, since air pollution is a global menace.

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Conflict of Interests

The author(s) have not declared any conflict of interests.

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