TREES PHYSIOLOGICAL RESPONSES TO AIR POLLUTION IN TAMAN MARGASATWA RAGUNAN AND UI DEPOK CAMPUS

DIANA SELVILIA HAMID[1], RATNA YUNIATI[1,2*] AND AFIATRY PUTRIKA[1,3]

[1]*Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia*
[2]*Reseacrh Group of Metabolomics and Chemical Ecology, Universitas Indonesia, Depok 16424, Indonesia*
[3]*Research Group of Wildlife Biology and Sustainable Landscape, Universitas Indonesia, Depok 16424, Indonesia*

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ABSTRACT

Air pollution is a common environmental problem. Planting trees can minimize the adverse effects of air pollution. Plants can absorb and accumulate air pollutants through stomata. Biochemical changes in the leaves will appear as a physiological response of plants to air pollution that can be known by calculating the APTI (Air Pollution Tolerance Index) value. This study aimed to analyze the differences in physiological responses of five tree species in Taman Margasatwa Ragunan (TMR) South Jakarta and Universitas Indonesia (UI) Depok Campus as well as to find out the proper tree species planted in areas with high levels of air pollution. The leaves of five species (*Hevea brasiliensis*, *Manilkara kauki*, *Artocarpus heterophyllus*, *Ficus septica*, and *Mangifera indica*) were used to examine the effect of air pollution. Biochemical parameters (relative water content, leaf extract pH, total chlorophyll content, and ascorbic acid content) were observed from each species. The value of each parameter was calculated into the APTI equation. *H. brasiliensis*, *F. septica*, and *M. indica* were categorized as moderately tolerant plants, *M. kauki* were included as intermediate plants, and *A. heterophyllus* was a sensitive plant to air pollution in both locations. The highest APTI values were observed in *M. indica* in both locations. Thus, the recommended species planted in a polluted area was *M. indica*.

Keywords: APTI, ascorbic acid content, leaf extract pH, relative water content, total chlorophyll content

INTRODUCTION

Air pollution is one of the environmental problems faced by many countries in the world (Shaddick *et al.* 2020), especially in developing countries (Mannucci & Franchini 2017). Air pollution comes from natural factors and anthropogenic factors (humans) (Susanto 2020). The use of motor vehicles is the largest contributor to pollution in the air. The use of low-quality fuel can worsen air quality in the environment (Uka *et al.* 2019). Pollutant gases produced include carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), hydrocarbons, volatile organic compounds (VOCs), and particulate matter (PM) (Uka *et al.* 2019). Developing countries account for 50 - 80% of the NO_2 and CO gases in the air from motor vehicles (Adeyanju 2018). Poor air quality can cause diseases in humans, such as cough, asthma, respiratory diseases, lung cancer, to cardiovascular disease (Manisalidis *et al.* 2020).

Plants can absorb and accumulate various air pollutants by absorption through stomata on the leaves (Uka *et al.* 2019). Based on research by Roshintha and Mangkoedihardjo (2016) mentioned that *Samanea saman* can absorb CO_2 of 3,252.1 g/hour, *Swietenia macrophylla* 3,112.43 g/hour followed by *Bauhinia purpurea* 1,331.38 g/hour, *Alstonia scholaris* 1,319.35 g/hour, and *Ficus benjamina* 1,146.51 g/hour. This proves that plants can absorb and accumulate air pollutants, such as CO_2. Plants exposed to air pollutants will show morphological, anatomical, biochemical, and physiological responses (Uka *et al.* 2019).

*Corresponding author, email: ratnayuniati@sci.ui.ac.id

Changes in biochemical content in the leaves, namely RWC (Relative Water Content), leaf extract pH, total chlorophyll content, and ascorbic acid content will occur when pollutant gases enter leaf tissue (Uka *et al.* 2019). This happens in response to plant physiology to air pollution. The level of plants tolerance to air pollution can be determined by calculating the value of the air pollution tolerance index (APTI) based on changes in biochemical content that happens in the leaves (Zhang *et al.* 2016). Plants having a good tolerance level can play a role in controlling air pollutants in the environment (Ogunkunle *et al.* 2015).

Taman Margasatwa Ragunan (TMR) South Jakarta and UI Depok Campus are green areas located in urban areas (Taman Margasatwa Ragunan 2021; Universitas Indonesia 2021) with a high level of air pollution. However, conditions in both locations are assumed to be different. The intensity of vehicles in the UI Depok Campus is higher than that in the TMR. Hence, the study aimed to: 1) analyze the difference in physiological responses of five tree species in TMR and UI Depok Campus based on the tolerance index and 2) find out the right tree species to plant in areas with high levels of air pollution.

MATERIALS AND METHODS

Study Area

The study was conducted in November 2021 located at Taman Margasatwa Ragunan (TMR) South Jakarta and UI Depok Campus (intersection area near the rectorate building). Sampling points were depicted in Figure 1. Five tree species observed in this study were *Hevea brasiliensis*, *Manilkara kauki*, *Artocarpus heterophyllus*, *Ficus septica*, and *Mangifera indica*. The coordinate points of the five tree plant species in both locations were recorded based on GPS (Global Positioning System) (Table 1).

Figure 1 Location of sampling points in Taman Margasatwa Ragunan (left) and UI Depok Campus (right) (intersection area near the rectorate building)
Notes: Plants shown are: 1 = *H. brasiliensis*, 2 = *M. kauki*, 3 = *A. heterophyllus*, 4 = *F. septica*, and 5 = *M. indica*.

Table 1 Coordinate points of five tree species at TMR and Campus UI Depok

No.	Species	TMR	UI
1.	*Hevea brasiliensis*	06°18.385' S 106°49.165' E	06°20.923' S 106°49.609' E
2.	*Manilkara kauki*	06°18.492' S 106°49.206' E	06°21.998' S 106°49.571' E
3.	*Artocarpus heterophyllus*	06°18.602' S 106°49.158' E	06°22.017' S 106°49.628' E
4.	*Ficus septica*	06°18.658' S 106°49.142' E	06°21.996' S 106°49.580' E
5.	*Mangifera indica*	06°18.699' S 106°49.239' E	06°21.993' S 106°49.567' E

Environmental Parameters

Soil temperature, relative humidity, and soil pH were measured in November 2021 at both study locations. Temperature and relative humidity were measured over the 4 weeks at both study locations starting from the first sampling activity. Monthly average rainfall data were obtained from BPS Kota Jakarta Selatan (2021) for South Jakarta and from the study conducted by Said and Widayat (2014) for Depok area. Soil samples were collected from 3 different points at each location. The measurement of soil pH was based on a method described by Nadgórska-Socha *et al.* (2017) using a digital pH meter with a ratio of soil and distilled water weight of 1 : 2.5.

Sampling and Preparation

Leaf samples came from five species, i.e., *H. brasiliensis*, *M. kauki*, *A. heterophyllus*, *F. septica*, and *M. indica*. The samples came from a tree with a height of at least 1.5 m (Kaur & Nagpal 2017) which faced toward sunlight and roads (Zhang *et al.* 2016). Samples were collected three times from the same individual. The samples were taken to the laboratory for cleaning, and then weighed according to the required leaf weight for each test. Subsequently, the samples were stored in a freezer having temperature of -20 ºC until the sample were ready to be tested (Zhang *et al.* 2016).

Relative Water Content (RWC)

RWC measurement was carried out following the method described by Ghafari *et al.* (2020) with modifications. As much as 5 g of leaves samples were soaked in distilled water for 24 hours. Then, the samples were re-weighed and recorded as turgid weight. Subsequently, the samples were oven-dried at 50 ºC until reaching a constant weight and the weight was recorded as dry weight. The RWC values were expressed in percent and calculated based on the formula:

$$\text{RCW (\%)} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

where:
FW = fresh weight (g);
TW = turgid weight (g);
DW = dry weight (g).

Leaf Extract pH

The pH measurement of leaf extract was conducted following the method described by Kaur and Nagpal (2017) with modifications. A total of 5 g of leaves samples were extracted with 50 mL of distilled water. The extract was filtered and measured using a digital pH meter.

Total Chlorophyll Content

Measurement of total chlorophyll content was carried out following the method described by Manjunath and Reddy (2019). A total of 0.5 g of leaves samples were extracted and homogenized with 10 mL of 80% acetone. The extract was centrifuged at 2,500 rpm for 3 minutes. Supernatant volumes were measured and absorbed at wavelengths of 663 nm and 645 nm using UV-Visible spectrophotometers. The total chlorophyll content was calculated based on formula as follows (Bharti *et al.* 2018):

$$\text{Chlorophyll a (mg/g)} = 12.7\ (A_{663}) - 2.69\ (A_{645}) \times \frac{V}{1{,}000} \times W$$

$$\text{Chlorophyll b (mg/g)} = 22.9\ (A_{645}) - 4.68\ (A_{663}) \times \frac{V}{1{,}000} \times W$$

Total chlorophyll (mg/g) = chlorophyll a + chlorophyll b

where:
A_{663} = absorbance at wavelength 663 nm;
A_{645} = absorbance at wavelength 645 nm;
V = supernatant volume (mL);
W = sample weight (g).

Ascorbic Acid Content

Measurement of ascorbic acid content were carried out following the method described by Patel and Kumar (2018) using titration. The leaves samples solution was extracted with 100 mL of 4% oxalic acid. The extract was centrifuged at 2,500 rpm for 3 minutes. The sample solution and blanko were titrated using a dye solution until the color turned pink. The ascorbic acid content was calculated based on the formula:

$$\text{Ascorbic acid (mg/100 g sample)} = \frac{0.5\ \text{mg}}{V_1\ \text{mL}} \times \frac{V_2\ \text{mL}}{5\ \text{mL}} \times \frac{100\ \text{mL}}{W} \times 100$$

where:
W = sample weight (g);
V_1 = volume of blanko solution;
V_2 = volume of sample solution.

Air Pollution Tolerance Index (APTI)

The value of each parameter is calculated into an equation described by Zhang *et al.* (2016):

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

where:
A = ascorbic acid content (mg/100g sample);
T = total chlorophyll content (mg/g);
P = leaf extract pH;
R = Relative Water Content (RWC).

The values obtained are categorized based on the category of plant responses described by Sahu *et al.* (2020):

a) APTI < Mean APTI – SD : sensitive (S)
b) Mean APTI – SD < APTI < Mean APTI : intermediate (I)
c) Mean APTI < APTI < Mean APTI + SD : moderately tolerant (MT)
d) APTI > Mean APTI + SD : tolerant (T)

Air Pollution Data Collection

The daily average of air pollutants ($PM_{2.5}$, PM_{10}, CO, HC, NO_2, O_3, and SO_2) in both study locations (TMR and UI Depok Campus) was obtained from the ISPUNet KLHK ver 1.4.5 application. The data were recorded in the morning at 7 AM, noon at 12 PM, and in the afternoon at 5 PM. Data were collected from early October to the end of November 2021. The established range of ISPU (air pollutant standard index) values is as follows: a) Good: 1 - 50, b) Medium: 51 - 100, c) Unhealthy: 101 - 200, d) Very unhealthy: 201 - 300, e) Dangerous: > 301 (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia 2020).

Data Analysis

Data were analyzed descriptively. Environmental and biochemical parameters as well as APTI values were calculated for the average values. The average values of those parameters at the two study locations were then compared. Data were presented in the form of tables and bar charts.

RESULTS AND DISCUSSION

The average air temperature in UI Depok Campus was relatively higher than that in TMR (Table 2). Both study locations are green areas that have similar environmental conditions. Higher air temperatures can reduce the humidity (Utami *et al.* 2020). Our study found out that the average air temperature in TMR was lower with higher relative humidity than that in UI Depok Campus. Within the period of our study, the average rainfall in South Jakarta was 235.96 mm per month (BPS Kota Jakarta Selatan 2021) and in Depok was 278 mm per month (Said & Widayat 2014).

Table 2 Comparison of environmental parameters in TMR and UI Depok Campus in November 2021

No.	Environmental parameters	TMR	UI Depok Campus
1.	Average temperature (°C)	30.35±0.53	30.75±0.64
2.	Average relative humidity (%)	57.50±3.51	55.50±3.11
3.	Average soil pH	7.45±0.77	7.21±0.88

Based on the ISPU data, the range of APTI value for all types of pollutants was 0.00 - 80.72 (Fig. 2). The lowest index was observed on HC in Depok (0.00) and the highest on $PM_{2.5}$ in Jakarta (80.72). Both were observed in October 2021. In October 2021, the $PM_{2.5}$, CO, HC, NO_2, and O_3 indices were observed to be higher in Jakarta, while SO_2 was higher in Depok. Meanwhile, similar indices in both regions were observed in PM_{10}. Furthermore, in November 2021, the $PM_{2.5}$, PM_{10}, NO_2, O_3, and SO_2 indices were observed higher in Depok, while CO and HC remained high in Jakarta. The high SO_2 and $PM_{2.5}$ indices in Depok was presumably due to the high level of vehicle traffic on the highway, especially during peak hours. Visibility will decrease along with the increased levels of $PM_{2.5}$ and PM_{10} in the air (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia 2021) because the air is filled with fine dust that can be inhaled by the respiratory system. The main sources of $PM_{2.5}$ and PM_{10} pollutants come from combustion activities, such as the use of vehicles, construction activities, up to coal-fired power plants (Haryanto *et al.* 2016).

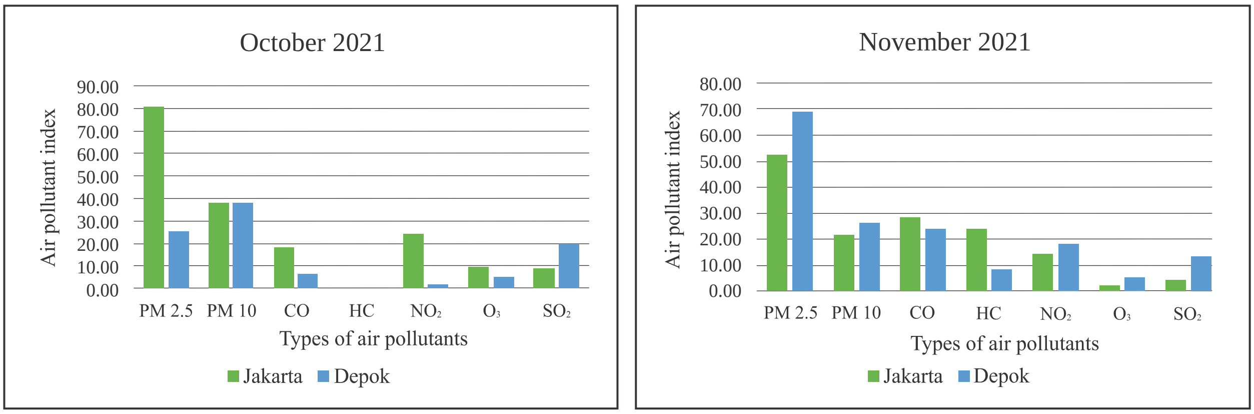

Figure 2 Average air pollutant index in Jakarta and Depok in October and November 2021

H. brasiliensis, *M. kauki*, *F. septica*, and *M. indica* are the three tree species which have higher scores of RWC in the UI Depok Campus than that in TMR (Fig. 3A). Meanwhile, the RWC value of *A. heterophyllus* in both locations had the similar lowest RWC values. Water plays a role in maintaining the physiological balance of plants under environmental stress. Humidity and temperature in the environment affect the RWC values of the leaves. RWC values tend to decrease in plants that are exposed to high temperature and drought environment (Rowshanaie *et al.* 2014; Zhang *et al.* 2016). Meanwhile, tolerant plants usually have a high RWC value (Bahadoran *et al.* 2019). RWC values are related to plant tolerance levels to air pollution. The high RWC value of a species indicates that plants have a good tolerance to air pollution (Zhang *et al.* 2016; Kaur & Nagpal 2017). Based on RWC values in our study, *M. indica*, *F. septica*, and *H. brasiliensis* are more tolerant to air pollution. Meanwhile, the lowest RWC values were observed in *A. heterophyllus* at both locations. This is presumably because *A. heterophyllus* cannot adapt well to an environment that tends to be dry (Centre for Agriculture and Bioscience International 2019).

Leaf extract pH of the five species in UI Depok Campus was higher than that in TMR (Fig. 3B). Leaf extract pH is related to the sensitivity of plants to air pollution (Kaur & Nagpal 2017). Plants exposed to air pollutants, especially SO_2, tend to produce a large amount of H^+ cellular fluid. The H^+ will react with SO_2 to form H_2SO_4 which cause a decrease in leaf extract pH. The high leaf extract pH indicates that the plant can well absorb SO_2 and NO_x (Zhang *et al.* 2016). Trees having low leaf extract pH values indicate that the trees are more sensitive to air pollution compared to those having high leaf extract pH, which are more tolerant to air pollution (Bahadoran *et al.* 2019; Uka *et al.* 2019). *F. septica* and *H. brasiliensis* in our study have high leaf extract pH value compared to other species and are thought to be more tolerant to air pollution.

The total chlorophyll content of three species namely *H. brasiliensis*, *F. septica*, and *M. indica* was observed to be higher in TMR than in UI Depok Campus. On the other hand, *M. kauki* and *A. heterophyllus* have higher total chlorophyll in UI Depok Campus than that in TMR (Fig. 3C). Chlorophyll is the main component of green coloring in plants (Kaur & Nagpal 2017). Air pollutants entering the leaf tissue through the stomata cause chlorophyll to degrade. SO_2 in the air affects the total chlorophyll of the leaves. High concentration of SO_2 cause a decrease in total chlorophyll content (Zhang *et al.* 2016). Total chlorophyll in the leaves is also affected by high temperatures, dry environments, salt stress, and light intensity (Zhang *et al.* 2016). Other factors, such as plant species and leaf age, also affect total chlorophyll content (Kaur & Nagpal 2017). The observed higher SO_2 index value in Depok area is suspected to be the cause of the low total chlorophyll content in tree species in UI Depok Campus. The higher average air temperature, trees position, and high light intensity are also suspected to be the cause of the low total chlorophyll content. Meanwhile, *M. kauki* and *A. heterophyllus* showed lower total chlorophyll content in TMR, which is attributed to the location of trees that are more exposed to sunlight, thus having high light intensity.

The ascorbic acid content of *H. brasiliensis*, *M. kauki*, and *A. heterophyllus* was higher in TMR. Meanwhile, *F. septica* and *M. indica* in UI Depok Campus had a higher ascorbic acid content than that in TMR (Fig. 3D). Ascorbic acid is an antioxidant that plays an important role in maintaining the stability of cell division and cell membranes while in environmental stress. The ascorbic acid plays an important role in the synthesis of the cell wall. Ascorbic acid in plants is related to plants responses to environmental stress such as air pollution, heavy metals, drought, and high temperatures (Gallie 2013; Zhang *et al.* 2016). High ascorbic acid content indicates a good tolerance to SO_2 in the air (Uka *et al.* 2019). Plants having high ascorbic acid content are more tolerant to air pollution compared to those having low ascorbic acid content (Zhang *et al.* 2016). *M. indica* and *F. septica* in UI Depok Campus had a higher ascorbic acid content than those in TMR, which indicated that both species had a good tolerance to SO_2 gas that was observed to be higher in Depok. *H. brasiliensis* in TMR was also observed to have the highest ascorbic acid content compared to other species, which indicated that the three tree species (*M. indica, F. septica,* and *H. brasiliensis*) were more tolerant plants.

Air pollution tolerance index (APTI) values illustrate the level of plants tolerance to air pollution. Based on our study, the APTI values of *H. brasiliensis*, *M. kauki*, *F. septica*, and *M. indica* in UI Depok Campus were higher than that in TMR. Meanwhile, APTI value of *A. heterophyllus* were higher in TMR compared to that in UI Depok Campus. Based on the categories of plant responses to air pollution described by Sahu *et al.* (2020), each species has the same responses in both locations (Table 3).

The higher the APTI value, the higher the tolerance of plant to air pollution. Plants that are sensitive to air pollution tend to have low values of RWC, leaf extract pH, and ascorbic acid content. Meanwhile, plants that are more tolerant of air pollution tend to have high values of RWC, leaf extract pH, and ascorbic acid content. There is a link between the leaf extract pH and ascorbic acid content. The high leaf extract pH increases the efficiency of converting hexose sugar into ascorbic acid which leads to an increase in the ascorbic acid content (Bakiyaraj & Ayyappan 2014). Conversely, the low leaf extract pH decreases the efficiency of converting hexose sugar to ascorbic acid, so the ascorbic acid content tends to be low (Kaur & Nagpal 2017).

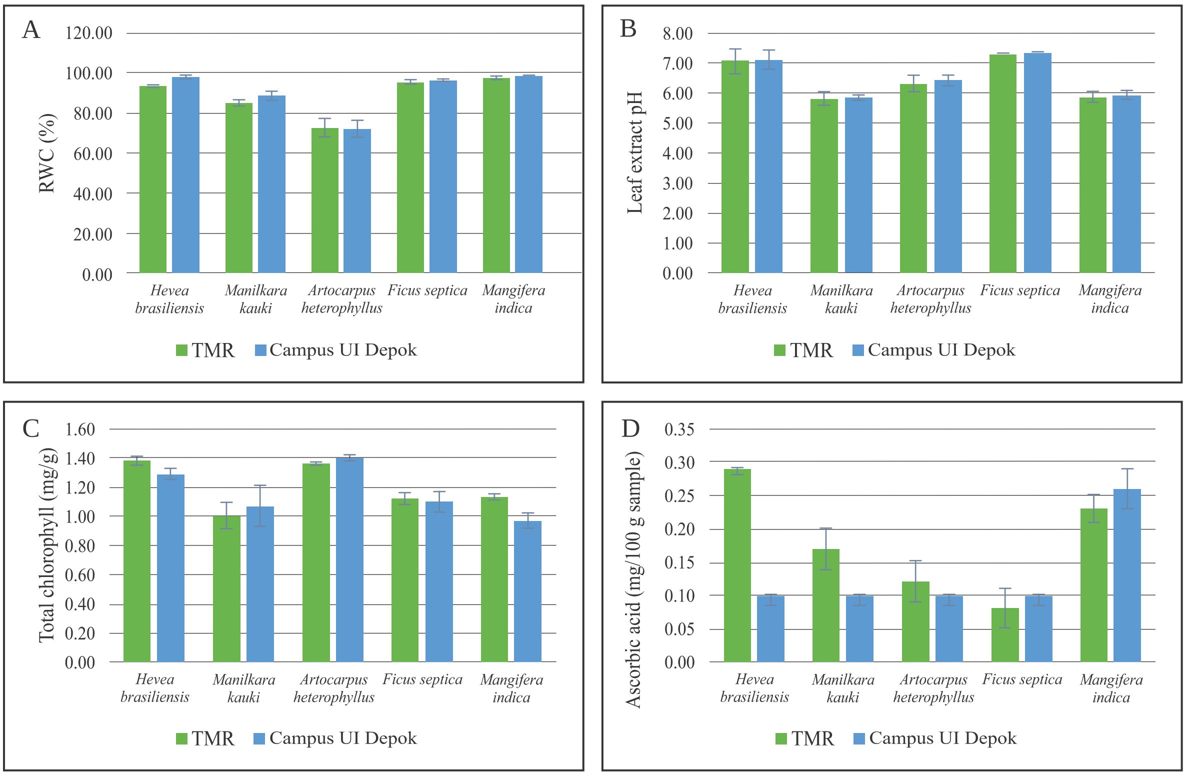

Figure 3 Biochemical parameters of five tree species in TMR and UI Depok Campus
Notes: A = Relative Water Content; B = leaf extract pH; C = total chlorophyll; and D = ascorbic acid.

Table 3 Biochemical parameters, APTI values, and response categories of five tree species in TMR and UI Depok Campus

Species	RWC (%)		Leaf extract pH		Total chlorophyll (mg/g)		Ascorbic acid (mg/100g sample)		APTI		Response categories	
	TMR	UI	TMR	UI	TMR	UI	TMR	UI	TMR	UI	TMR	UI
Hevea brasiliensis	93.45±0.58	98.13±0.57	7.04±0.41	7.10±0.32	1.38±0.03	1.29±0.04	0.29±0.00	0.10±0.00	9.59±0.50	9.89±0.57	MT	MT
Manilkara kauki	85.11±1.33	88.61±2.68	5.80±0.20	5.84±0.07	1.00±0.09	1.07±0.14	0.17±0.03	0.10±0.00	8.62±0.15	8.93±0.27	I	I
Artocarpus heterophyllus	72.66±4.35	72.22±4.12	6.30±0.29	6.42±0.18	1.36±0.01	1.40±0.02	0.12±0.03	0.10±0.00	7.35±0.43	7.30±0.41	S	S
Ficus septica	95.52±1.10	96.38±0.38	7.31±0.00	7.33±0.01	1.12±0.04	1.10±0.07	0.08±0.03	0.10±0.00	9.62±0.12	9.72±0.04	MT	MT
Mangifera indica	97.51±0.61	98.39±0.27	5.86±0.18	5.92±0.15	1.13±0.02	0.97±0.05	0.23±0.02	0.26±0.03	9.91±0.06	10.02±0.02	MT	MT

Notes: Mean (n = 3); S = sensitive, I = intermediate, MT = moderately tolerant, T = tolerant.

Plants tolerance levels studied in TMR can be sequenced as follows: *M. indica* > *F. septica* > *H. brasiliensis* > *M. kauki* > *A. heterophyllus*. Meanwhile, the sequence of tolerance level in UI Depok Campus is as follows: *M. indica* > *H. brasiliensis* > *F. septica* > *M. kauki* > *A. heterophyllus*. In addition, the study results showed that APTI values in TMR and UI Depok Campus had similar values, which was presumably due to the current condition of the Covid-19 pandemic. During the Covid-19 pandemi, the number of vehicles passing through the UI Depok Campus area become fewer, so the pollutants produced are also less compared to the conditions before the Covid-19 pandemic. The environmental conditions in both locations tend to be the same.

Plants having low APTI values can act as environmental bioindicators, as they are more sensitive to air pollution. Meanwhile, plants having higher APTI values can be used as bioaccumulators of air pollution because they have a good ability to absorb and accumulate various pollutants scattered in the air through leaf stomata. Plants which are tolerant and moderately tolerant to air pollution can be grown in environments having high levels of air pollution, such as in urban areas, areas with heavy traffic, and industrial areas (Kaur & Nagpal 2017; Uka *et al.* 2019).

A. heterophyllus has the lowest APTI values in both locations and is categorized as a sensitive plant to air pollution. The plant has a high total chlorophyll content and low leaf extract pH as well as ascorbic acid content. Meanwhile, *M. indica* has the highest APTI values in both locations. The total chlorophyll content and leaf extract pH in *M. indica* is quite low when compared to other species. However, *M. indica* has a high ascorbic acid content and the highest RWC value compared to other species. Therefore, *M. indica* is the best plant to be grown in areas with high levels of air pollution. Other than that, *M. indica* has a large tree stature, a large and wide canopy, and a large number of leaves (Febrianti & Sulistyantara 2020). *M. indica* is also a native plant of Indonesia (Centre for Agriculture and Bioscience International 2022) and resistant to strong winds, so it is not easily uprooted (Plants For A Future 2022). *F. septica* and *H. brasiliensis* can be the alternative choices because these two tree species have moderate level of tolerance as *M. indica* to air pollution.

CONCLUSION

H. brasiliensis, *M. kauki*, *A. heterophyllus*, *F. septica*, and *M. indica* had the same responses in Taman Margasatwa Ragunan South Jakarta and UI Depok Campus. *H. brasiliensis*, *F. septica*, and *M. indica* are categorized as moderately tolerant, *M. kauki* includes intermediate plant, and *A. heterophyllus* is a sensitive plant to air pollution based on air pollution tolerant index (APTI) values. Based on APTI values and physical characteristics of the tree, the right tree species to plant in an area with high levels of air pollution is *M. indica*.

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