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# Air pollution monitoring and green belt assessment of three urban tree species in Erbil City, Iraq

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**Abstract.** *Sabr HA, Ali KA. 2025. Air pollution monitoring and green belt assessment of three urban tree species in Erbil City, Iraq. Asian J For 9:* 299-311. This study evaluates the tolerance levels of three roadside tree species—*Brachychiton populneus, Ligustrum lucidum,* and *Olea europaea*—to air pollution for the establishment of an urban greenbelt in Erbil City, Iraq. The Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) were calculated using biochemical and physiological parameters, including leaf area, proline, and total carbohydrate content. Leaf samples were collected from four locations with differing pollution intensities. Results showed that *B. populneus* had the highest APTI values at Locations 3 and 2, with 12.67±0.33 and 11.67±1.20, respectively, compared to other species. The same species also maintained a pH range from 6.11 to 7.1 across all locations studied. Additionally, *L. lucidum* exhibited lower percentages of LRWC in less polluted sites. The highest ascorbic acid content was found in *B. populneus*, measuring 2.76±0.07 mg $g^{-1}$. No significant differences in total chlorophyll were observed among all species in polluted locations compared to less polluted sites during the study, except for *L. lucidum* at Location 2. At the same time, a significant increase in total chlorophyll was observed for *B. populneus* in Location 3 (0.22±0.03 mg $g^{-1}$). There was a significant positive correlation between APTI and LRWC% ($R^2$=0.89). The findings support the integration of *B. populneus, O. europaea,* and *L. lucidum* as primary candidates for urban greenbelt development in Erbil to enhance air quality and ecological sustainability.

**Keywords:** Air pollution, APTI, chlorophyll, leaf pH, tree species

**Abbreviations:** ACA: Ascorbic Acid, API: Anticipated Performance Index, APTI: Air Pollution Tolerance Index, *B. populneus*: *Brachychiton populneus*, Cs: Canopy structure, EI: Economic Importance, *L. lucidum*: *Ligustrum lucidum*, LA: Leaf Area, LS: Laminar Structure, LRWC%: Leaf Relative Water Content, mm: millimeters, MAE: Mean Absolute Error, *O. europaea*: *Olea europaea*, $R^2$: Correlation Coefficient, SEE: Standard Error of Estimates, T. Chl: Total Chlorophyll, TH: Tree habitat, TS: Type of tree

## INTRODUCTION

The atmosphere contains various gases and particulate matter generated from different combustion processes, including $SO_x$, $NO_x$, CO, and suspended particles, as well as smaller quantities of hazardous metals, organic compounds, and radioactive isotopes. Erbil is a modern, growing city, and as its economy expands, air pollution levels are also increasing. Understandably, the buildup of air pollution is a direct result of industrial growth. The declining air quality is an environmental issue affecting various urban areas and their neighboring regions worldwide (Kuddus et al. 2011). According to the research by Onojeghuo et al. (2025), the highest pollution levels were found closer to major cities including Erbil City, Iraq, with scores greater than 6.5 through using the composite air pollution score was computed by combining the normalized values of five pollutants: $PM_{2.5}$.CO, $NO_2$, aerosol and $SO_2$. Considering that trees and shrubs are continuously subjected to chemical pollutants in the surrounding environment, the damage caused by air pollution to plants correlates with the severity of the pollution. The impacts are mostly evident on the leaves, which serve as the most common and visible primary sensors for different air contaminants (Pandit and Sharma 2020). The vegetation belt is one of the most effective natural methods for purifying the atmosphere because it provides a substantial leaf area for the absorption and accumulation of air pollutants to various degrees. Plants act as scavengers for air pollution, serving as the primary receptors of airborne contaminants (Mahecha et al. 2013). The capacity of each plant species to adsorb contaminants through its foliar surface significantly varies and is reliant upon a number of biochemical, physiological, and morphological traits (Seyyednejad et al. 2011). Plant growth is restricted by several stressors, such as water stress and increased heavy metals, and it requires a specific adaptability capacity (Mundada et al. 2021).

Proline, an amino acid, plays a vital role in plants under various stress circumstances (Amini et al. 2018; Alagoz et al. 2023). Some researchers assume that proline accumulation is a symptom of injury, which does not confer protection against metal stress (Siddique et al. 2018). On the contrary, Aslam et al. (2017) indicated that proline may protect plants from heavy metal toxicity. Carbohydrates are essential to plant function due to supporting plant metabolism (Hartmann et al. 2018). Research on the distribution of carbohydrates across tree organs has been conducted for several decades (Turfan and Meşe 2019). Several studies indicated that intracellular and tissue pollutants lead to oxidative stress, inhibiting photosynthesis and carbon metabolism (Pimple 2017). In addition, researchers point out that tolerant species possess enhanced antioxidative defense mechanisms, including soluble compounds such as carbohydrates, pigments, and the amount of proline (Celiktas et al. 2019).

The tolerance level of plants can be evaluated using the Air Pollution Tolerance Index (APTI) and the Anticipated Performance Index (API), which are derived from four key biochemical and physiological parameters (Singh and Rao 1983). APTI is a quantitative measure that evaluates the resilience of plant species to air pollution by analyzing leaf biochemical parameters, including total chlorophyll, Ascorbic Acid (ACA), leaf extract pH, and Leaf Relative Water Content (LRWC)% (Sharma et al. 2017). According to many studies, API and APTI are two essential indices for selecting plants in severely polluted areas (Malav et al. 2022). The ecological approach uniquely uses APTI and socioeconomic criteria to select plant species that help reduce air pollution (Supriya et al. 2025). In addition, the findings of the studied tree species have a high potential for reducing air pollution in the long run and developing green ecomanagement practices. According to Yadav and Pandey (2020) and Rasool et al. (2025), *Ficus benghalensis* was the best performer based on APTI and API value in the greenbelt development to mitigate air pollution. Currently, the urban region of Erbil City, a semi-arid capital in the Kurdistan Region, has experienced a notable increase in pollution due to the rise in automobile numbers and a decreasing green cover. According to research by Rashid and Abdulla (2024), the city requires a minimum of 81 parks and gardens to meet its residents' needs. This research represents the first effort to integrate the Air Pollution Tolerance Index (APTI) with the Anticipated Performance Index (API). The proposed integrated methodology establishes an innovative framework for assessing tree species, enhancing the efficacy of air pollution tolerance evaluation, and contributing new strategies for urban green belt development, in contrast to previous studies that did not use these indices individually. Additionally, there is little research on the tolerance of plant species in Erbil City, Iraq. Therefore, the study aims to assess the (APTI) and (API) of three selected species, *Brachychiton populneus*, *Ligustrum lucidum* and *Olea europaea* in an urban environment, to determine their tolerance levels and potential use in urban areas.

## MATERIALS AND METHODS

### Study site

The city of Erbil is the capital of Kurdistan Region of Iraq. It is called a spider city due to its unique layout that resembles a spider web. This location marks the location of the capital of the Kurdistan Region. Between the latitudes 35 and 37 and the longitudes 43 and 45, it is located in the middle of the range. At a height of 414 meters above mean sea level, it achieves its highest point. Erbil has a climate that may be described as mild to moderate in terms of its circumstances. In the winter, precipitation occurs more frequently than it does in the summer. There is an average temperature of 20.3°C within this city. Every year, there is nearly a total of 560 millimeters of precipitation, and the summer season begins in the month of June and lasts until September.

### Sampling

Four study locations in Erbil were selected altogether: L1 at Sami Abdulrhaman Park, which has less pollution; L2 at the 100 m ring road; L3 at the 60 m ring road; and L4 at the 30 m ring road. Three species were chosen at each location, with all three species present at each site, as shown in Figure 1. For each species, three healthy trees were randomly selected as replicates. Leaf samples were collected from three selected tree species: *Brachychiton populneus*, *L. lucidum* and *O. europaea*. The study was conducted in February 2025, with consistent temperature and rainfall conditions during sample collection. Fully mature leaf samples were randomly gathered in triplicate from all sides of each tree using polyethylene gloves and stainless-steel scissors, as documented by Deljanin et al. (2016). The samples were immediately transported to the laboratory in plastic bags for parameter assessment.

### APTI determination

The following formula was used to determine APTI, as documented by Alotaibi et al. (2020), Yadav et al. (2020), Ali et al. (2021), and Qadir et al. (2022).

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

Where:
A: The ascorbic acid content of the leaf sample (mg $g^{-1}$)
T: The total chlorophyll content (mg $g^{-1}$)
P: The pH of the leaf extract
R: The relative water content (%) of the leaf sample

### Anticipated Performance Index (API)

API was applied according to Prajapati and Tripathi (2008) methodology. API calculation can be done first from the determination of APTI and grading them, and then biological and socioeconomic values for each tree species in all locations need to be determined as indicated in Tables 1 and 2.

**Table 1.** Assessment criteria to evaluate API

| Grade | Score (%) | Evaluation category |
|---|---|---|
| 0 | equal to 30 | Not recommended |
| 1 | 31-40 | Very poor |
| 2 | 41-50 | Poor |
| 3 | 51-60 | Intermediate |
| 4 | 61-70 | Good |
| 5 | 71-80 | Very good |
| 6 | 81-90 | Excellent |
| 7 | 91-100 | Best |

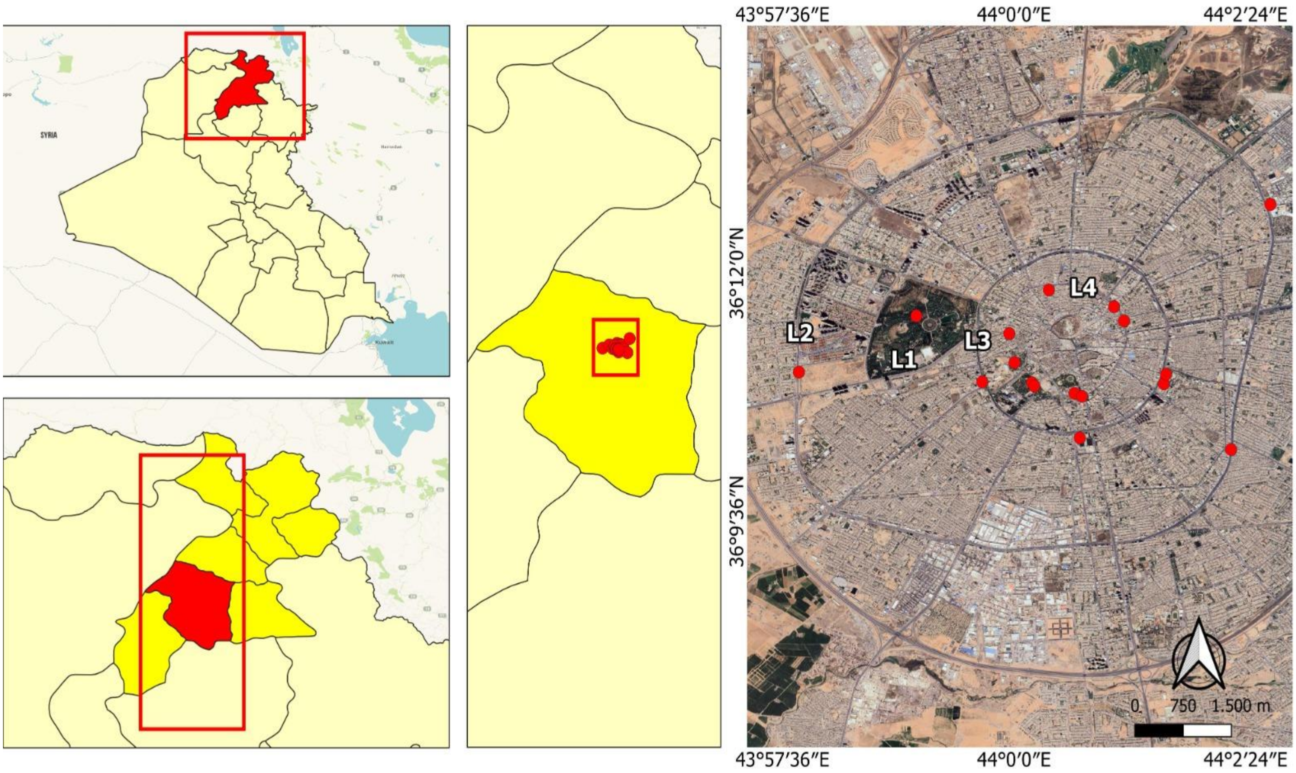

**Figure 1.** The sampling locations in Erbil City, Iraq

**Table 2.** Classification of tree species according to APTI and different biological and socioeconomic features for the assessment of the API of the studied species

| **Biological and socioeconomic, and APTI** | | | **No. of symbols** |
|---|---|---|---|
| APTI | 5-6 | | + |
| | 6.1-7 | | ++ |
| | 7.1-8 | | +++ |
| | 8.1-9 | | ++++ |
| | 9.1-10 | | +++++ |
| TH | Small | | - |
| | Medium | | + |
| | Large | | ++ |
| CS | Sparse/irregular/globular | | - |
| | Spread crown/semi-dense | | + |
| | Spreading dense | | ++ |
| TS | Deciduous | | - |
| | Evergreen | | + |
| LS | Size | Small | - |
| | | Medium | + |
| | | Large | ++ |
| | Texture | Smooth | - |
| | | Coriaceous | + |
| | Hardness | Delineate | - |
| | | Hardy | + |
| EI | Less than three | | - |
| | Three to four | | + |
| | 4 or more than four | | ++ |
| Total plus (+) that can be scored by a plant = 16 | | | Total |

Note: TH: Tree habitat, Cs: Canopy structure, TS: Type of tree, LS: Laminar structure, EI: Economic importance

## Leaf area (cm$^2$)

Leaf areas of sampled leaves were measured by the use of ImageJ software. To calculate the area of a leaf based on an image, first take a photograph of the leaf that is sharp, has a high contrast, and includes a scale reference inside the same frame. Next, use image analysis software, such as ImageJ. If you want to set the scale within the software, you will need to use the reference object. To do this, you will need to go to the Analyse tool and then select the Set Measurements option. From there, you will select the options that correspond to the measurements you want, such as "Area." After that, you will convert the image to a binary format (8-bit) and adjust it. Finally, you will count the pixels in the highlighted area and then calculate the actual area of the leaf by using the scale that you have set. as documented by Sabr (2024).

## Proline (mg g$^{-1}$)

Proline levels in leaf samples were assessed at the central laboratory of the College of Agricultural Engineering Sciences, Mosul University, Iraq. The proline content in three species was assessed using the method established by Agbaire (2016).

## Total carbohydrate (mg g$^{-1}$)

Total carbohydrate in leaf samples was assessed at the central laboratory of the College of Agricultural Engineering Sciences, Mosul University. Total carbohydrates were determined based on the methodology of Nielsen (2010).

### Data analysis

For analyzing the interaction between species and studied locations, a general Randomized Complete Block Design (RCBD) with three replications was used, and the data were statistically analyzed using the mixed procedure in SPSS software version 25. Duncan's method was employed to compare the means of the interaction levels, examining significant differences at F values ($p \leq 0.05$). SPSS software version 25 was also used to determine the correlation matrix between APTI Values and biochemical parameters. Finally, to assess the degree of correlation, regression analyses were performed using Startograph software, and the best equation was selected based on certain criteria to evaluate the performance of the developed model.

## RESULTS AND DISCUSSION

The physiological parameters related to APTI of the three species at all locations showed significant differences between the species (Table 3). It was found that both *B. populneus* and *L. lucidum* have the highest APTI values at Location 3 (12.67±0.33) and at Location 2 (12.00±1.00), respectively, compared to other species, while the lowest values were observed at less polluted locations in *L. lucidum* (6.33±0.88) (Figure 2). The physiological parameters related to APTI of the three species at all locations exhibited significant variations between the species (Table 3). According to Table 3, leaf samples of different species were obtained from several sites, with pH values ranging from 5.70 to 7.1 for *B. populneus*, from 5.48 to 5.57for *O. europaea*, and from 5.04 to 5.45 for *L. lucidum* during the study. All the leaf samples collected from various locations had a pH below 7, except for *B. populneus* from Location 2, which had pH values much higher than the rest of the samples. It was observed that each species demonstrated notable pH variations both within and between sites, except for *O. europaea*, where the pH differences across locations were not statistically significant (Figure 3). The results of the study showed that there was no statistically significant variation in the mean LRWC% across the site tested for *B. populneus* (Figure 4). However, exceptions were noted for *O. europaea*, and *L. lucidum* had the lowest percentages of LRWC% in less polluted locations, with the percentages being 69.11±5.63% and 47.89±11.24%, respectively, as shown in Table 3. On the basis of the four characteristics, it was found that *B. populneus* showed a significant increase in ascorbic acid content (2.76±0.07 mg g$^{-1}$) at Locations 3 and 4, respectively, when compared to the less polluted location; however, the minimum concentration of ACA was recorded for *O. europea* in a less polluted environment (0.75±0.06 mg g$^{-1}$). (Figure 5). There were significant differences in the amount of total chlorophyll in polluted locations compared to better air quality locations (Table 3), while a significant increase in total chlorophyll was observed for *B. populneus* in Location 3 (0.22±0.03 mg g$^{-1}$) (Figure 6). The Air Pollution Tolerance Index (APTI) is computed by comparing the studied tree species from all locations based on biochemical factors. The species' pollution tolerance levels differ according to their scores and grades, with some ranked very good and others as good or moderately good. The findings can help in determining which species are the best suited for planting in contaminated locations (Table 4).

It was found that the leaf area percentage decreased in all species compared to less polluted locations. The smallest reduction in leaf area was observed in both *O. europaea* and *B. populneus* (-9.1% and -33%), while the greatest decrease was obtained in *L. lucidum* (-76%) (Table 5). Proline and total carbohydrates are presented in Table 6 for all locations. Significant differences were observed among the leaf samples of the studied species. The highest proline value was observed in the better-quality location in *L. lucidum* (11.89±0.87 mg g$^{-1}$), compared to other locations, while the lowest value was found in Location 2 (7.50±0.21 mg g$^{-1}$) for the same species. There was no significant variation based on tree species interaction conditions on leaf proline content. Changes in carbohydrate contents per leaf area are presented in Table 6. A significant increase in total carbohydrate content was found in the leaves of *O. europaea* in Location 3 (18.49±6.10 mg g$^{-1}$). Conversely, the lowest values were recorded for *L. lucidum* across all studied locations (Table 6).

**Table 3.** Leaves biochemical parameters and APTI of tree species

| Species | Locations | Leaf pH | LRWC% | ACA (mg g$^{-1}$) | Total Chl. (mg g$^{-1}$) | APTI |
|---|---|---|---|---|---|---|
| *Brachychiton populneus* | L1 | 5.70±0.07 cd | 89.92±1.82 a | 2.10±0.11 b | 0.13±0.02 bc | 11.33±0.33 ab |
| | L2 | 7.10±0.05 a | 84.70±5.18 a | 1.71±0.36 bc | 0.06±0.01 cd | 11.67±1.20 a |
| | L3 | 5.72±0.04 c | 91.12±0.73 a | 2.72±0.16 a | 0.22±0.03 a | 12.67±0.33 a |
| | L4 | 6.11±0.01 b | 76.77±7.31 a | 2.76±0.07 a | 0.03±0.01 d | 10.33±1.20 ab |
| *Olea europaea* | L1 | 5.49±0.08 def | 69.11±5.63 b | 0.75±0.06 d | 0.05±0.01 d | 8.00±0.58 bc |
| | L2 | 5.55±0.06 cdef | 78.09±2.52 a | 1.35±0.10 c | 0.06±0.02 cd | 9.33±0.33 abc |
| | L3 | 5.57±0.05 cde | 79.75±4.29 a | 1.67±0.01 bc | 0.01±0.00 d | 9.67±0.33 ab |
| | L4 | 5.48±0.00 def | 84.92±2.64 a | 1.38±0.14 c | 0.03±0.01 d | 10.00±0.58 ab |
| *Ligustrum lucidum* | L1 | 5.33±0.05 f | 47.90±11.24 b | 1.39±0.04 c | 0.02±0.00 d | 6.33±0.88 c |
| | L2 | 5.45±0.02 ef | 89.60±1.31 a | 1.48±0.04 c | 0.15±0.06 ab | 12.00±1.00 a |
| | L3 | 5.08±0.055 g | 83.44±11.753 a | 1.39±0.06 c | 0.04±0.01 d | 11.00±1.00 ab |
| | L4 | 5.04±0.035 g | 81.18±0.258 a | 1.29±0.14 cd | 0.03±0.00 d | 10.00.±0.00 ab |

Note: Means with different letters indicate a significant differences

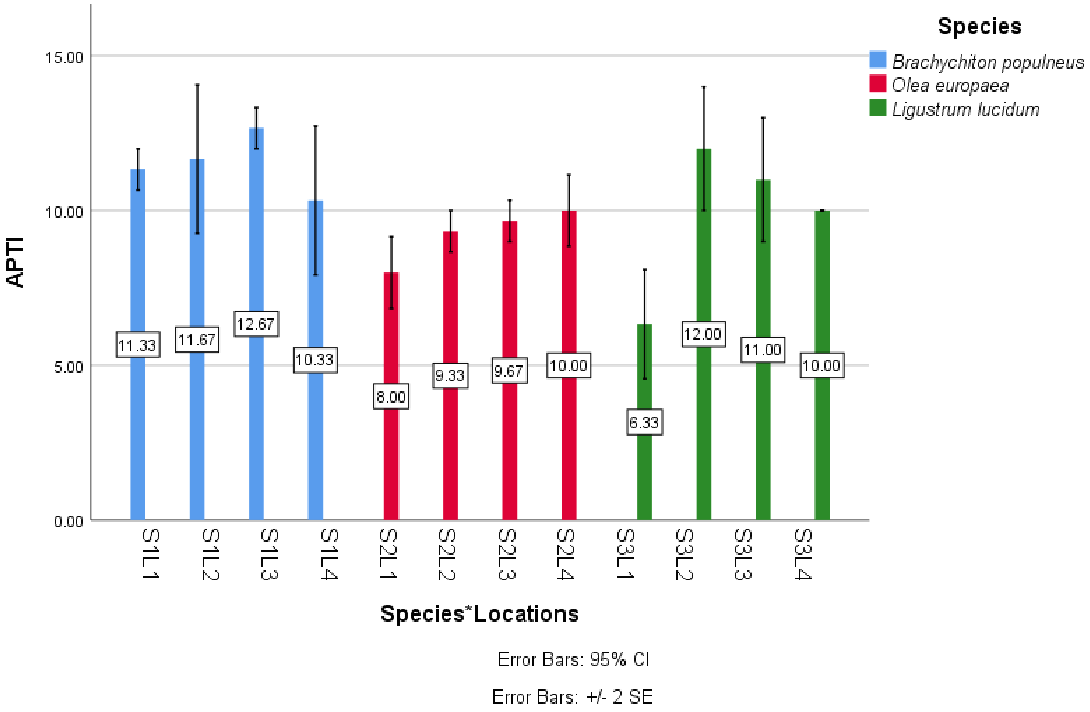

**Figure 2.** APTI variations for *B. populneus, O. europaea,* and *L. lucidum* tree species at study locations

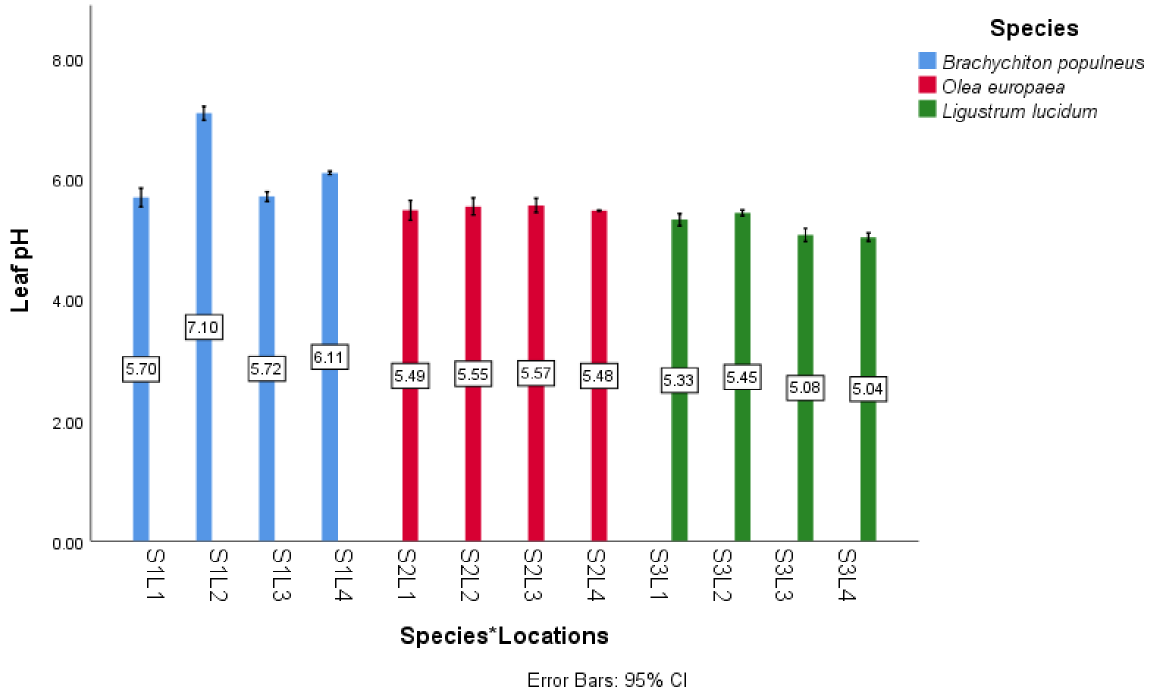

**Figure 3.** pH variations for *B. populneus, O. europaea,* and *L. lucidum* tree species at study locations

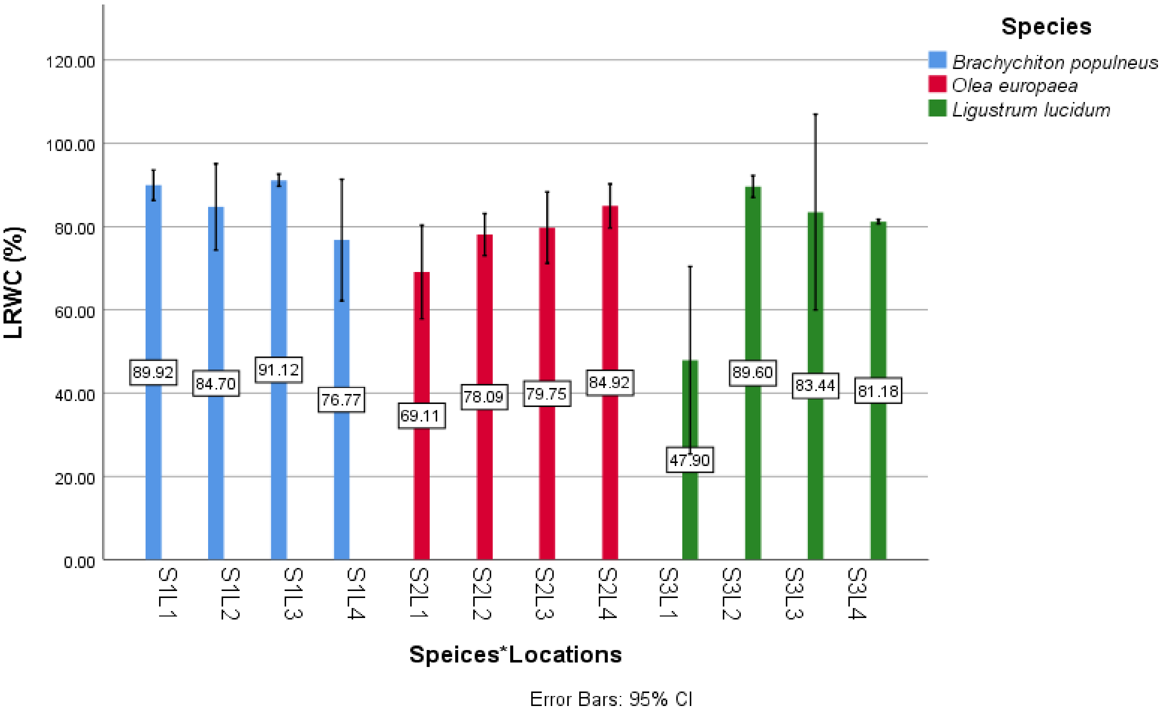

**Figure 4.** LRWC (%) variations for *B. populneus, O. europaea,* and *L. lucidum* tree species at study locations

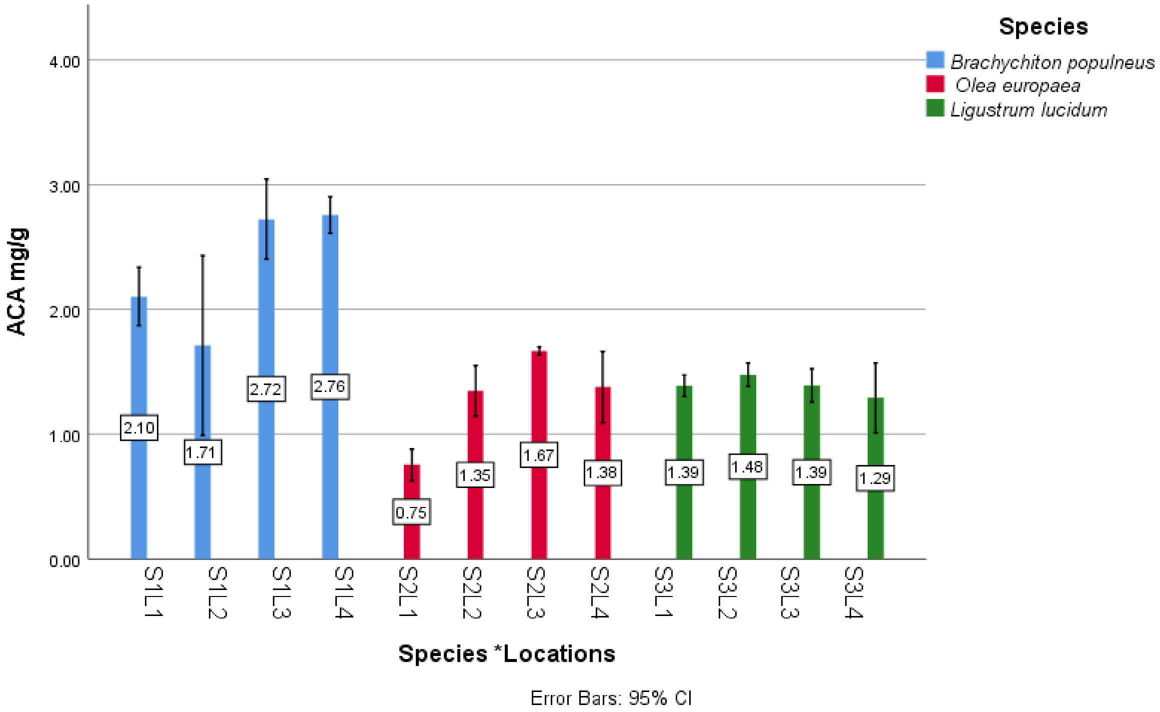

**Figure 5.** ACA (mg $g^{-1}$) variations for *B. populneus, O. europaea,* and *L. lucidum* tree species at study locations

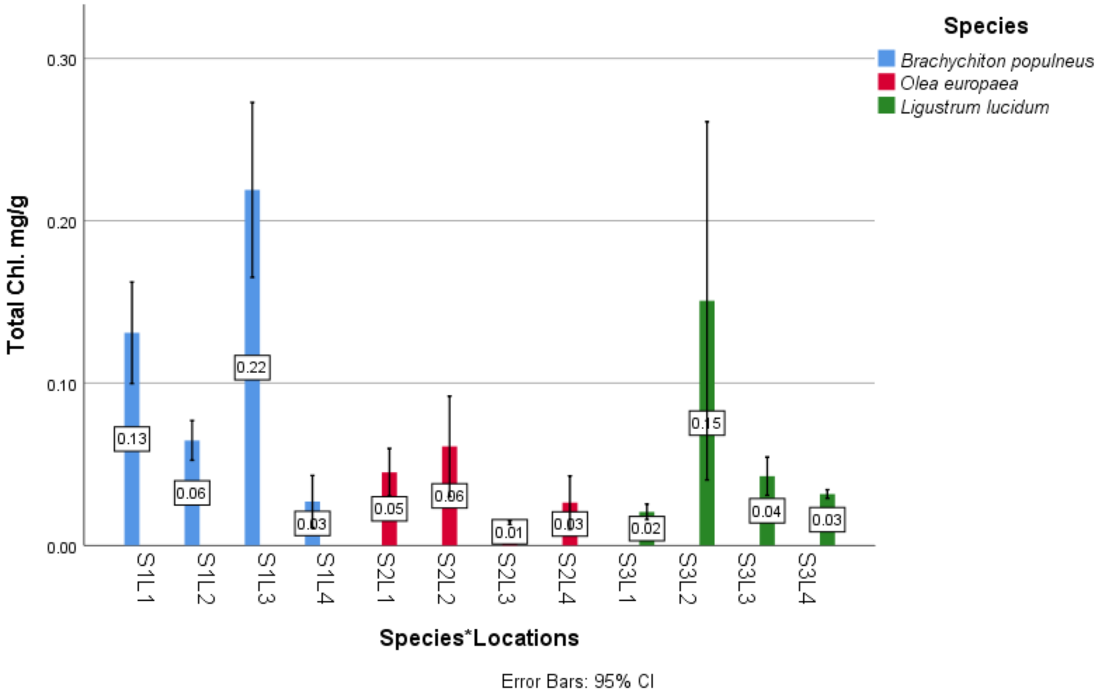

**Figure 6.** Total chlorophyll (mg $g^{-1}$) variations for *B. populneus, O. europaea,* and *L. lucidum* tree species at study locations

**Table 4.** API values for selected tree species in the studied locations

| Tree species | Locations | APTI | Biological and socioeconomic values | Grade allotted | | | API grade | Evaluation |
|---|---|---|---|---|---|---|---|---|
| | | | | Total plus | Grade for any plant species | Score % | | |
| *Brachychiton populneus* | L1 | +++++ | 8 | 13 | 16 | 81.25 | 6 | Excellent |
| | L2 | +++++ | 5 | 10 | 16 | 62.5 | 4 | Good |
| | L3 | +++++ | 7 | 12 | 16 | 75 | 5 | Very good |
| | L4 | +++++ | 6 | 11 | 16 | 68.7 | 4 | Good |
| *Olea europaea* | L1 | ++++ | 7 | 12 | 16 | 75 | 5 | Very good |
| | L2 | +++++ | 5 | 10 | 16 | 62.5 | 4 | Good |
| | L3 | +++++ | 7 | 12 | 16 | 75 | 5 | Very good |
| | L4 | +++++ | 7 | 12 | 16 | 75 | 5 | Very good |
| *Ligustrum lucidum* | L1 | +++ | 6 | 9 | 16 | 56.2 | 3 | Intermediate |
| | L2 | +++++ | 6 | 11 | 16 | 68.7 | 4 | Good |
| | L3 | +++++ | 7 | 12 | 16 | 75 | 5 | Very good |
| | L4 | +++++ | 6 | 11 | 16 | 68.7 | 4 | Good |

**Table 5.** Leaf area percentage reduction (%) in the studied location as compared to the less polluted location

| Tree species | LA ($cm^2$) in L1±SE | Change in leaf area percentage (%) | | |
|---|---|---|---|---|
| | | L1 to L2 | L1 to L3 | L1 to L4 |
| *Brachychiton populneus* | 2.7±0.20 | -22 | -33 | -33 |
| *Olea europaea* | 1.2±0.08 | -71 | -33 | -9.1 |
| *Ligustrum lucidum* | 4.4±0.29 | -41 | -69 | -76 |

### Correlation and regression analysis

The selection of the most appropriate regression equation for predicting the response variable will be based on specific measures of precision used to evaluate its performance (Sabr 2024). It is found that there was a strong positive correlation between APTI and LRWC (R=0.956, p<0.000), indicating that as LRWC increases, APTI tends to increase too (Table 7). The outcome showed that fitting a linear model explained the relationship between APTI and four parameters. There was a significant correlation between APTI and LRWC% at the 95.0% confidence level (F (1, 36)=128.74, P=0.000). The R-Squared statistic indicates that the model explains 79.10% of the variability in APTI. The $R^2$ was 0.89 demonstrates a reasonably strong relationship between the variables (Table 8). The standard error of the estimate shows the residuals' standard deviation is 0.939. The Mean Absolute Error (MAE) of 0.71 is the average residual value (Figure 7).

**Table 6.** Proline and total carbohydrate content in less polluted and polluted locations

| Species | Locations | Proline (mg $g^{-1}$) | Total carbohydrates (mg $g^{-1}$) |
|---|---|---|---|
| *Brachychiton populneus* | L1 | 10.66±0.63 ab | 13.64±2.59 ab |
| | L2 | 10.57±0.89 ab | 13.77±0.28 ab |
| | L3 | 11.04±0.51 ab | 13.51±0.84 ab |
| | L4 | 10.60±0.25 ab | 10.91±0.71 ab |
| *Olea europaea* | L1 | 9.60±0.45 ab | 11.31±0.89 ab |
| | L2 | 9.90±1.71 ab | 7.52±0.58 b |
| | L3 | 10.30±0.43 ab | 18.49±6.10 a |
| | L4 | 9.12±0.17 ab | 9.94±3.15 ab |
| *Ligustrum lucidum* | L1 | 11.89±0.87 a | 5.94±0.08 b |
| | L2 | 7.50±0.21 b | 5.03±2.24 b |
| | L3 | 9.63±0.35 ab | 4.88±0.28 b |
| | L4 | 8.99±1.26 ab | 4.58±0.36 b |

**Table 7.** Correlation matrix between APTI and biochemical parameters

| | | ACA | Total Chl. | Leaf pH | LRWC% | APTI |
|---|---|---|---|---|---|---|
| ACA | Pearson Correlation | 1 | -.212 | .357* | .281 | .514** |
| | Sig. (2-tailed) | | .214 | .033 | .096 | .001 |
| Total Chl. | Pearson Correlation | | 1 | .007 | .193 | .130 |
| | Sig. (2-tailed) | | | .966 | .260 | .449 |
| Leaf pH | Pearson Correlation | | | 1 | .171 | .261 |
| | Sig. (2-tailed) | | | | .320 | .124 |
| LRWC% | Pearson Correlation | | | | 1 | .956** |
| | Sig. (2-tailed) | | | | | .000 |
| APTI | Pearson Correlation | | | | | 1 |
| | N | 36 | 36 | 36 | 36 | 36 |

Note: *: Correlation is significant at the 0.05 level (2-tailed), **: Correlation is significant at the 0.01 level (2-tailed)

**Table 8.** Developed a model for APTI estimation

| Equation No. | Model name | Correlation Coefficient ($R^2$) | Standard Error of Estimates (SEE) | Mean Absolute Error (MAE) |
|---|---|---|---|---|
| 1 | APTI = 7.46646 + 1.63843*ACA | 0.49 | 1.78884 | 1.20415 |
| 2 | APTI = 4.31887 + 1.04264*pH | 0.27 | 1.97713 | 1.51132 |
| 3 | APTI = 0.106804 + 0.126556*LRWC% | 0.89 | 0.939476 | 0.71645 |
| 4 | APTI = 8.95257 + 0.160094*CHL | 0.36 | 1.9107 | 1.45245 |

## Discussion

In all examined locations, trees may be negatively affected by air pollution, with these effects usually visible on their leaves. The pH level in leaves is crucial in regulating plants' sensitivity to pollutants. The acidic nature of pH may result from the entry of gaseous air pollutants such as $NO_2$, $CO_2$, and $SO_2$ into the cell sap, leading to the formation of acid radicals (Dash and Dash 2018). It can be seen that the breakdown of hexose sugar into ascorbic acid is reduced considerably when the pH level is low (Bora and Joshi 2014), while alkaline pH enhances the reducing activity of ascorbic acid, resulting in potentially elevating plants' tolerance to air pollution (Bora and Joshi 2014). The pH values observed in the current study correspond to the findings of a previous investigation by Aji et al. (2015), which documented a pH range of 4.6 to 6.7 in on-road trees, specifically *Anacardium occidentale*, *Azadirachta indica*, *Cassia angustifolia*, *Eucalyptus* spp., *Khaya senegalensis,* and *Mangifera indica*, sampled from three different sites. In addition, a study conducted by Tsega and Prasad (2014) found that plant species collected from the roadsides of Mysore in India, were found to have a pH range that was between 5.89 to 6.37. Some earlier papers that supported our findings consisted of Salaa and Al-Kawaz (2017), Karmakar and Padhy (2019), and Yadav et al. (2020).

A statistical analysis found that site air pollution had no observable effect on the LRWC. Even though slight differences were observed between the sites, they were not statistically significant, and this indicates that air pollution levels mainly reduced leaf relative water content. It has been shown to increase plant cell permeability, leading to water loss and early leaf senescence (Dhankhar and Rana 2016). The LRWC of plant leaves is connected with protoplasmic permeability and increased levels during tension circumstances, enhancing plant tolerance to air contaminants (Bahadoran et al. 2019). Increased water content in plants can neutralize the acidity within leaf cell sap and enhance the resistance to water stress (Kaur and Nagpal 2017). An elevated percentage of LRWC in plants enhances their resistance and improves tolerance to stress conditions caused by pollution (Gupta et al. 2016). It was reported that the lowest relative water content was found in polluted areas of Baghdad city, which was lower than the values obtained in polluted locations for the same species in our study. A comparable result regarding relative water content was previously documented by Seyyednejad et al. (2011). Yadav and Pandey (2020) stated that the loss of water is a result of increased permeability, which eventually leads to the premature senescence of tree leaves.

ACA serves as an antioxidant, thus it can influence plants' tolerance to air pollution (Pathak et al. 2011). The amount of ACA in all studied species in better quality air was less than in polluted locations. An increased in concentration of ascorbic acid in leaves has been determined to enhance air pollution tolerance in plants (Mittler 2002). The elevated ACA concentration may serve as a good mechanism of protecting thylakoid membranes from oxidative damage during conditions involving strain due to water limitation (Tambussi et al. 2000). This may be attributed to the role of ACA in protecting in opposition to reactive oxygen species generated by the photosynthetic system (He and Häder 2002). Previous researchers in many locations of the world have revealed corresponding findings regarding the concentration of ACA in collected leaves (Kaur and Nayyar 2014; Pandey et al. 2015, 2016). Due to elevated pollution levels in the study area, the examined species may demonstrate resistance and increased tolerance throughout all locations. A number of studies, including those by Jain et al. (2018), Karmakar and Padhy (2019), Sharma et al. (2019), and Yadav et al. (2020), have reported elevated amounts of ascorbic acid, corroborating our findings. The citrus plants indicated an increased in ascorbic acid content at the private generating site (AlObaidy and Rabee 2018). The significant seasonal impact on ascorbic acid levels in oleander leaves is evidenced by a test result indicating that superior values in the fall season compared to those in other locations, with a recorded value of 0.8267 mg/g during the Sawas area in Mosul city (Al-Healy and Ibrahim 2022). Salih and Al-Adily (2017) found that the quantities of ascorbic acid in the two plants that were evaluated were very low in comparison to the current study.

The total chlorophyll level indicates the photosynthetic activity and growth of plants (Ninave et al. 2001). In a highly structured form, chlorophyll could go through many photochemical processes, comprising oxidation and reduction, that can be reversed at any point (Puckett et al. 1973). Upon entry through stomata, $SO_x$, $NO_x$ stimulate partial denaturation of chlorophyll, thereby leading to a significant reduction in the total chlorophyll of the leaves that were polluted (Rai 2016). Other published studies, such as Achakzai et al. (2017), Kaur and Nagpal (2017), and Karmakar and Padhy (2019), also reported a lower total chlorophyll was also reported at polluted sites compared to control sites. There is a direct conflict between this and the findings of the current investigation. In contrast to the conclusions of the present investigation, contrary to the present findings found that contaminated sites had a lower chlorophyll concentration than control sites. Finally, the findings of the investigation by Ahmed and Sabr (2020) and Sabr (2023) revealed that the control site had the highest mean values of total chlorophyll in comparison to the polluted areas. The citrus plants indicated increased chlorophyll content at the private generating site (AlObaidy and Rabee 2018).

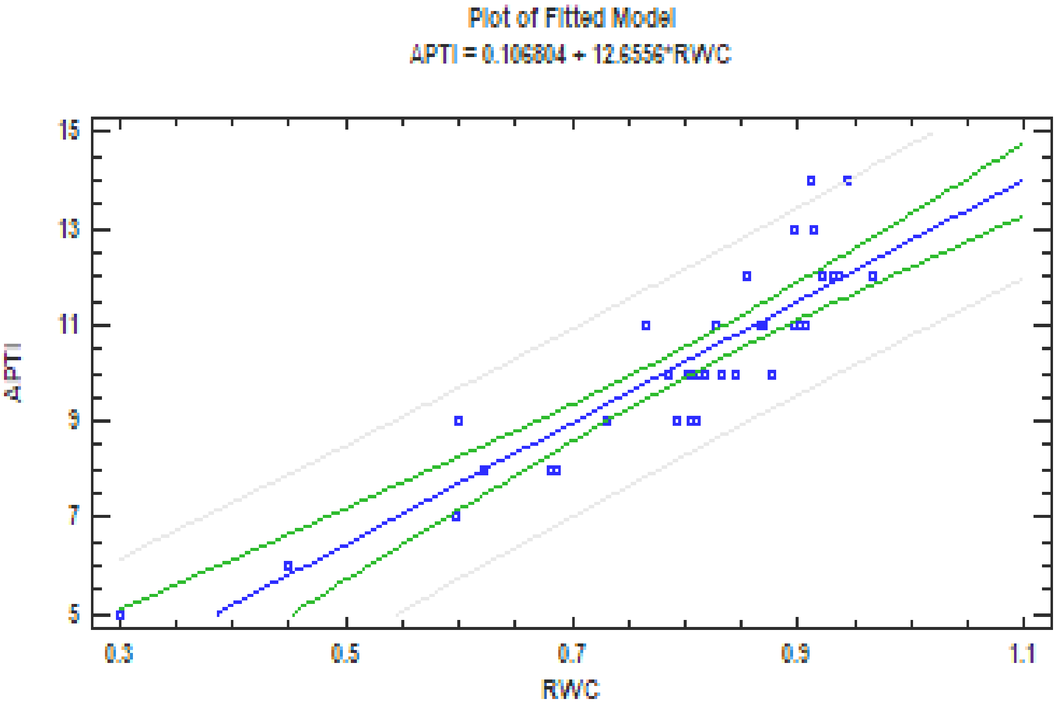

**Figure 7.** Regression analysis between APTI and RWC% variables

Leaf area is an important physiological and morphological parameter in plant growth. Understanding the causes of the reduction in leaf area (%) is also essential for tree ecology. It is shown that all species experienced a decrease in leaf area compared to areas with better air quality. This study may establish a baseline for using leaf area reduction as an early biomarker of contamination-induced stress in plants, as documented by de la Paz Pollicelli et al. (2018). The results of the study by Leghari and Zaidi (2013) suggested that the percentage reduction in leaf qualities in contaminated plants was greater compared to non-polluted plant species. That may primarily result from the exposure of plants to air contaminants originating from automotive emission sources. The increased mean leaf area was observed in less polluted locations compared to others; conversely, the lowest mean values were recorded at Gulan Road in Erbil City. This phenomenon can be attributed to the penetration of pollutants, specifically gases such as $O_3$ and $SO_2$, through the opening and closing of leaf stomata (Ahmed and Sabr 2020). In the present study, the reduction of leaf area measured in the polluted locations is in accordance with findings by Tiwari et al. (2006) and Alotaibi et al. (2020).

The present study indicates that each index used can play a crucial role in determining plant sensitivity to pollution stress, as highlighted by Singh et al. (1991). Assessing tree responses based on only one criterion may be impractical in the complex context of an urban industrial environment, where various unidentified pollutants exist. Additionally, many researchers suggest that combining different parameters can provide more reliable results than relying solely on a single biochemical parameter. Therefore, combining four parameters is recommended as the optimal index for assessing the sensitivity levels of trees in open field conditions, as stated by Das and Prasad (2010). *Brachychiton populneus* was identified as the most tolerant tree species suitable for planting along urban parks and gardens. Furthermore, tree species categorized as intermediate, good, and very good are considered suitable candidates for landscaping near polluting industries (Tsega and Prasad 2014). The socioeconomic importance of these trees is well recognized, and they may be recommended for greenbelt planting as a first barrier. All three species were found to perform exceptionally well, particularly in Location 3, while other sites showed outstanding, good, or intermediate performance. It can be observed that *O. eurpea* has a higher API, making it suitable for use as a pollution sink. Conversely, *B. populneus* and *L. lucidum* are attractive trees that can enhance the visual appeal of city areas. *Ficus altissima* was selected as the best species in a study by Alotaibi et al. (2020) because it performed well across all measurements. *Ficus altissima* is the species recommended for planting in industrial regions prone to heavy metal pollution. The same criteria were used by Yadav and Pandey (2020) for *A. indica* and *Melia azedarach*, which performed well in developing green belts in and around metropolitan areas based on API.

A study on proline's response to different stresses found that an increase in osmolytes like proline in leaves may suggest a mechanism of adaptation to unfavorable conditions (Regni et al. 2019). According to Iqbal et al. (2014), proline improves water retention in the cytoplasm, and higher levels seem to correspond to a specific method plants use to better cope with stress. It was discovered that in less polluted areas, the proline content in *L. lucidum* was higher than in other areas. Some authors indicate that proline concentrations are generally higher in stress-tolerant plants compared to stress-sensitive ones under stress conditions (Anjum et al. 2011). The study by Kijowska-Oberc et al. (2023) reported that proline accumulation responses are more pronounced in deciduous plants, which are considered more susceptible to drought conditions. Proline accumulation levels in seedlings of various tree species may reflect how much species are affected by adverse environmental conditions. Using this information in forest management can help predict drought-induced tree mortality (Kijowska-Oberc et al. 2020). A study indicates that proline levels in leaves exposed to air pollution have significantly increased, suggesting that proline may act as a free radical scavenger, protecting plants from oxidative stress damage (AlObaidy and Rabee 2018). Studies by Noreen et al. (2018) demonstrate that the positive effect of proline is partly due to limiting metal uptake or translocation. Notably, some studies have shown that the addition of proline can increase the uptake and buildup of metals in plants (Yu et al. 2017). Applying proline as an external stress mitigator for plants exposed to metals could produce beneficial results.

Many studies across different species have found that seasonal changes in carbohydrate reserves are moderate in mature trees, indicating that a significant portion of the stored carbon is not used under 'normal' conditions but can be remobilized for recovery and re-growth after environmental stress (Hartmann et al. 2018). Except for the total carbohydrate level at locations 2 and 3 of *O. eurpea*, the carbohydrate content in polluted leaves was generally lower than in leaves from areas with better air quality (Table 6). Zhao et al. (2021) reported that the lowest soluble sugar content in leaves was found in areas with high-traffic roads. Our results align with those of Liang et al. (2008) and Zhao et al. (2021), who observed a reduction in soluble sugar in all examined species, including *L. lucidum*, in contaminated areas. Pollutants are believed to inhibit photosynthesis in leaves, reducing the availability of soluble sugars (Irerhievwie et al. 2014). One inhibitory effect involves the blockage of light by airborne particulate matter, and another involves the clogging of stomatal pores caused by deposition on the leaf surface (Bae et al. 2009). The concentration of sugar in plant leaves may decline due to environmental pollutants like $SO_2$ and $NO_2$, as reported by Rai (2016). These contaminants rapidly impair photosynthesis while simultaneously increasing respiration rates associated with ATP synthesis to enhance pollutant removal activities (Pandey et al. 2016). Seyyednejad and Koochak (2011) found that total soluble sugar content in plant leaves decreased in areas affected by pollution. This study replicates that phenomenon through research on certain plant species. Typically, these plants produce significant amounts of sugar molecules to regulate various metabolic and physiological processes. The amount of total soluble sugar varied among the plant species when exposed to different levels of air pollution at selected study sites (Banerjee et al. 2021).

In conclusion, a study estimates the capability of three tree species to serve as the most persistent and suitable sinks for air pollution in Erbil City. Tree species with higher APTI and API scores may be planted in areas with increased air pollution levels. APTI = 0.106804 + 0.126556*LRWC% was chosen to predict APTI because it contains acceptable values of the coefficient of determination, SEE, and MAE. In Erbil, the government plans to establish a green belt around the city using this technique, which may assist the city director in selecting the appropriate tree species while being less expensive and time-consuming. The city should prioritize the selection of suitable tree species for greenbelt expansion based on this study's findings. These results provide valuable guidance for policymakers and urban planners in identifying resilient species for sustainable urban greening and air pollution mitigation in semi-arid environments. However, the study was limited to one season and three species, focusing solely on leaf biochemical indicators without direct measurements of air or soil pollutants. Future research should incorporate multi-seasonal observations, a wider range of species, and pollutant monitoring to enhance model reliability and support broader greenbelt initiatives across Iraq.

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