



## Elucidating the Leaf Anatomical and Micromorphological Characteristics of an Air-Purifying Plant: *Heptapleurum arboricola* (Araliaceae)

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### ABSTRACT

*Heptapleurum arboricola* (Araliaceae) is recognized for its potential as an air-purifying plant. This study aimed to elucidate the general leaf anatomical structure of *H. arboricola* and discuss the relevance of these structures in relation to its air-purifying capabilities. Additionally, the study aimed to provide valuable data for plant identification, aiding in the accurate classification and recognition of this species. Leaf samples were collected and sectioned, followed by observations using a light microscope to examine anatomical features. For micromorphological characteristics, samples were prepared and gold coated prior to observation under Scanning Electron Microscope (SEM). Results of the present study revealed that the leaf blade is bifacial, with a mesophyll layer consisting of a compact adaxial palisade and a spongy abaxial layer. The hypodermis beneath the adaxial epidermis consists of two to three layers of colorless cells, which protect the mesophyll from excess solar radiation. The epidermis is covered by a cuticle that, along with a dense arrangement of stomata on the abaxial surface, enhances the plant's capacity to remove indoor air pollutants like benzene. Notably, the mesophyll palisade cells are irregular in shape and smaller than typical columnar forms, which is attributed to the plant's adaptation to low light conditions. Furthermore, the presence of waxes, mucilage cells, and secretion canals indicates the potential presence of chemical compounds that may contribute to the plant's medicinal properties. In conclusion, the study highlights the anatomical adaptations of *H. arboricola* that contribute to its effectiveness as an air-purifying plant. These findings provide essential insights into the structure-function relationship in this species, with implications for its use in improving indoor air quality and in medicinal applications.

**KEYWORDS:** Anatomical characteristics, Air quality, Ornamental plants, Indoor plants, *Heptapleurum arboricola*

### ABSTRAK

*Heptapleurum arboricola* (Araliaceae) dikenali kerana potensinya sebagai tumbuhan penulen udara. Kajian ini bertujuan untuk menjelaskan struktur anatomi umum daun *H. arboricola* dan membincangkan kepentingan struktur-struktur ini dalam hubungannya dengan keupayaan penulenan udara tumbuhan tersebut. Selain itu, kajian ini bertujuan untuk menyediakan data yang berguna bagi tujuan pengenalanpastian tumbuhan, membantu dalam pengelasan spesies ini dengan tepat. Sampel daun telah dikumpulkan dan dipotong, diikuti dengan pemerhatian menggunakan mikroskop cahaya untuk mengkaji ciri-ciri anatomi. Bagi ciri mikromorfologi, sampel disediakan dan dilapisi emas sebelum pemerhatian dijalankan menggunakan Mikroskop Elektron Imbasan (SEM). Hasil kajian menunjukkan bahawa bilah daun bersifat bifasial, dengan lapisan mesofil yang terdiri daripada palisad adaksial padat dan lapisan spongy abaksial. Hipodermis di bawah epidermis adaksial terdiri daripada dua hingga tiga lapisan sel tidak berwarna, yang melindungi mesofil daripada sinaran cahaya yang berlebihan. Epidermis ditutupi oleh kutikel yang tebal, bersama dengan susunan stomata yang padat di permukaan abaksial, meningkatkan keupayaan tumbuhan untuk menyingkirkan pencemar udara dalaman bangunan seperti benzena. Menariknya, sel palisad mesofil berbentuk tidak teratur dan lebih kecil daripada bentuk kolumnar biasa, yang dikaitkan dengan adaptasi tumbuhan ini terhadap keadaan pencahayaan rendah. Selain itu, kehadiran lilin, sel musilaj, dan saluran rembes menunjukkan potensi kehadiran sebatian kimia yang mungkin menyumbang kepada sifat perubatan tumbuhan ini. Kesimpulannya, kajian ini membuktikan ciri adaptasi anatomi daun bagi *H. arboricola* yang menyumbang kepada keberkesannya sebagai tumbuhan penulen udara. Penemuan ini memberikan pandangan penting tentang hubungan struktur-fungsi dalam spesies ini, dengan implikasi untuk penggunaannya dalam meningkatkan kualiti udara dalaman dan juga aplikasi perubatan.

**KATA KUNCI:** Ciri anatomi, Kualiti udara, Tumbuhan hiasan, Tumbuhan *indoor*, *Heptapleurum arboricola*

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## Introduction

*Heptapleurum* Gaertn. previously classified under the genus *Schefflera* J.R. Forst. & G. Forst., is part of the *Araliaceae* family, which includes over 600 species, making *Schefflera* the largest genus in this family. However, recent molecular studies have addressed the overlap in both morphology and geographic distribution within *Schefflera*, leading to the recognition of *Heptapleurum* and *Schefflera* as separated genera. Following this taxonomic revision, *Heptapleurum* has emerged as the largest genus in the *Araliaceae* family, with 317 species, after the resurrection of the genus for the Asian Clade by Lowry and Plunkett (2020).

One well-known species of *Heptapleurum* is *H. arboricola* Hayata (syn. *Schefflera arboricola* (Hayata) Merr.), a tropical plant native to Hainan and Taiwan. This species has been introduced to many countries, including Malaysia, primarily for ornamental purposes due to its distinctive palmate leaves, which comprise seven to nine oval leaflets arranged in a whorl, resembling the spokes of an umbrella (Figure 1). Beyond its ornamental value, many species within *Heptapleurum* have been used in traditional medicine, containing various chemical compounds (Wang et al., 2021). *Heptapleurum arboricola* itself is known for its medicinal properties, including its use in treating pain, rheumatic arthritis, fractures, sprains, and traumatic bleeding (Li et al., 2014). It also has potential analgesic and anti-inflammatory effects (Huang et al., 2012), and recent studies have formulated it into a tablet for managing diabetic neuropathic pain (DNP) (Lin et al., 2023). The plant contains

sesquiterpenes and nor-sesquiterpenes (Zhao et al., 2010), terpenes (Hansen & Boll, 1986), and aromatic compounds (Ye et al., 2020).



**Figure 1** Umbrella plant: *Heptapleurum arboricola* palmate leaves, which comprise seven to nine oval leaflets arranged in a whorl.

In addition to its medicinal uses, *H. arboricola* has been reported as an effective natural indoor air purifier, particularly in removing benzene vapor (Parseh et al., 2018; Wijayanti, 2023). Nonetheless, phytodegradation is the primary mechanism for removing volatile organic compounds (VOCs) from polluted air (Lee et al., 2020). The phyllosphere, which includes the leaves and stems of plants, is recognized as an effective absorber of air pollutants. Additionally, adsorbed pollutants in the phyllosphere can be transferred to the soil and rhizosphere through rainfall and leaf fall, where they can be metabolized, sequestered, or excreted (Weyens

et al., 2015; Kumar et al., 2023). The uptake of VOCs primarily occurs through the leaf stomata, though the cuticle also plays a significant role. Once inside the leaf, VOCs diffuse into the intercellular spaces, where they may be converted to acids or react with inner-leaf surfaces (Agarwal et al., 2018). The phloem then translocated and stores these compounds in various plant organs (Pandey & Bajpai, 2019). Lee et al. (2020) emphasized that the leaf surface and ultrastructure, especially the stomata, play critical roles in the successful phytoremediation of air pollution. Ravindra and Mor (2022) also recommended more research is required to explore plant characteristics, including leaf size, thickness, surface area, the effectiveness of species, and the specific plant parts involved in air pollutant removal.

In general, this study aims to elucidate the general leaf anatomical structure of the plant to identify any special characteristics that may contribute to its ability to remediate air pollution. The specific objectives of this study were 1) to study the general leaf anatomical and micromorphological structure of *H. arboricola*; and 2) to discuss the relevance of these structures in relation to the plant's air-purifying potential. Additionally, understanding the leaf anatomy can provide valuable data for plant identification, aiding in the accurate classification and recognition of this species. This study will provide a foundational understanding of the leaf characteristics that may underlie the plant's phytoremediation mechanisms and contribute to its identification.

## Materials and methods

This study was conducted on *H. arboricola* specimens collected from different localities in Pahang. *Heptapleurum arboricola* is an introduced ornamental plant, therefore all samples were obtained from landscapes and gardens. Fresh samples were collected with three replicates taken from each site. Voucher specimens of the fresh leaf samples were deposited at the herbarium of the International Islamic University Malaysia (IIUM). The fresh leaf samples were fixed in a 3:1 AA solution (70% alcohol: 30% acetic acid). The lamina was sectioned using a microtome, while both leaf surfaces were scraped using a surgical blade with the aid of Jeffery's reagent. The sectioned leaf parts were stained with Safranin and Alcian Blue, dehydrated through a graded alcohol series, and mounted on slides using Euparal before being observed under a light microscope. Anatomical images were captured using a 3CCD video camera attached to a Leitz Diaplan microscope, with images processed using Cell<sup>^</sup>B software. Modifications in fixation and embedding techniques were made according to the methods described by Johansen (1940) and Sass (1958).

For the leaf micromorphological study, specimens were taken from dried leaf samples and then underwent SEM procedures. Lamina samples were cut to approximately 1 cm<sup>2</sup> in size and mounted on a mounting holder. These samples were then coated with gold using a sputter coater. Subsequently, the samples were observed under a Zeiss Model Evo 50 scanning electron microscope. Important characteristics such as the structure of waxes, presence of trichome and stomata arrangement were

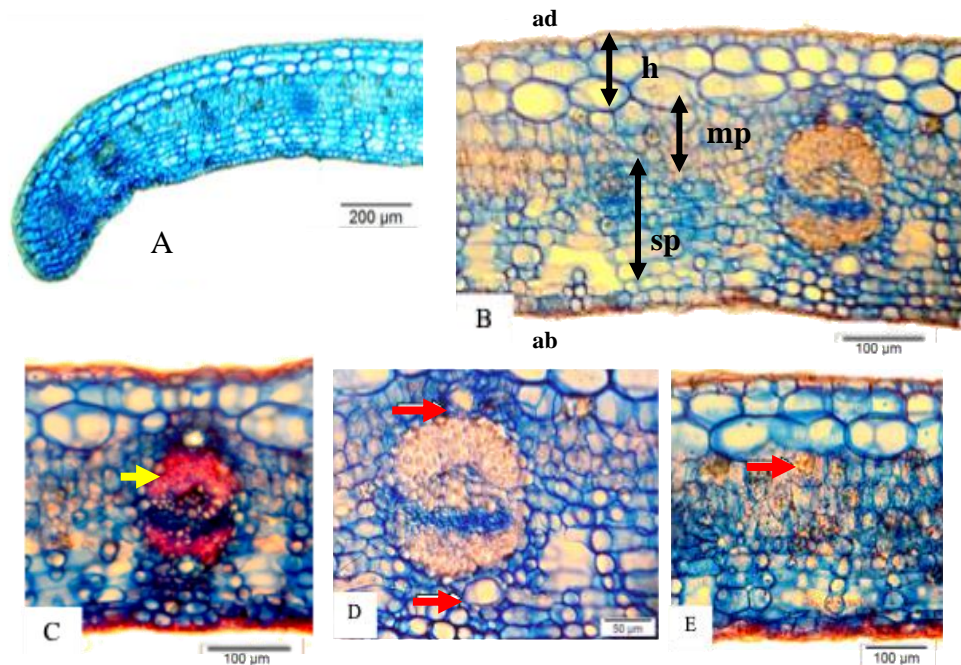
observed under magnifications of 100x, 500x, 1000x, and 2000x.

## Results

### *Leaf blade transections characteristics*

Outline shape of leaf margin: Rounded, curved at a 45° angle towards the abaxial surface of the leaf (Figure 2 A). Cuticle: Present on both the adaxial and abaxial epidermal surfaces, relatively thick at 3-5 µm. Epidermal Cells: A single layer of cells with a mix of height-to-width ratio of 1:1 and 1:2 on both the adaxial and abaxial epidermis. Hypodermal cells: Two layers of hypodermal cells located beneath the adaxial epidermis, covering the entire leaf tip (Figure 2 B). Chlorenchyma cells: Three to four layers of palisade cells with a height-to-width ratio of 1:1, representing one-third of the lamina thickness. Eight to twelve layers of

spongy mesophyll cells representing two-thirds of the lamina thickness (Figure 2 B). Vascular bundle: The vascular bundle is situated in the center of the lamina. The adaxial and abaxial epidermal surfaces are flat in the areas corresponding to the position of the vascular bundle (Figure 2 D). Sclerenchyma cells: Several layers of sclerenchyma cells are present on the adaxial and abaxial sides of the primary, secondary, and tertiary vascular bundles (Figure 2 C). Secretion cells and ducts: There are two secretion ducts flanking the vascular bundle on both the adaxial and abaxial sides, in contact with the sclerenchyma cell layer (Figure 2 D). Single crystals and druses: Mostly present in the palisade cells, with a minority present in the spongy mesophyll cells (Figure 2 E).

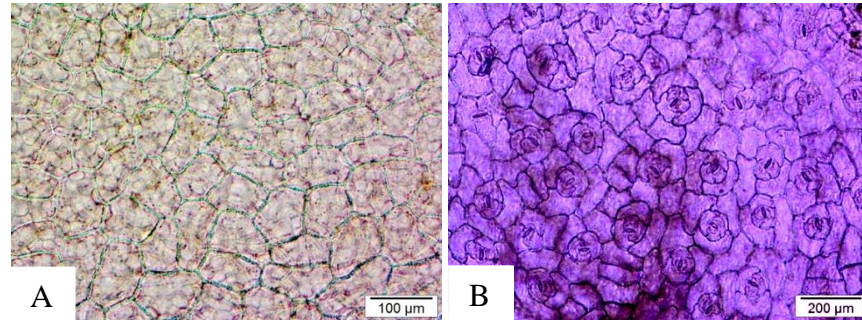


**Figure 2** Leaf blade transections of *H. arboricola*. A) Leaf marginal; B) Leaf cross section in between adaxial (ad) and abaxial (ab) layers showing the mesophyll palisade (mp), spongy palisade (sp) and hypodermal layers (hp); C) Cuticle layers and fibers cap; D) Vascular bundles and secretaries' ducts; and E) Abundance of CaOx in form of druses in mesophyll palisade.

### ***Leaf surface characteristics***

Anticlinal wall pattern on adaxial epidermal surface: Straight to curved (Figure 3 A). Anticlinal wall pattern on abaxial

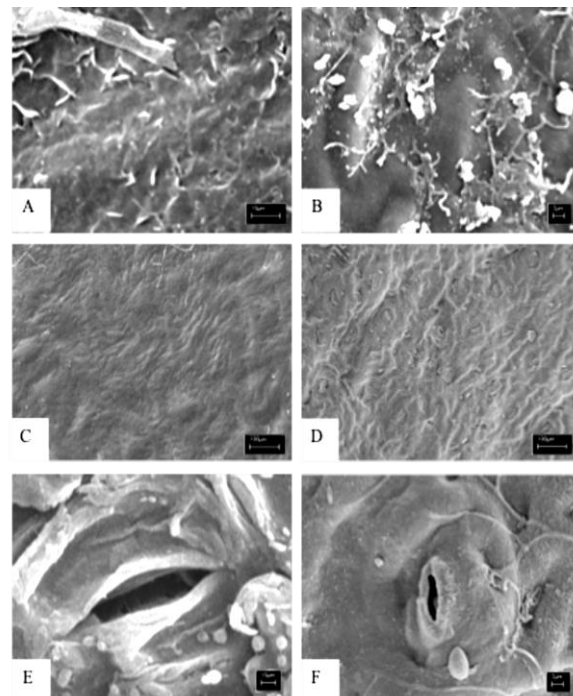
epidermal surface: Curved to wavy (Figure 3 B). Stomata: Anisocytic stomata are present randomly and densely on the abaxial epidermal surface only (hypostomatic) (Figure 3 B).



**Figure 3** Leaf surface of *H. arboricola* A) Anticlinal wall of adaxial B) Anticlinal wall of abaxial and anisocytic stomata

### ***Leaf morphological characteristics***

Wax: Thick film with crustose and flaky types of wax are present on the adaxial epidermal surface (Figure 4 A). Thick film with granular or bead-like wax is present on the abaxial epidermal surface (Fig 4 B). Cuticle ornamentation on adaxial epidermis: Not distinct, with anticlinal and periclinal walls difficult or impossible to distinguish (Figure 4 C). Cuticle ornamentation on abaxial epidermis: Not distinct, with anticlinal and periclinal walls difficult to differentiate (Figure 4 D). Stomatal structure: Stomata are only present on the abaxial epidermal surface (hypostomatic) (Figure 4 E), distributed randomly and densely, with an elliptical shape, prominent and raised stomatal frame, but the stomatal rim is not distinct. The size of the stomata is 7 μm in length by 3 μm in width. The stomata are parafacial, and no epidermal or subsidiary cells are observed (Figure 4 F). Trichomes: Absent.



**Figure 4** A) Crustose and flaky types of wax on adaxial surface, B) Granular or bead-like wax is present on abaxial surface, C & D) Indistinct cuticle ornamentation on the adaxial and abaxial epidermis, E & F) Parafacial stomata.

## Discussions

The anatomical and micromorphological characteristics of *H. arboricola* offer valuable insights into its potential as an air-purifying plant, especially in indoor environments with low light conditions. The bifacial structure of the leaf, featuring well-defined palisade and spongy mesophyll layers, suggests an efficient adaptation for photosynthesis and gas exchange (Redondo-Bermúdez et al., 2021). The lamina's thickness, ranging between 400-500 µm, aligns with that of other shade-adapted species in the Araliaceae family, such as *Oreopanax* (ginseng). In these species, the presence of multiple layers of palisade cells enhances chlorophyll content and light absorption capabilities, making them more effective in low-light environments (Guerrero-Analco et al., 2023).

In most plants, palisade mesophyll cells are typically columnar, optimizing light capture and photosynthesis (Borsuk et al., 2022). However, in *H. arboricola*, the palisade cells exhibit a smaller, irregular shape with a height-to-length ratio of 1:1, which is notably smaller than the hypodermal cells. This irregularity might be an adaptation to the plant's shaded habitat, where light is diffused and less intense. The compact nature of these cells likely enhances light absorption efficiency by increasing chlorophyll content and restricting chloroplast movement (Lehmeier et al., 2017), thereby optimizing photosynthesis under low-light conditions. This characteristic is consistent with findings in *Tetrapanax* and *Hedera* species, where irregular palisade cells are observed as adaptations to shaded environments, improving

photosynthetic efficiency (Zanlorenzi et al., 2023).

The spongy mesophyll in *H. arboricola* also displays unique characteristics compared to typical plants. While spongy mesophyll cells generally have numerous intercellular spaces to facilitate gas exchange (Earles et al., 2018), in *H. arboricola*, these cells are more densely packed with fewer intercellular spaces. This compact arrangement might be an adaptation to minimize water loss and improve the plant's ability to thrive in drier or controlled indoor environments (Borsuk et al., 2022). Additionally, the dense packing of these cells could enhance the plant's structural integrity, providing mechanical support and aiding in the plant's ability to filter volatile organic compounds (VOCs) like benzene and formaldehyde more efficiently (Jhanji & Datt, 2021).

The presence of a hypodermis beneath the adaxial epidermis, composed of two to three layers of colorless cells, likely plays a crucial role in protecting the mesophyll from excess solar radiation (Jordan et al., 2005; Karabourniotis et al., 2021). This is particularly relevant for plants situated in environments with varying light intensities, such as indoor settings where light is often diffuse. The hypodermis in *H. arboricola* corresponds to that found in other *Heptapleurum* species and *Cussonia* (Araliaceae), where it functions as a barrier against harmful UV radiation and aids in water storage like mangrove species (Rylott & Bruce, 2009), contributing to the plant's survival in different environmental conditions (De Villiers et al., 2010; Jordan et al., 2005).

The wavy anticlinal walls of the epidermal cells in *H. arboricola* provide flexibility and resilience against environmental stress, such as mechanical forces exerted by wind or physical contact (Sapala et al., 2018). This structural adaptation, combined with higher vein density, contributes to the mechanical support and elasticity of the leaf, essential for maintaining leaf integrity under fluctuating environmental conditions (Sotiriou et al., 2018). The absence of trichomes and the presence of a thick cuticle layer on both the adaxial and abaxial surfaces of *H. arboricola* highlight the role of cuticular waxes in minimizing water loss, reducing gas exchange, and protecting against biotic factors like herbivores and pathogens. This feature aligns with findings in *Sansevieria cylindrica*, another houseplant known for its potential in air purification (Shewale et al., 2022; Pieniazek et al., 2022).

Importantly, the cuticular waxes in *H. arboricola* play a significant role in the plant's ability to absorb VOCs (Cruz et al., 2014), such as benzene, especially when the stomata are closed, such as at night. The chemistry of these waxes, which includes both hydrophobic and hydrophilic characteristics, enhances the plant's phytoremediation capabilities (Treesubuntorn et al. 2013; Pieniazek et al., 2022). The lipid properties of the cuticular waxes allow for the efficient absorption and retention of lipophilic VOCs like benzene on the leaf surface, even when stomatal pathways are not available (Kumar et al., 2023). This makes *H. arboricola* particularly effective in removing benzene from indoor environments, functioning as an air purifier even during the dark phases, unlike many other plants whose

air-purifying efficiency declines significantly when stomata are closed.

The specialized anatomy of the stomata in *H. arboricola* further contributes to its air-purifying capabilities. The dense distribution of anisocytic stomata on the abaxial epidermal surface (hypostomata) facilitates efficient gas exchange (Liu et al., 2019), particularly in the absorption of VOCs like benzene and formaldehyde (Parseh et al., 2018). Studies have indicated that plants with higher transpiration rates and chlorophyll concentrations are more effective at removing benzene from indoor air (Tani et al., 2007). The higher number of stomata in *H. arboricola* enhances its transpiration rate, thereby improving its ability to remove benzene more effectively (Jhanji & Datt, 2021). This characteristic is consistent with findings in *Tetrapanax* and *Hedera*, where similar stomatal features have been observed (Zanlorenzi et al., 2023).

Additionally, the spongy parenchyma cells in *H. arboricola* not only store essential nutrients but also play a role in the synthesis and storage of natural compounds, which could be related to the plant's medicinal properties (O'Connor & Maresh, 2006). The presence of mucilage cells and secretion canals further suggests the potential production and storage of bioactive compounds, commonly associated with traditional medicinal plants (Ziegler & Facchini, 2008). This is supported by studies on other Araliaceae species, such as *Oreopanax* and *Hedera helix*, where similar structures have been linked to medicinal properties (Guerrero-Analco et al., 2023; Sulborska et al., 2022).

Finally, the presence of calcium oxalate (CaOx) crystals in the palisade cells may provide additional light-scattering functions (Karabourniotis et al., 2021), optimizing light use in shaded environments. These biominerals may also play a role in regulating calcium levels within the plant, contributing to its

## Conclusion

In summary, the combination of anatomical features such as a thick cuticle, hypodermis, irregular mesophyll palisade cells, densely packed spongy mesophyll, CaOx crystals (druses), and dense stomata underscores *H. arboricola*'s suitability as an air-purifying plant indoor. Its ability to thrive in low-light conditions, coupled with its capacity to filter harmful VOCs and potential medicinal properties, makes it an ideal candidate for improving indoor air quality and possibly for use in medicinal applications. Additionally, understanding the detailed anatomical structure of *H. arboricola* is crucial for plant identification, particularly in the development of pharmaceutical products derived from leaf-based compounds. The precise identification and classification of this species are essential for ensuring the consistency and efficacy of such products in medicinal applications. Further studies on the specific mechanisms of benzene remediation in the leaves of *H. arboricola* are recommended to enhance our understanding of how this plant interacts with and neutralizes harmful pollutants particularly under indoor environments.

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overall resilience under varying environmental conditions. Anatomical studies of various Araliaceae species have revealed the common occurrence of such crystals, further supporting their role in the plant's adaptive strategies (Wahba et al., 2022).

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