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POTENTIAL USE OF MEMBERS OF GENUS *Bougainvillea* IN ALLEVIATING ENVIRONMENTAL POLLUTIONS

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ABSTRACT

Background: The present day environment in many urban areas is greatly polluted due to industrialization and over-exploitation of available natural resources. An acceptable way of combating this menace is bioremediation.

Objectives: The leaves of five species of genus *Bougainvillea*, an attractive plant used in landscaping, were studied anatomically in order to document their taxonomic properties and establish their potential in mitigating environmental pollution.

Methods: Epidermal peels were made following standard procedure. The epidermal cells – shape and size, anticlinal wall patterns, stomata shape, type and dimension as well as the stomata index of each of the species were studied and documented.

Results: The epidermal characteristics of *Bougainvillea* species show more similarities than differences. All species have polygonal epidermal cells, straight anticlinal walls, elliptic stomata, and stomata complexes that are anisocytic, tetracytic, anomocytic, and heptacytic. They also possess multicellular uniseriate non-glandular trichomes. Hexacytic stomata were observed in all species except *B. glabra*. Octacytic stomata type was observed only in *B. peruviana*. The leaves of *B. spectabilis* and *B. peruviana* are hypostomatous. Raphides were observed only in *B. brasiliensis*. Typically, the stomatal index value was higher on the abaxial surfaces compared to the adaxial surfaces, while the stomatal size was lower on the abaxial surfaces than on the adaxial surfaces, except for the two hypostomatic species.

Conclusion: The stomata distribution, stomata size and stomata index values observed in the *Bougainvillea* species established the effectiveness of the plants in transpiration and photosynthesis and also confirm the ability of the plants to help in improving air quality.

Keywords: *Bougainvillea*, Stomata Index, Pollution, Taxonomy, Stomata Complex

INTRODUCTION

Living in a serene, well landscaped environment has a substantial effect on human health. The significance of this cannot be overemphasized because plants can improve the overall health and well-being of humans especially the urban residents (Sullivan and Chang, 2017). Urban areas tend to have more air pollution due to the increased concentration of cars and factories, so, having plants in urban areas can help to improve air quality (Sharma *et al*., 2005). Plants can also reduce stress levels by providing a calming, natural environment. They can help to repel insects and pests; boost productivity and focus by creating a more pleasant and stimulating environment as well as improve physical health by providing opportunities for exercise and recreation (Sullivan and Chang, 2017). Plants have also been reported to improve mental health by providing a sense of connection to nature and reducing feelings of isolation (Ijaz *et al*., 2017).

Stomata, tiny pores on leaf surfaces, facilitate the exchange of gases, enabling plants to absorb carbon dioxide and release oxygen and water vapour (Dhea and Entin, 2021). Essentially, when a plant takes in carbon dioxide through its stomata, the carbon dioxide interacts with the chlorophyll pigment in the leaves. This interaction triggers photosynthesis, the process which produces oxygen and energy for the plant. At the same time, the stomata on the plants release water vapour into the air (Ciais *et al*., 1997; Xiong and Flexas, 2020). The released water vapour is thought to help to purify the air by removing some of the pollutants, such as carbon monoxide and sulphur dioxide (Sharma *et al*., 2005). Stomata thus play a major role in carbon and water cycles. Plant stomata also functions in photosynthesis and transpiration (Titus *et al*., 2023). Also, the study of stomata features in plants has been established to have taxonomic significance (Wang *et al*., 2007).

Members of genus *Bougainvillea* naturally beautifies the environment where they grow or are cultivated (Salam *et al*., 2017). They are popular as ornamental plants because of their colorful flowers, which can be purple, red, pink, orange, or white. They originate from South America. They possess thorns on their stem (Xuan *et al*., 2011), which may likely discourage their cultivation in some environments especially where there are little children or elderly ones. The genus is part of the Nyctaginaceae family, often referred to as the Four O'clock family, and includes 11 recognized species (Bautista *et al*., 2022). The comprehensive morphological characteristics of the genus have been recorded (Kobayashi *et al*., 2007; Chew, 2010; Xuan *et al*., 2011; Shilpi *et al*., 2016; Najmaddin and Saeed, 2020). *Bougainvillea* plants are also known for being drought-tolerant, so they are a good choice for xeriscaping and low-water gardens (Kobayashi *et al*., 2007). They are even known to be resistant to pests and diseases, making them low-maintenance plants (Chew, 2010).

There is a dearth of publication on the foliar anatomy of *Bougainvillea* species, especially the species growing in Nigeria. The aim of this study is to document the foliar anatomical characteristics of some *Bougainvillea* species and assess their potential effectiveness as air purifying agents.

Materials and Methods

Plants Materials

The plant materials utilized for this study belong to genus *Bougainvillea*. Five species were involved, they are: *Bougainvillea glabra* Choisy, *Bougainvillea peruviana* Humb. and Bonpl., *Bougainvillea buttiana* Holttum and Standl., *Bougainvillea spectabilis* Wild, and *Bougainvillea brasiliensis* Wied. Fresh plant specimens of each of the species were collected at various locations in Ile-Ife, Osun State, Nigeria (7.4905° N, 4.5521° E).

Epidermal Peels

Epidermal peels of the adaxial (upper) and abaxial (lower) surfaces of well extended part of the leaves of each of the species were made using scrape technique in which the required epidermis was obtained by scraping off the unrequired epidermis and the mesophyll layer using a razor blade. This method was as prescribed by Metcalfe (1960) and modified by Arogundade and Adedeji (2016). A minimum of five replicates was made for the two surfaces of each of the species. The epidermal peels were stored in 50% ethanol until mounting. They were later washed in clean water and stained with Safranin O for about 3-5 minutes. The stained peels were carefully rinsed with water to remove excess stain and then mounted on a glass slide using 2-3 drops of glycerol solution.

Microscopy

The specimens were observed with the aid of an Olympus XSZ-107BN binocular biological microscope factory-made by Zenith Laboratories, California at x400 (high power) magnification. Photomicrographs of the upper and lower epidermal surfaces were captured using an AmScope camera mounted on the eyepiece of the microscope.

Epidermal Studies

Epidermal characters studied include epidermal cell shape, anticlinal wall pattern, stomata shape, types and size as well as trichomes. The qualitative characters were studied by direct observation while the quantitative characters were either measured or counted. The dimensions of the long and short axes of the epidermal cells, as well as the length and width of the stomata, were measured and utilized to calculate the epidermal cell area and stomatal area, respectively. Measurements were made using a calibrated ocular lens. The values were later converted to micrometer (µm) by multiplying them with the ocular constant relative to the magnification at which they were measured. Counts of epidermal cells, subsidiary cells and stomata made were used to calculate the Stomata Index. The Stomatal Index was determined by expressing the number of stomata per unit area as a percentage of the total number of epidermal cells in the same unit area. It is expressed by the formula:

Stomata Index (S.I) = S /S+E X 100

Where, S= Number of stomata per unit area;

S+E= Number of subsidiary cells plus epidermal cells in the same unit area.

Statistical Analysis

The data gotten from this work were subjected to Univariate Analysis, Single Linkage Cluster Analysis (SCLA) and Principal Components Analysis (PCA) using the Paleontological Statistics Software Package (PAST).

Results

Epidermal Studies

The key qualitative foliar epidermal features of the adaxial/upper and abaxial/lower surfaces of the *Bougainvillea* species are summarized in Tables 1 and 2 respectively, while Table 3 shows the quantitative foliar epidermal features of the two surfaces of the species. Table 4 displays the eigenvalue and the percentage of total variation explained by the first two ordination axes components. Plates 1 and 2 show the photomicrographs of the adaxial and abaxial surfaces of the species respectively. Figure 1 is the Single Linkage Cluster Analysis (SCLA) dendrogram of the *Bougainvillea* species; while Figures 2 and 3 are the Principal Components Analysis showing the relationship of the *Bougainvillea* species centred on their quantitative foliar epidermal attributes.

Epidermal Cell Attributes of the Adaxial Surfaces

The shape of the epidermal cells of *B. brasiliensis* are polygonal to irregular with straight to slightly undulating anticlinal wall pattern. Their arrangement and sizes vary. Epidermal cell area has a mean value of 1173.00 ± 90.06 μm^2. The leaf has stomata on both surfaces, that is, amphistomatous and the stomata are restricted to the non-venous regions. The dominant type of stomata is Anomocytic. The other types occasionally observed are anisocytic, tetracytic and hexacytic (Plate 1 A). The stomata are elliptic in shape with a mean area value of 753.25 ± 31.19 μm^2 and mean stomata index value of 8.97 ± 0.47 %. Multicellular uniseriate non-glandular trichomes are present. Raphides were observed on this surface (Plate 1 B & C; Tables 1 & 3).

In *B. glabra*, the epidermal cells are polygonal to irregular in shape with straight to slightly undulating anticlinal wall pattern. Their arrangement and sizes also vary. Epidermal cell area has a mean value of 931.50 ± 51.87 μm^2. The leaf has stomata on both surfaces, that is, amphistomatous and the stomata are restricted to the non-venous regions. The dominant stomata type is hexacytic. The other types observed are tetracytic and Anomocytic. The stomata are elliptic in shape with a mean area value of 879.38 ± 51.54 μm^2 and mean stomata index value of 11.69 ± 0.78 %. Multicellular uniseriate non-glandular trichomes are present (Plate 1 D, E & F; Tables 1 & 3).

For *B. spectabilis*, the shape of the epidermal cells is polygonal with straight anticlinal wall pattern. Their arrangement and sizes also vary. Epidermal cell area has a mean value of 763.25 ± 51.86 μm^2. The leaf is hypostomatous as no stomata was observed on this surface. Multicellular uniseriate non-glandular trichomes are present (Plate 1 G & H; Tables 1 & 3).

For *B. buttiana*, the epidermal cells are polygonal in shape with straight anticlinal wall pattern. Their arrangement and sizes also vary. Epidermal cell area has a mean value of 1262.25 ± 61.64 μm^2. The leaf has stomata on both surfaces, that is, amphistomatous and the stomata are restricted to the non-venous regions. The principal type of stomata is anomocytic. The other types observed are heptacytic, tetracytic and hexacytic. The stomata are generally elliptic to circular in shape. Stomata area has a mean value of 672.75 ± 29.71 μm^2 and the stomata index, a mean value of 8.84 ± 0.41 %. Multicellular uniseriate non-glandular trichomes are present (Plate 1 I, J & K; Tables 1 & 3).

In *B. peruviana*, the shape of the epidermal cells is polygonal and the anticlinal wall pattern is straight to slightly undulating. Their arrangement and sizes also vary. Epidermal cell area has a mean value of 1191.00 ± 65.41 μm^2. The leaf is hypostomatous as no stomata was observed on this surface. Multicellular uniseriate non-glandular trichomes are present (Plate 1 L & M; Tables 1 & 3).

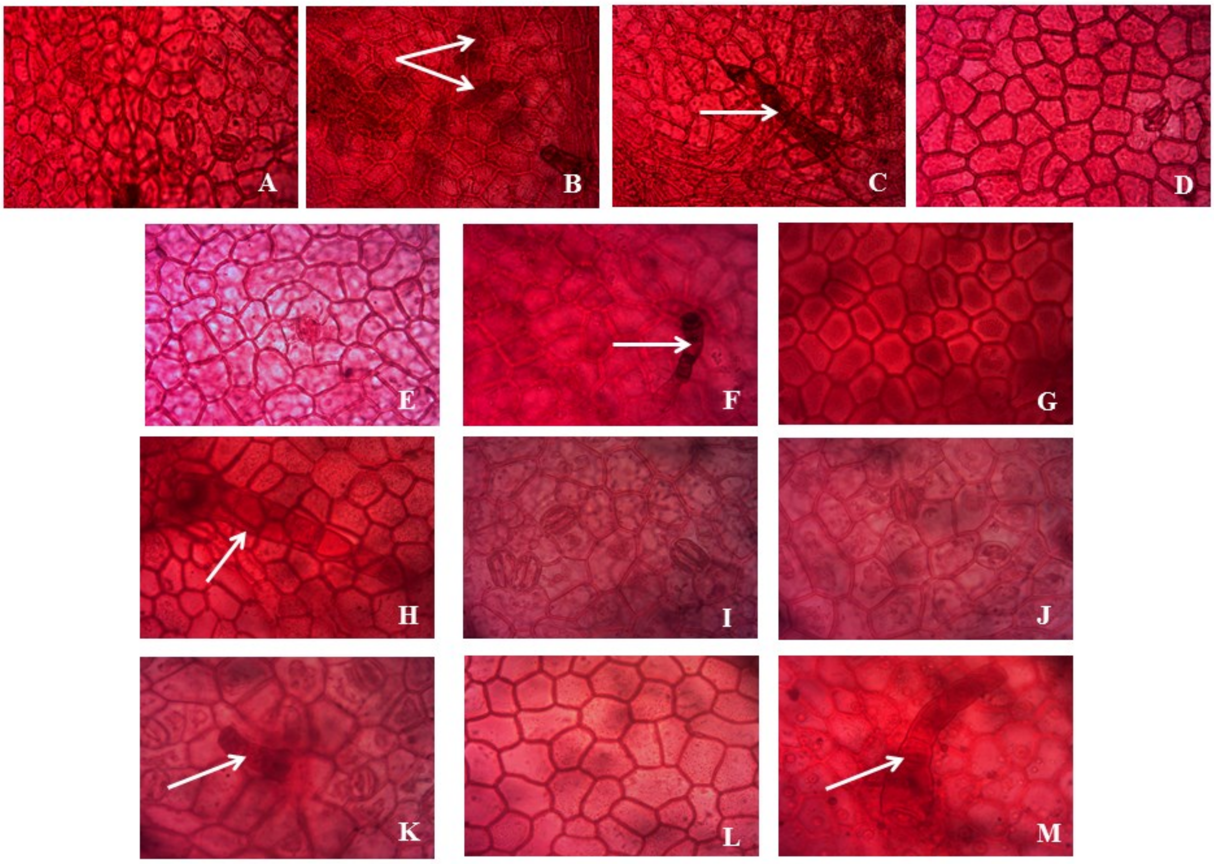

Plate 1: Adaxial Leaf Epidermal surfaces (x400)
Legend: A= *B. brasiliensis;* B = *B. brasiliensis* (Raphide arrowed); C = *B. bransiliensis* (Trichome arrowed); D & E= *B. glabra*; F= *B. glabra* (Trichome arrowed); G= *B. spectabilis*; H= *B. spectabilis* (Trichome arrowed); I & J= *B. buttiana*; k= *B. buttiana* (Trichome arrowed); L= *B. peruviana*; M= *B. peruviana* (Trichome arrowed)

Table 1. Summary of Key Qualitative Features of Adaxial Foliar Epidermis in Studied Species

Species	Epidermal cell shape	Anticlinal wall pattern	Stomata shape	Stomata type	Trichome type and other cell inclusions
B. brasiliensis	Polygonal to irregular	Straight to slightly undulating	Elliptic	Anomocytic Anisocytic Tetracytic Hexacytic	Multicellular uniseriate non-glandular Raphides
B. glabra	Polygonal to irregular	Straight to slightly undulating	Elliptic	Anomocytic Tetracytic Hexacytic	Multicellular uniseriate non-glandular
B. spectabilis	Polygonal	Straight	Nil	Nil	Multicellular uniseriate non-glandular
B. buttiana	Polygonal	Straight	Elliptic occasionally circular	Anomocytic Heptacytic Hexacytic Tetracytic	Multicellular uniseriate non-glandular
B. peruviana	Polygonal	Straight to slightly undulating	Nil	Nil	Multicellular uniseriate non-glandular

Abaxial Epidermal Cell Surface

The shape of the epidermal cells of *B. brasiliensis* is polygonal and the anticlinal wall pattern is straight; the cells vary in size and arrangement. Epidermal cell area has a mean value of 891.00 ± 40.35 μm^2. Stomata were observed only in non-venous regions of the leaves. The dominant stomata type is anomocytic. The other types observed are tetracytic, hexacytic and heptacytic. The stomata are generally elliptic in shape. Stomata area has a mean value 627.5 ± 28.83 μm^2 and the stomata index, a mean value of 19.30 ± 0.63 %. Multicellular uniseriate non-glandular trichomes are present and cuticular striations were observed (Plate 2 A & B; Tables 2 & 3).

In *B. glabra*, the epidermal cells are mostly polygonal in shape with straight anticlinal wall pattern as well as varying sizes and arrangements. Epidermal cell area has a mean value of 1161.75 ± 70.36μm^2. Stomata are confined to non-venous areas with anomocytic type being the dominant stomata type. The other types observed are anisocytic, tetracytic and heptacytic. The stomata are generally elliptic in shape. Stomata area has a mean value of 795.75 ± 26.37 μm^2 and the stomata index, a mean value of 23.07 ± 0.63 %. Multicellular uniseriate non-glandular trichomes are present and cuticular striations were also observed (Plate 2 C, D, E & F; Tables 2 & 3).

In *B. spectabilis*, the shape of the epidermal cells is irregular with wavy to undulating anticlinal wall pattern. They have varying sizes and arrangements. Epidermal cell area has a mean value of 8985.63 ± 626.59 μm^2. The leaves are hypostomatous and stomata are restrained to non-venous areas. The dominant stomata type is anomocytic. The other types observed are anisocytic, tetracytic, hexacytic and heptacytic. The stomata are generally elliptic but occasionally circular in shape. Stomata area has a mean value 7426.88 ± 368.97 μm^2 and the stomata index, a mean value of 22.88 ± 0.55 %. Multicellular uniseriate non-glandular trichomes are present (Plate 2 G, H & I; Tables 2 & 3).

In *B. buttiana*, the shape of the epidermal cells is polygonal to irregular and the anticlinal wall pattern is straight. The cells have varying sizes and arrangements. Epidermal cell area has a mean value of 777.50 ± 61.06 μm^2. Stomata are restricted to non-venous regions. The dominant stomata type is Anomocytic. The other types observed are anisocytic, tetracytic, hexacytic and heptacytic. The stomata are generally elliptic in shape but occasionally circular. Stomata area has a mean value of 646.00 ± 22.23 μm^2 and the stomata index, a mean value 28.56 ± 1.23 %. Multicellular uniseriate non-glandular trichomes are present (Plate 2 J, K & L; Tables 2 & 3).

In *B. peruviana*, the epidermal cells have irregular shape with wavy to undulating anticlinal wall pattern. The cells have varying sizes and arrangements. Epidermal cell area has a mean value of 1073.00 ± 71.87 μm^2. The leaves are hypostomatous and stomata are limited to non-venous areas. The dominant stomata type is anomocytic. The other types observed are anisocytic, tetracytic, hexacytic, heptacytic and octacytic. The stomata are generally elliptic but occasionally circular in shape. Stomata area has a mean value of 1040.25 ± 37.72 μm^2 and the stomata index, a mean value of 24.62 ± 1.10 %. Multicellular uniseriate non-glandular trichomes are present. (Plate 2 M, N & O; Tables 2 & 3).

Discussion

Leaf anatomy offers a range of characteristics useful for taxonomic classification. Anatomical features hold significant taxonomic value because they are less influenced by environmental factors (Stace, 1980, Hetherington and Woodward, 2003, Kalita *et al*., 2020). Numerous researchers have employed leaf anatomical features to address taxonomic issues across various plant species, highlighting the environmental significance of their findings. These include Illoh (2008) on *Celosia,* Adedeji and Illoh (2004) on *Hibiscus*, Adedeji (2004) on *Emilia*, Arogundade and Adedeji (2019a) on *Alocasia* and Titus *et al*. (2023) on *Plectranthus.*

The epidermal characteristics of the five *Bougainvillea* species showed more similarities than differences, reflecting their classification within the same genus. All species exhibited polygonal epidermal cell shapes, straight anticlinal wall pattern, elliptic stomata shapes, and the presence of tetracytic, anomocytic, and hexacytic stomata complexes on the adaxial surfaces. Dhea and Entin, 2021 affirms the fact that more than one stomata type can occur together on the same plant organ. Xuan *et al*. (2011) also reported polygonal epidermal cell shape with straight anticlinal wall pattern for *B. spectabilis*. Likewise, Najmaddin and Saeed (2020) reported hexacytic stomata types for some cultivars of *B. glabra*. The few exceptions to the similarities stated above, which are of taxonomic significance in the genus, include polygonal to irregular epidermal cell shape found on the adaxial surfaces of *B. brasiliensis* and *B. glabra*; slightly undulating anticlinal wall pattern on the adaxial surfaces of *B. brasiliensis*, *B. glabra* and *B. peruviana*; occasionally circular stomata shape found only on the adaxial surface of *B. buttiana* and anisocytic stomata type observed in *B. brasiliensis* as well as heptacytic stomata type observed in *B. buttiana.* Arogundade and Adedeji (2016) and Musila *et al*. (2017) among other researchers have employed epidermal cell shape, anticlinal wall pattern and stomata shape in separating plant species.

Worthy of note is the distribution of stomata on the surfaces of the leaves of the *Bougainvillea* species. Three of the five species of *Bougainvillea* in this study are amphistomatous, with stomata distributed both on their adaxial and abaxial surfaces while two of them – *B. spectabilis* and *B. peruviana* are hypostomatous with stomata observed only on their abaxial surfaces. This is a clear cut demarcation among the species and this attribute can be employed in their delimitation or separation (Raju and Rao, 2008). The amphistomatic nature of some of the species also affirms the effectiveness of transpiration and photosynthesis in them (Titus *et al*., 2023).

On the abaxial surfaces, irregular epidermal cell shape and wavy to undulating anticlinal wall pattern separated *B. spectabilis* and *B. peruviana* from the other species with majorly polygonal epidermal cell shape with straight anticlinal wall pattern. Idu *et al*. (2000) used epidermal morphology and the structure to separate some species of *Fabaceae*. Similarly, Adedeji *et al*. (2007) used anticlinal wall patterns to distinguish between species within the Solanaceae family. Anisocytic, Tetracytic, Anomocytic and Heptacytic stomata types are common to all the *Bougainvillea* species as a generic character. Hexacytic stomata type was observed in all the species as well, except in *B*. *glabra*. Octacytic stomata, characterized by having the highest number of subsidiary cells (eight), were observed exclusively in *B*. *peruviana*, which has hypostomatic leaves. Consequently, the *Bougainvillea* species studied can be distinguished by their stomata types. Ogundipe (2004) separated some species of *Sapindaceae* based on stomata types.

A common type of trichome, multicellular uniseriate non-glandular trichome, was observed on the adaxial and abaxial surfaces of all the species which is another generic feature. Trichomes alongside with stomata have been reported to have significant effect on human health and also to help plants to handle many environmental challenges (Wang *et al*., 2021).Another interesting aspect of this work is the presence of some types of cell inclusions and structures in some of the species. Striated cuticle observed on the abaxial surfaces of *B. brasiliensis* and *B. glabra* clearly separated them from the other *Bougainvillea* species. The striations were radiating from the stomata in the two species. Raphides, which are calcium oxalate crystals, were unique to *B. brasiliensis*. Calcium oxalate crystals are known to aid in calcium regulation in plants and provide protection against herbivores (Franceschi and Nakata, 2005).

The stomatal area varied among the *Bougainvillea* species studied. On the adaxial surface, *B*. *glabra* had the largest stomatal area, while *B*. *buttiana* had the smallest. On the abaxial surface, the hypostomatic leaves of *B*. *spectabilis* and *B*. *peruviana* exhibited relatively higher stomatal area values compared to the other three species, with *B*. *spectabilis* recording the highest value. The least stomata area was recorded in *B. brasiliensis*. Stomata index values also varied among the species with *B. glabra* having the highest value and *B. buttiana* having the least value on the adaxial surfaces. *B. buttiana* however has the highest value of stomata index on the abaxial surface while *B. brasiliensis* has the least. Overall, the stomatal index was higher on the abaxial surfaces than on the adaxial surfaces, while the stomatal size was lower on the abaxial surfaces. However, the two hypostomatic species, *B*. *spectabilis* and *B*. *peruviana*, exhibited significantly larger stomata sizes, likely to compensate for their hypostomatic nature and improve transpiration and photosynthesis efficiency. Several studies have confirmed higher stomatal frequency on the abaxial surfaces of most plant species (Muradoglu and Gundogdu, 2011; Suratman and Suranto, 2016; Arogundade and Adedeji, 2019b; Dhea and Entin, 2021) which is also an adaptation mechanism for many mesophytic and xerophytic plants (Carlson *et al*., 2016).

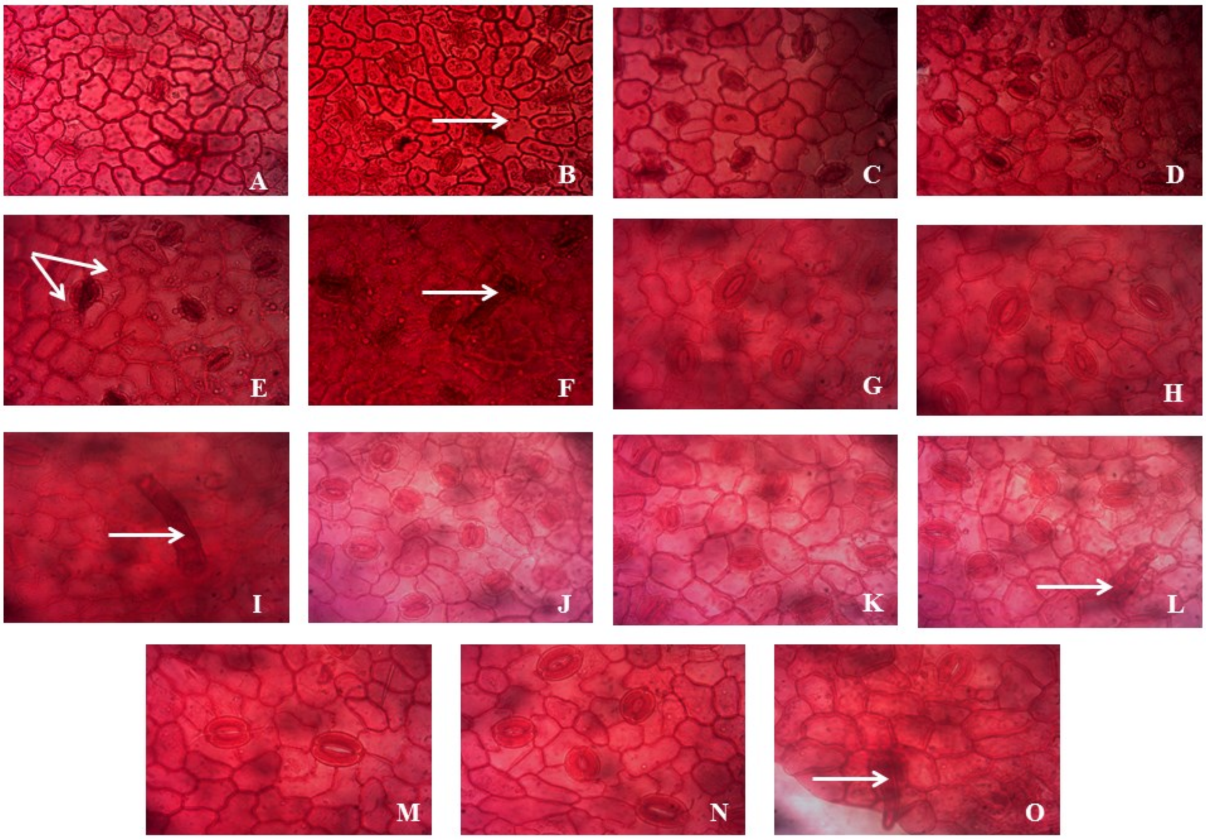

Plate 2: Abaxial Leaf Epidermal surfaces (×400)
Legend: A = *B. brasiliensis*; B = *B. brasiliensis* (cuticular striation arrowed); C & D = *B. glabra*; E= *B. glabra* (cuticular striation arrowed); F = *B. glabra* (Trichome arrowed); G & H = *B. spectabilis*; I = *B. spectabilis* (Trichome arrowed); J & K = *B.buttiana*; L = *B. buttiana* (Trichome arrowed); M & N = *B. peruviana*; O = *B. peruviana* (Trichome arrowed)

Table 2. Summary of Key Qualitative Features of Abaxial Foliar Epidermis in Studied Species

Species	**Epidermal cell shape**	**Anticlinal wall pattern**	**Stomata shape**	**Stomata type**	**Trichome type**	**Other features**
B. brasiliensis	Polygonal	Straight	Elliptic	Anomocytic Anisocytic Tetracytic Hexacytic Heptacytic	Multicellular uniseriate non-glandular	Cuticular striation
B. glabra	Polygonal	Straight	Elliptic	Anomocytic Anisocytic Tetracytic Heptacytic	Multicellular uniseriate non-glandular	Cuticular striation
B. spectabilis	Irregular	Wavy to undulating	Elliptic occasionally circular	Anomocytic Tetracytic Anisocytic Heptacytic Hexacytic	Multicellular uniseriate non-glandular	Nil
B. buttiana	Polygonal to irregular	Straight	Elliptic occasionally circular	Anomocytic Anisocytic Tetracytic Hexacytic Heptacytic	Multicellular uniseriate non-glandular	Nil
B. peruviana	Irregular	Wavy to undulating	Elliptic occasionally circular	Anomocytic Anisocytic Tetracytic Hexacytic Heptacytic Octacytic	Multicellular uniseriate non-glandular	Nil

Table 3. Summary of Key Quantitative Attributes of the Adaxial and Abaxial Foliar Epidermis in Species Studied

Species	**Adaxial Epidermal Area (µm^2)**	**Abaxial Epidermal Area (µm^2)**	**Adaxial Stomata Area (µm^2)**	**Abaxial Stomata Area (µm^2)**	**Adaxial Stomata Index (%)**	**Abaxial Stomata Index (%)**
B. brasiliensis	1173.00 ± 90.06	891.00 ± 40.35	753.25 ± 31.19	627.50 ± 28.83	8.97 ± 0.47	19.30 ± 0.63
B. glabra	931.50 ± 51.87	1161.75 ± 70.36	879.38 ± 51.54	795.75 ± 26.37	11.69 ± 0.78	23.07 ± 0.63
B. spectabilis	763.25 ± 51.86	8985.63 ± 626.59	Nil	7426.88 ± 368.97	Nil	22.88 ± 0.55
B. buttiana	1262.25 ± 61.64	777.50 ± 61.06	672.75 ± 29.71	646.00 ± 22.23	8.84 ± 0.41	28.56 ± 1.23
B. peruviana	1191.00 ± 65.41	1073.00 ± 71.87	Nil	1040.25 ± 37.72	Nil	24.62 ± 1.10

Table 4: The eigenvalue and the percentage of total variation elucidated by the first two ordination axes components

Principal Components	**Eigen value**	**% of total variation**	**Accumulative percentage**
1	2.17E+07	99.862	99.862
2	24595.4	0.11295	99.975

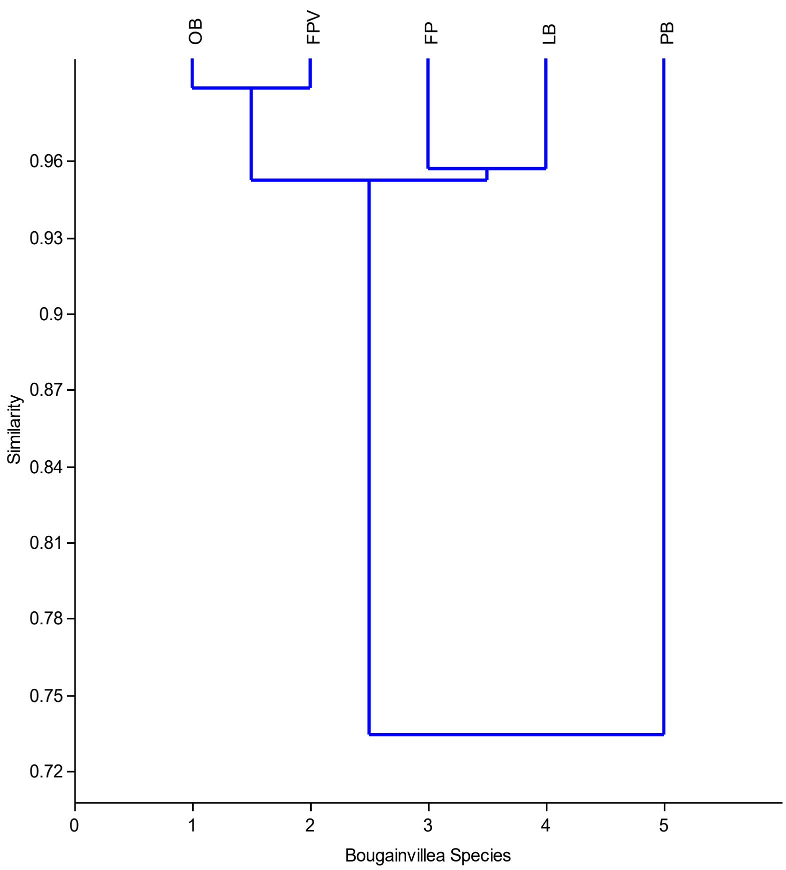

Figure 1: Dendrogram of the five species of *Bougainvillea* species studied
Legend: PB: *Bougainvillea spectabilis;* LB: *Bougainvillea peruviana;* FP: *Bougainvillea glabra;* OB: *Bougainvillea buttiana;* FPV: *Bougainvillea brasiliensis*

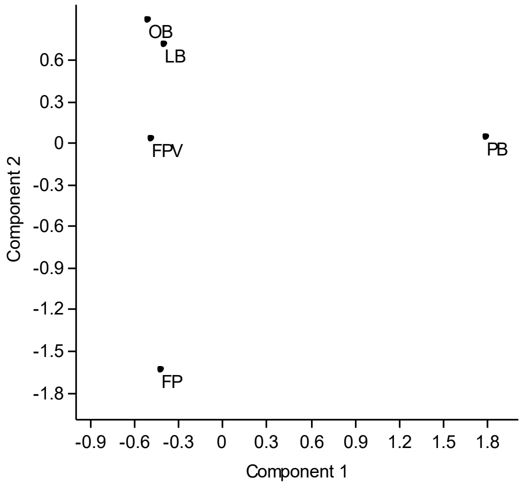

Figure 2: Principal Components Analysis of five species of *Bougainvillea* studied with respect to Components 1 and 2.
Legend: PB: *Bougainvillea spectabilis;* LB: *Bougainvillea peruviana;* FP: *Bougainvillea glabra;* OB: *Bougainvillea buttiana;* FPV: *Bougainvillea brasiliensis*

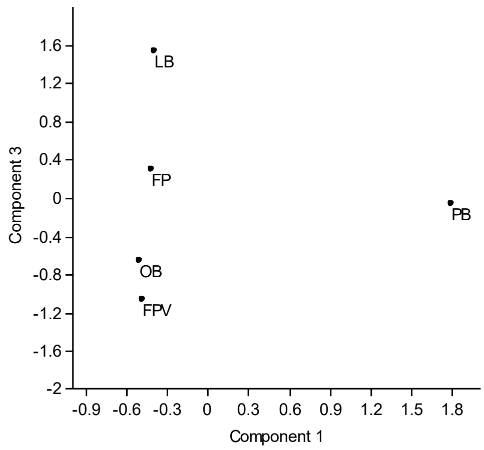

Figure 3: Principal Components Analysis of five species of *Bougainvillea* studied with respect to Components 1 and 3.
Legend: PB: *Bougainvillea spectabilis;* LB: *Bougainvillea peruviana;* FP: *Bougainvillea glabra;* OB: *Bougainvillea buttiana;* FPV: *Bougainvillea brasiliensis*

The stomata distribution, stomata size and stomata index values observed in the *Bougainvillea* species established the effectiveness of the plants in transpiration and photosynthesis. Like other plants, they take in carbon dioxide and produce oxygen through photosynthesis. This further ratifies the ability of the plants to mitigate the effects of air pollution. Further research is needed here to ascertain the specific pollutants the *Bougainvillea* species will be able to remove since their stomata attributes have endowed them with the potential ability to alleviate air pollutants. Researchers have documented plants' ability to absorb volatile organic compounds (VOCs) such as formaldehyde and benzene, common pollutants in highly industrialized urban areas, along with sulfur dioxide and nitrogen dioxide, which contribute significantly to smog (Sharma *et al*., 2005; Datta *et al*., 2021).

The Cluster Analysis divided the species into two main groups. In the first grouping, all species were separated into two clusters, with *B. spectabilis* distinctly isolated from the other four species. In the second grouping, *B. glabra* and *B. peruviana* were clustered together and separated from *B. buttiana* and *B. brasiliensis*, which were also clustered together at a higher similarity level. This result aligns with the Principal Components Analysis, where the first two components accounted for 99.86% of the total variation among the species. According to the PCA loadings, the abaxial stomata area and abaxial epidermal area are the two key components for distinguishing the species.

Conclusion

In conclusion, the *Bougainvillea* species studied can be distinguished by foliar anatomical characters such as stomata type, epidermal cell shape, anticlinal wall pattern, and cuticular striations. These features are highly diagnostic and play a significant role in the taxonomy of genus *Bougainvillea*. The stomata distribution, stomata size and stomata index values observed in the *Bougainvillea* species established the effectiveness of the plants in transpiration and photosynthesis and also confirms the potential ability of the plants to mitigate the effects of air pollution and help to improve air quality.

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