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ANATOMY AND HISTOCHIEMISTRY OF THE LEAF BLADE OF *Minquartia guianensis* Aubl. (COULACEAE)

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ABSTRACT

The study of leaf anatomy is essential for understanding the mechanisms of plant adaptation to environmental conditions. The species Acariquara (*Minquartia guianensis* Aubl.) is widely distributed, has high durability and timber importance, and is used for medicinal purposes by traditional populations. Therefore, this study aimed to describe the anatomical structures and histochemistry of *M. guianensis* leaves, with a view to contributing essential information that is lacking in the literature. The research was conducted in the municipality of Itacoatiara, in Amazonas. Adult leaves in good phytosanitary condition were collected from adult trees located in a forest management area. Histological techniques of epidermal dissociation were applied, stained with safranin, in addition to leaf sections stained with safrablau, which were subsequently observed and photographed under an optical microscope. For histochemical testing, fragments of the leaf sections were subjected to reagents and photographed to record the original coloration of the tissues. In the frontal view, the epidermis has a more rectilinear and elongated periclinal wall compared to the anticlinal wall. The stomata, classified as paracytic, are distributed on both leaf surfaces, characterizing the leaf as amphistomatic. In cross section, the epidermis is uniseriate, with branched multicellular trichomes and a thick cuticle. The midrib consists of an amphivasal vascular bundle. Histochemical tests indicated the presence of starch, phenolic compounds, tannins, lipids, proteins, and alkaloids. The results contribute to the identification of the species in studies of adaptation and acclimatization to biotic and abiotic factors and prospects for possible metabolites with medicinal properties.

Keywords: Plant histology; Trichomes; Amphioestomatic

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ANATOMIA E HISTOQUÍMICA DA LÂMINA FOLIAR DE *Minquartia guianensis* Aubl. (COULACEAE)

RESUMO O estudo da anatomia foliar é essencial para entender os mecanismos de adaptação das plantas às condições ambientais. A espécie Acariquara (*Minquartia guianensis* Aubl.) tem ampla distribuição, possuindo alta durabilidade e importância madeireira, além de conter uso para fins medicinais por populações tradicionais. Com isso, neste trabalho, objetivou-se descrever as estruturas anatômicas e a histoquímica das folhas de *M. guianensis*, visando contribuir com informações essenciais sobre registros ausentes na literatura. A pesquisa foi conduzida no município de Itacoatiara, no Amazonas. Folhas adultas e em boas condições fitossanitárias foram coletadas em árvores adultas localizadas em uma área de manejo florestal. Foram aplicadas técnicas histológicas de dissociação de epiderme, corada com safranina, além de secções foliares coradas com safrablau, sendo posteriormente observadas e fotografadas sob um microscópio óptico. Para a realização dos testes histoquímicos, fragmentos das seções foliares foram submetidos a reagentes e fotografados, visando registrar a coloração original dos tecidos. Em vista frontal, a epiderme apresenta uma parede periclinal mais retilínea e alongada em comparação à parede anticlinal. Os estômatos, classificados como paracíticos, estão distribuídos em ambas as faces foliares, caracterizando a folha como anfiestomática. Em secção transversal, observa-se que a epiderme é unisseriada, apresentando tricomas tectores multicelulares ramificados e uma cutícula espessa. A nervura central é constituída por feixe vascular do tipo anfivasal. Os testes histoquímicos apontaram a presença de amido, compostos fenólicos, taninos, lipídios, proteínas e alcaloides. Os resultados encontrados contribuem para identificação da espécie, em estudos de adaptação e aclimatação à fatores bióticos e abióticos, e prospecta os possíveis metabolitos que possuem propriedades medicinais.

Palavras-Chave: Histologia vegetal; Tricomas; Anfioestómatica

1. INTRODUCTION

The Amazon rainforest is home to a wide variety of tree species that contribute significantly to maintaining the planet's biodiversity (Freitas, 2023). The available resources are essential for providing ecosystem goods and services to society (Natividade et al., 2018). However, it is important to note that a significant part of this potential remains unknown.

Minquartia guianensis Aubl. is a species belonging to the Coulaceae Tiegh family, one of the families recently segregated from Olacaceae (Alexandre et al., 2023). The family consists of only three monotypic genera that occur in tropical regions around the world: Coula Baill. (including *Coula edulis* Baill.), which is found in western Africa; Minquartia Aubl. (with *M. guianensis* Aubl.), which is distributed in Central and South America; and Ochanostachys Mast. (containing *Ochanostachys amentacea* Mast.), present in western Malaysia (Nickrent et al., 2010; Costa-Lima & Chagas, 2024). Phytochemical studies conducted on some species of Coulaceae have shown their metabolic capacity to produce various chemical compounds (Alexandre et al., 2023).

The species *M. guianensis*, popularly known as acariquara, aquariquara-roxa, acari, among other names, is widely distributed in Central America and the Amazon Basin, with a notable presence in northern Brazil, especially in the states of Acre, Amazonas, Amapá, Pará, Rondônia, and Roraima (Flora do Brasil, 2024).

This species grows in mature or secondary forests, both on dry land and in periodically flooded forests, in regions with annual rainfall ranging from 2,000 to 4,000 mm (Freitas, 2023; Jansen et al., 2024). Its seeds do not regenerate in open areas, showing that it is a shade-dependent species and, consequently, classifiable as belonging to late stages of ecological succession (shade tolerant) (Antezana-Vera & Marenco, 2021).

The *M. guianensis* tree has a small oval crown, is evergreen, and has an erect and distinctly hollow trunk. Its bark is thin and has longitudinal cracks, exuding white latex when cut (Morais, 2021). Its wood is widely recognized for its high density and durability, offering remarkable mechanical strength, as well as being resistant to insects and microorganisms (Lucena, 2021). Acariquara wood is widely used in the timber industry, particularly in the manufacture of electric poles. In addition, due to its aesthetic appeal when polished, it is often used in civil construction, especially in the production of columns (Andrade et al., 2017; Camargo & Ferraz, 2004).

Studies have shown the presence of secondary metabolites in the species, which have therapeutic potential as antifungal, antibiotic, and anti-inflammatory agents, as well as antimalarial and leishmanicidal activities (Silva, 2018). Some indigenous populations in Ecuador use an infusion of the bark to treat intestinal infections, muscle pain, skin irritations, lung cancer, and tuberculosis (Casas, 2016).

However, the identification and histolocalization of the chemical constituents of a species are fundamental to obtaining information about beneficial bioactive substances present in the plant. Anatomical analysis allows us to establish relationships between the internal structures of the plant and their specific functions, identifying adaptive patterns to different environments, as well as contributing to their correct identification (Silva et al., 2023). Similarly, histochemistry has been used as a tool for identifying and locating active ingredients in plants.

Microscopic study is crucial in the identification of medicinal compounds, as it assists in the standardization of plants used as medicines. In addition, it allows the determination of which vegetative organ is most effective for pharmacological treatment, avoiding the indiscriminate use of the species and promoting a more precise and efficient application of the plant (Gonçalves, 2022).

To expand knowledge about the Coulaceae family, and specifically about the species *M. guianensis*, the present study aimed to describe the anatomical structures and histolocalize the chemical compounds of the leaves of *M. guianensis*, providing crucial information about records previously unavailable in the literature regarding the cells and substances that make up the tissues of this plant.

2. MATERIAL AND METHODS

2.1 Study area and procedures for collecting botanical material

The study was conducted in the municipality of Itacoatiara, located on the right bank of the Amazon River, 266 kilometers from Manaus, along Highway AM-010, in the eastern region of the state of Amazonas. The selection criteria for the species were based on the existence of literary records highlighting its medicinal use, combined with the scarcity of data on its anatomy and histochemistry.

M. guianensis was collected in a management area belonging to the company Mil Madeiras Preciosas Ltda, in the Nossa Senhora do Livramento Community, located in the municipality of Silves, between the geographical coordinates 2º30'36" S, 2º30’42” S, 60º01’29” W, and 60º01’46” W, for anatomical descriptions and histochemical analysis.

According to the Köppen climate classification, the municipality of Silves has a predominantly type A climate, characterized as tropical, rainy, hot, and humid. It has frequent rainfall throughout the year, with a short dry season. Average temperatures are around 25 °C, while annual precipitation reaches 2,316 mm.

The material to be studied was obtained from adult leaves in good phytosanitary conditions and in replicate , collected in the morning, totaling three individuals. The samples were fixed in FAA (formaldehyde, acetic acid, and 70% alcohol), according to Johansen (1940), for a period of 24 hours. After fixation, they were kept in 70% alcohol for subsequent analysis.

2.2 Optical microscopy: Anatomical and histochemical analysis

Light microscopy analysis was performed at the CESIT/UEA Biology Laboratory between May and August 2023. For the study of leaf anatomy, samples were taken from the median regions of the leaf

Revista ÁRVORE
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blade and petiole of the previously fixed leaves, using cross sections made manually with a razor blade on a manual microtome. Subsequently, the sections were clarified with 20% sodium hypochlorite, washed in distilled water twice for 10 minutes, and stained with safrablau solution (1% safranin and 0.1% astra blue, in a 9:1 ratio) at room temperature. The sections were then mounted in glycerin gelatin containing 50% glycerin, according to Kraus & Arduin (1997).

The regions of the apex, base, midrib, and margin of the leaf blade were used for the dissociation of the epidermis, which was subjected to a solution of hydrogen peroxide and acetic acid in a 1:1 ratio (Franklin, 1946). After this step, the material remained in an oven at 70°C for 24 hours. Next, the sections were carefully cleaned with a fine, soft brush (number zero) to remove the mesophyll, the material was stained with fuchsin, and the slides were mounted in glycerin gelatin (Kraus & Arduin, 1997).

Manual paradermal cuts were also performed to obtain the epidermis, to confirm the classification of the stomata, and to enable detailed observation of the trichomes, epidermal cells, and epidermal appendages. The classification of trichomes and stomata was based on the criteria described in the specialized literature (Cutler et al., 2011; Appezzato-da-Glória & Carmello-Guerreiro, 2022). The classification of petiole shape and vascular tissue arrangement follows the criteria proposed by Metcalfe & Chalk (1979) and Fahn (1990), who describe different anatomical configurations based on the position and shape of vascular bundles and cross-sectional geometry.

For the histochemical study, part of the leaf sections of the fresh material was subjected to specific reagents to identify groups of substances by coloration (Table 1). Histological sections of the midrib and petiole of the leaf were made with a manual microtome. After staining, the slides were mounted on semipermanent slides with 50% glycerin (Kraus & Arduin, 1997).

The slides were analyzed and the images recorded using an optical microscope from the CESIT/UEA Biology Laboratory, using 4x, 10x, and 40x objectives. The images were captured with a digital color CMOS camera attached to the microscope, using Mosaic V2 (TUCSON) software, which was used for image acquisition, mosaic assembly, and documentation of anatomical structures. Morphometric analyses, such as stomatal density and cell dimensions, were performed in the same software, using the measurement tool calibrated based on the objective lens used.

2.3 Stomatal density analysis

Stomatal density, defined as the number of stomata per unit area, was determined by counting the stomata in 40 microscopic fields observed with a 40x objective lens. The number of stomata recorded in each field was divided by 0.39 mm² (field area), calculating the stomatal density in stomata/mm². The average density of the 40 fields was then calculated to obtain the average stomatal density of the leaves, according to the methodology adapted from Silva et al. (2022).

3. RESULTS

3.1 Anatomy

In frontal view, the epidermis of the leaf blade of *M. guianensis*, on the adaxial side,

Table 1. Histochemical tests applied to identify chemical compounds in the leaves of *M. guianensis*
Tabela 1. Testes histoquímicos aplicados para identificação de compostos químicos nas folhas de *M. guianensis*

Reagent	Substance	Positive reaction	Reference
Lugol	Starch	Blue-black	Jensen (1962)
Sudan III	Lipid	Orange-yellow	Pearse (1972)
Xylidine Ponceau	Protein	Reddish brown	Berlyn & Miksche (1976)
Ferric chloride III	Total phenolic compounds	Brown	Johansen (1940)
Fluoroglucinol	Lignin	Pink	Johansen (1940)
Wagner's reagent	Alkaloids	Brown	Furr & Mahlberg (1981)
Hydrochloric vanillin	Tannins	Dark brown	Mace & Howell (1974)

exhibits epidermal cells with anticlinal walls of slightly sinuous to polyhedral contours and irregular sizes. On the abaxial side, the epidermal cells are elongated and have anticlinal walls with sinuous contours (Figure 1A-B). The leaf is amphistomatic, with paracytic stomata, which are more abundant on the abaxial surface.

Analysis of stomatal density revealed a distinct distribution between the leaf surfaces. On the abaxial surface, values ranged from 69.23 to 174.36 stomata/mm² (mean = 121.35; SD = 25.64), showing a high concentration of stomata on this surface. On the adaxial surface , values ranged from 0.00 to 5.13 stomata/mm² (mean = 0.38; SD = 1.09), characterizing low density in this region.

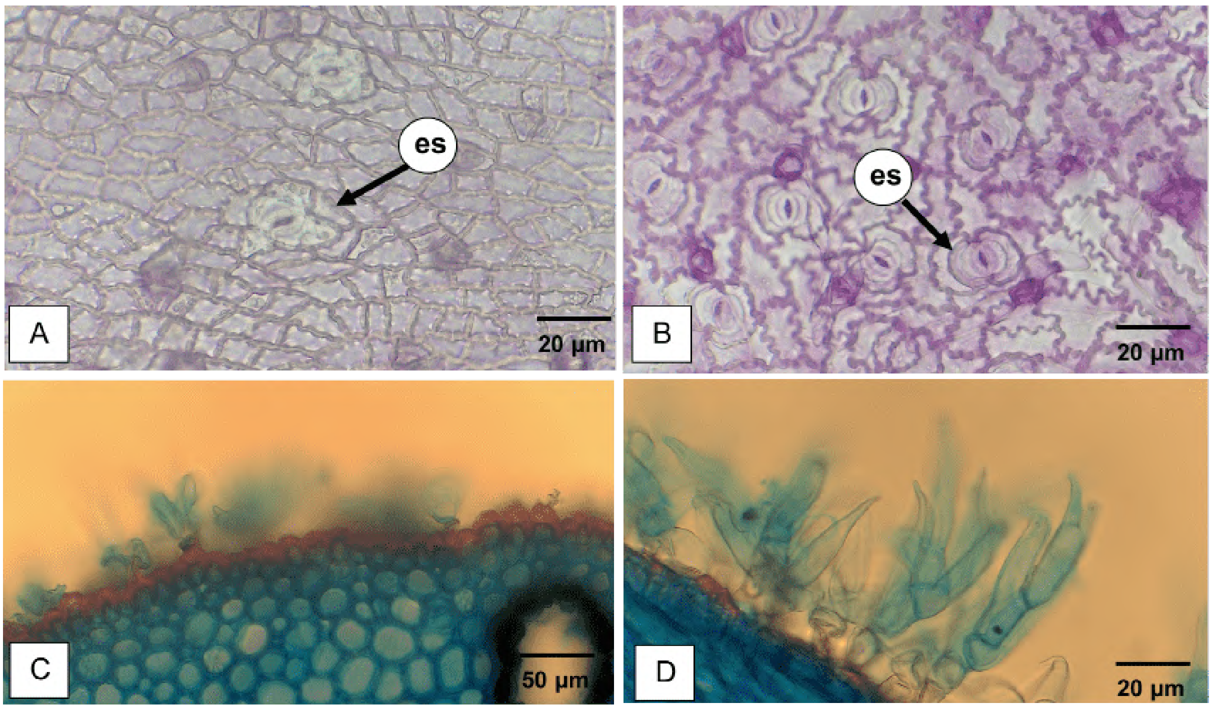
In cross section, the leaf blade has a single-layered epidermis covered by a thick cuticle (21.15 µm; range = 19.38–22.91 µm). The cells on the adaxial surface are quadrangular or rectangular, while those on the abaxial surface are smaller and tabular. Multicellular branched trichomes are also observed on both surfaces (Figures 1C-E). Below the epidermis, there is angular collenchyma (Figure 1C), followed by filling parenchyma.

The mesophyll is dorsiventral, with palisade parenchyma, uniseriate, arranged in a single layer of elongated cells near the epidermis, while the spongy parenchyma has about 7 to 9 layers of cells (Figure 1F).

The central vein, in cross section, has a biconvex shape, being slightly convex on the adaxial side (Figure 1E). The epidermis is unistratified, with cells of varying sizes, covered by a thick cuticle. Just below the epidermis is the annular collenchyma, followed by the fundamental parenchyma. The vascular bundle is amphivasal and surrounded by an almost complete sclerenchymatic sheath. Secretory cavities are visible in the region of the midrib and in the mesophyll, mainly on the abaxial surface (Figure 1E).

The petiole is flat-convex, with a slightly concave adaxial surface and a convex abaxial surface, with two small lateral projections in the adaxial region (Figure 1H). The epidermis is unistratified, covered by a thick cuticle, and has branched multicellular trichomes. Adjacent to the epidermis are up to three layers of angular collenchyma with scattered sclereids (Figure 2A). The fundamental parenchyma has cells of varying sizes and intercellular spaces of varying dimensions (Figure 2A).

In the central region, there is a set of collateral vascular bundles arranged in an open "U" shape, without a fiber sheath



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Revista ÁRVORE
ISSN 1806 – 9088

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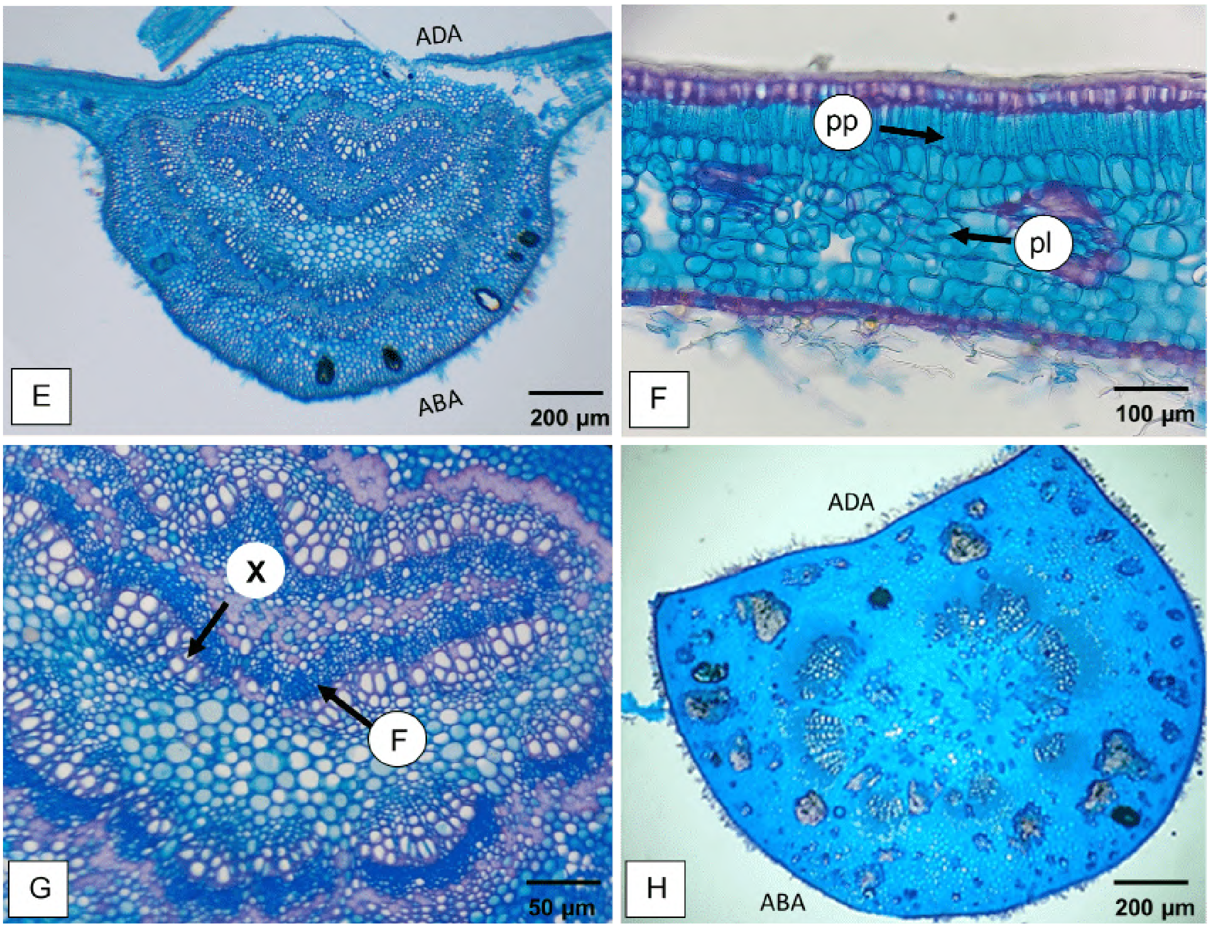

Figure 1. Anatomical characteristics of the leaf of *M. guianensis*. A: Cells on the adaxial surface. B: Elongated sinuous cells on the abaxial surface. C: Uniseriate epidermis with branched multicellular trichomes and thick cuticle. D: Multicellular trichomes. E: Central vein of the leaf. F: Dorsiventral mesophyll. G: Vascular bundle. H: Leaf petiole. ADA= Adaxial; ABA= Abaxial es= stomata; pp= palisade parenchyma; pl= spongy parenchyma; x= xylem; f= phloem

Figura 1. Caracteres anatômicos da folha de *M. guianensis*. A: células na face adaxial. B: células sinuosas alongadas na face abaxial. C: epiderme unisseriada com tricomas tectores multicelulares ramificados e cutícula espessa. D: Tricomas multicelulares. E: Nervura central da folha. F: Mesofilo dorsiventral. G: Feixe vascular. H: Pecíolo da folha. ADA= Adaxial; ABA= Abaxial es= estômato; pp= parênquima paliçádico; pl= parênquima lacunoso; x= xilema; f= floema

(Figure 2B-C). Possible secretory cavities are present in the petiole cortex region (Figure 2D), located near the epidermis on both sides of the blade.

3.2 Histochemistry

In the histochemical analyses of *M. guianensis*, a positive response was obtained for all reagents applied to primary and secondary metabolites, as demonstrated by the positive (+) signal (Table 2).

The presence of starch was evident in the midrib of the leaf blade and in the petiole, concentrated mainly in the contours of the vascular bundles, with greater accumulation in the upper portion (Figure 3A-B). Starch accumulations were also observed in cavities present in the petiole (Figure 3C).

Lipid concentration was observed in the cuticle of both the midrib and petiole (Figure 3D, E). The presence of proteins was evidenced by intense staining in the epidermis of the midrib and in regions of the collenchyma (Figure 3G), as well as in the pith of the petiole (Figure 3H). Parenchymal cells in the cortical and medullary regions

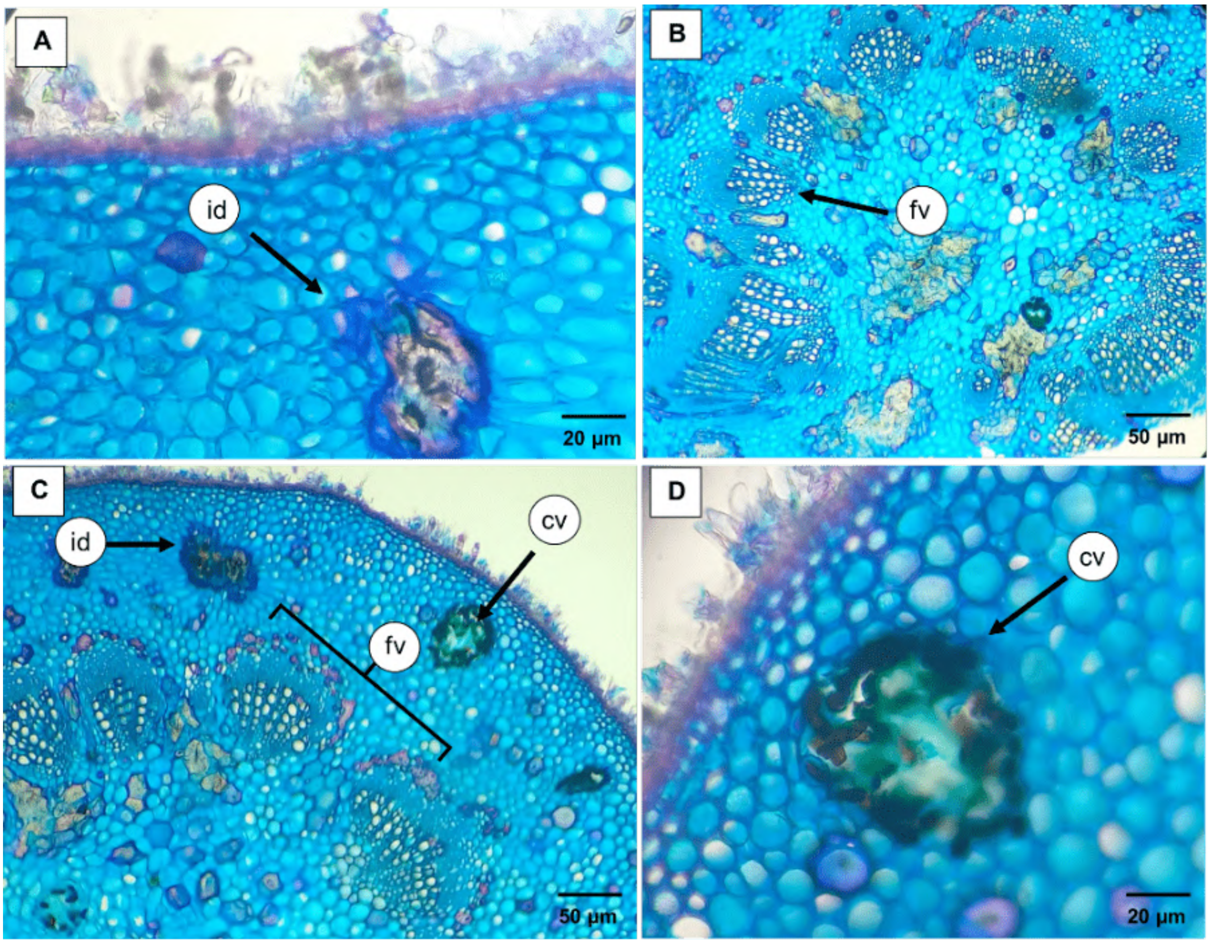

Figure 2. Cross-section of the petiole. A: Angular collenchyma and presence of idioblasts; B: General view of the petiole C: Vascular bundle; D: Cavities. Id= idioblast; fv=vascular bundle; cv=cavities
Figura 2. Corte transversal do pecíolo. A: Colênquima angular e presença de idioblastos; B: Visão geral do pecíolo C: Feixe vascular; D: Cavidades. Id= idioblasto; fv=feixe vascular; cv=cavidades

Table 2. Results of the metabolites present in *M. guianensis* leaves
Tabela 2. Resultados dos metabólitos presentes nas folhas de *M. guianensiss*

Substance	Reagent	Positive reaction	Response Obtained
Starch	Lugol	Blue-black	+
Lipid	Sudan III	Orange-yellow	+
Protein	Xylidine Ponceau	Reddish brown	+
Total phenolic compounds	Ferric chloride III	Brown	+
Lignin	Phloroglucinol	Pink	+
Alkaloids	Wagner's reagent	Brown	+
Tannins	Hydrochloric vanillin	Dark brown	+

also showed a positive reaction, with strong intracellular staining (Figure 3I).

The presence of total phenolic compounds was evident in the epidermis, collenchyma, and vascular bundles (Figure 4A-C). A reaction was observed in the leaf blade vein and petiole, indicating the presence of lignin in the fibers and vascular bundles (Figure 4D-F).

A positive reaction for alkaloids was observed in the epidermis, in the collenchyma of the leaf blade and petiole, as well as in the vascular bundle of the petiole (Figure 4G-I). Tannins were evident in the

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ISSN 1806 – 9088

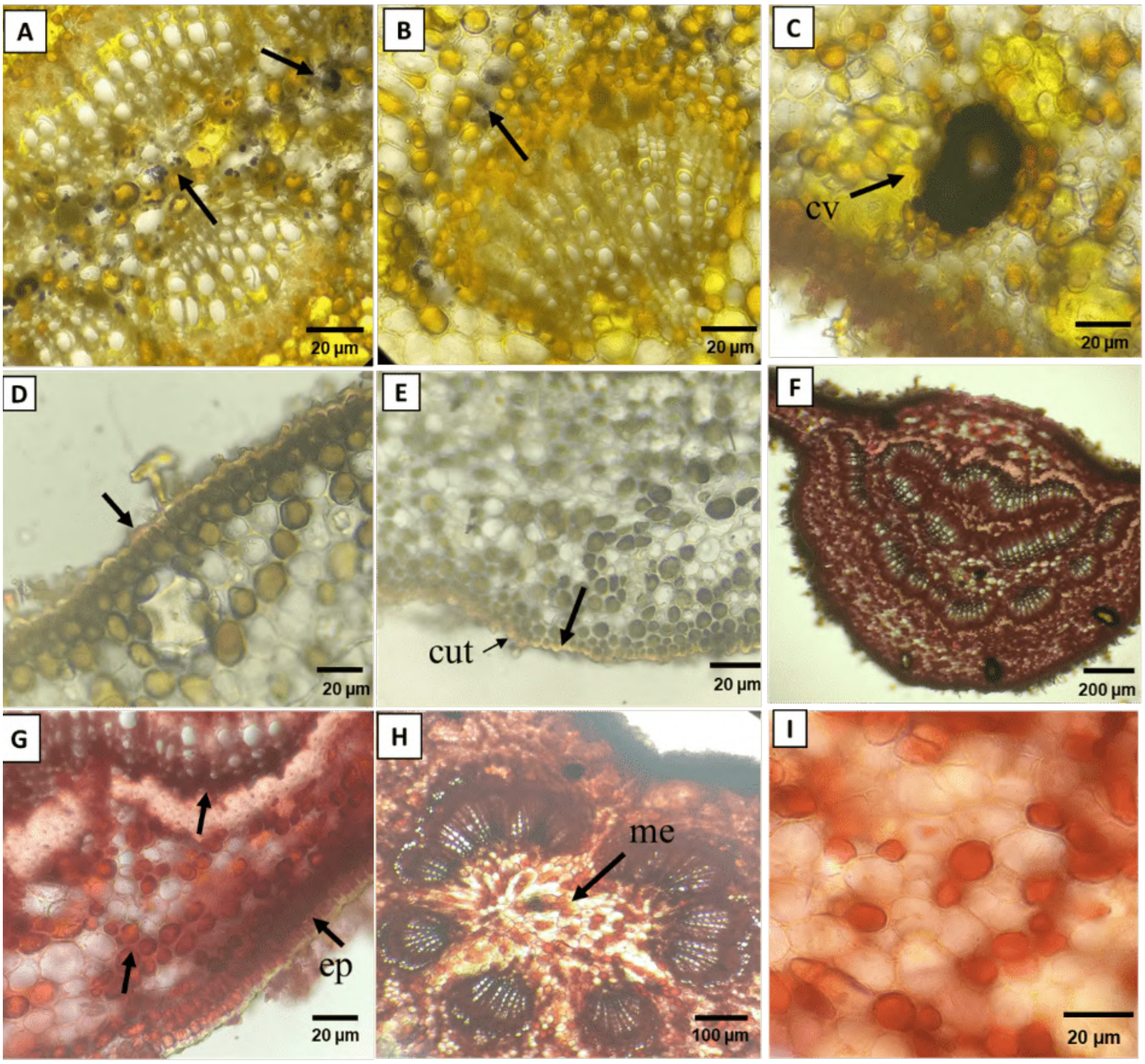

Figure 3. Histochemistry of metabolites present in sections of *M. guianensis* leaves characterizing the reaction of primary compounds. A, B, C - Lugol's reaction staining the phloem, xylem, and pith. D, E - Lipid reaction in the cuticle. F, G, H, I - Presence of proteins in the epidermis of the midrib, regions of the collenchyma, and pith of the petiole. (me = pith, cut = cuticle, ep = epidermis)
Figura 3. Histoquímica de metabólitos presentes em cortes das folhas de *M. guianensis* caracterizando reação dos compostos primários. A, B, C – Reação do Lugol corando o floema, xilema e na medula. D, E – Reação de Lipídios na cutícula. F, G, H, I – Presença de proteínas na epiderme da nervura central, regiões do colênquima e medula do pecíolo. (me =Medula, cut=Cutícula, ep=Epiderme)

epidermis of the leaf blade and in the vascular bundle (Figure 4J-L).

4. DISCUSSION

4.1 Anatomy

Leaves are plant organs that are highly sensitive to environmental changes, exhibiting structural modifications that reflect the adaptability of plants, known as ecological plasticity. This plasticity allows plants to adjust their morphology and physiology in response to variations in the environment, ensuring their survival and performance (Dardengo et al., 2017; Oliveira, 2023).

Analysis of the leaf anatomy of the species under study reveals the presence of a distinctive set of anatomical characteristics

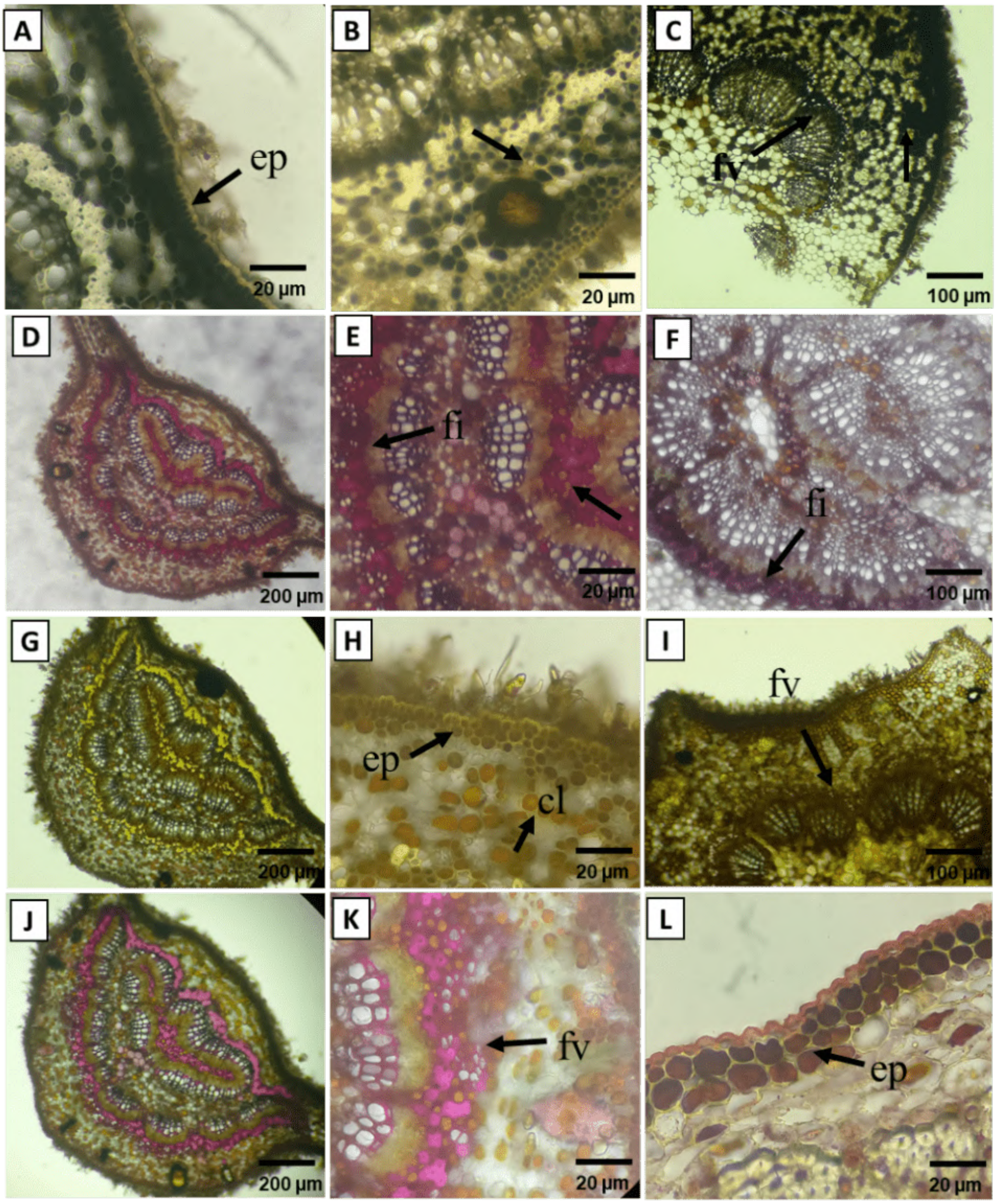

Figure 4. Distribution of secondary compounds in cross sections of *M. guianensis* leaves, reactions to histochemical tests. A.B.C Reaction of total phenolic compounds staining in the epidermis, collenchyma, and vascular bundles. D.E.F - Lignin reaction in fibers and vascular bundles. G.H.I - Wagner's reagent reacted in the epidermis, collenchyma of the leaf blade and petiole, and vascular bundle of the petiole, indicating the presence of alkaloids. J.K.L – Vanillin Chloride stained the epidermis and vascular bundle of the analyzed structures. (cl=Collenchyma, ep=Epidermis, fv=Vascular bundles, fi=Fibers)

Figura 4. Distribuição dos compostos secundários em cortes transversais da folha de *M. guianensis*, reações aos testes histoquímicos. A.B.C Reação de composto fenólico totais corando na epiderme, colênquima e feixes vasculares. D.E.F – Reação de lignina nas fibras e feixes vasculares. G.H.I - Para o Reagente de Wagner houve reação na epiderme, no colênquima da lâmina foliar e pecíolo, e no feixe vascular do pecíolo, mostrando a presença de alcaloide. J.K.L – Vanilina Clorídica coraram a epiderme e feixe vascular das estruturas analisadas. (cl=Colênquima, ep=Epiderme, fv=Feixes vasculares, fi=Fibras) typical of plants that inhabit environments with high temperatures and light intensity. Anatomically, these characteristics can be represented, among other features, by an increase in cuticle thickness, leaf thickness, volumetric expansion of the palisade parenchyma, and greater trichome density (Jardim et al., 2018; Lemos et al., 2020).

No anatomical and histochemical studies on species of the Coulaceae family were found in the literature, making it impossible to compare the structures found in the species *M. guianensis*. Therefore, this study highlights the characteristics of the plant that can aid in its identification. This is the first record of anatomical and histochemical descriptions made for the species.

Distinct sets of morphological, anatomical, or physiological characteristics can be considered adaptive responses to different types of environmental stress (Lourenço, 2023). Consequently, plants that share the same environment may develop similar characteristics, even if they are not related.

Thus, Lopes et al. (2019) indicate that light radiation stands out as the environmental resource that has the greatest influence on plant development. Acariquara is a late-succession, shade-tolerant species that reaches the forest canopy. According to Jardim et al. (2018), individuals located in the forest canopy exhibit characteristics associated with water conservation, as they are subject to intense exposure to sunlight and likely experience more pronounced evapotranspiration. A common adaptive response to high light intensity is an increase in the thickness of the cuticle, leaf blade, epidermis, and palisade parenchyma (Dickison, 2000; Lemos et al., 2020).

The leaf blade is the part of the plant that undergoes the most significant changes in response to environmental changes, since tissues such as the epidermis and parenchyma adjust to these conditions, increasing the plant's ability to survive in its specific environment (Frade, 2017). Thus, a single-layered epidermis, as discussed by Daningsih et al. (2023), facilitates light absorption inside the leaf, helping the plant adapt to environmental conditions.

The cuticle, composed of lipid components such as wax and cutin, serves to minimize the loss of water vapor from the internal tissues of the leaf to the atmosphere (Matos, 2020). As the thickness of this layer increases, there is greater resistance to water loss through the leaf surface, which can result in lower transpiration and more efficient water use by plants (Reyes et al., 2018).

As highlighted by Santos et al. (2022), amphistomatic leaves, which have a more significant number of stomata on the abaxial surface, can also be designated as amphihypostomatic. The average density of 121.35 stomata/mm² on this surface is consistent with patterns observed in other Amazonian tree species adapted to high light levels, as reported by Silva & Garcia (2020) in *Acacia mangium*.

On the other hand, the adaxial surface had an average density of only 0.38 stomata/mm², corroborating the adaptive pattern described by Camargo & Marenco (2011), in which the reduced presence of stomata on the upper surface minimizes water loss through direct transpiration, especially in environments exposed to intense solar radiation. This functional pattern reflects a common strategy in canopy species, such as *M. guianensis*. This characteristic constitutes a long-term evolutionary adaptation, in which plants modulate the anatomical characteristics of their leaves to cope with extreme variations in environmental conditions (Camargo & Marenco, 2011).

According to Driesen et al. (2020), the number of stomata can be influenced by these conditions, presenting variations in different regions of a leaf, in different leaves of the same plant, or even in plants of the same species but at different stages of development.

Regarding the mesophyll, the dorsiventral type, according to Accioly (2022), has a cellular arrangement that allows for better use of light, since the vast majority of chloroplasts are concentrated in the palisade tissue, as well as allowing the spongy parenchyma to develop further and expand its intercellular spaces, leading to improvements in gas exchange.

The existence of trichomes on the epidermal surface of plants offers several advantages in adverse environments, such as physical, chemical, and mechanical protection, in addition to acting as a barrier against insects and pathogens (Karabourniotis et al., 2020). Likewise, the presence or absence of trichomes can be important characters for taxonomy (Chandra et al., 2019).

The presence of branched multicellular tectoric trichomes may be an inherent characteristic of *M. guianensis*, which may aid in its identification. The high density of trichomes in canopy individuals may be closely linked to the strategy of minimizing water loss through leaves during hot periods, in addition to helping to maintain tissue temperature above air temperature during the night (Jardim et al., 2018).

According to Taiz & Zeiger (2021), these plants require specialized structures, mainly to conserve water efficiently and to protect themselves from solar radiation in their habitats, especially ultraviolet rays, preventing damage to the photosynthetic apparatus caused by intense exposure to light. Thus, anatomical analysis of the leaves clarifies how tissue arrangement can help them cope with different environmental stresses.

4.2 Histochemistry

To expand knowledge about the therapeutic potential of plants, it is essential to explore the presence and distribution of metabolites through histochemical analyses. These analyses allow the precise identification of specific regions of plant tissues where bioactive compounds are concentrated, providing a detailed view of the distribution of these molecules (El Babili et al., 2021).

Starch is commonly found in plant cells, where it is synthesized and stored in granular form in specialized organelles, such as plastids, which perform different functions (Soares, 2016; Rocha et al., 2024). In chloroplasts, starch is produced as a temporary energy source, while in amyloplasts it is stored to provide long-term energy, especially during periods of dormancy and germination (Silva, 2019; Galeriani & Cosmo, 2020).

In relation to lipids, waxes and cuticles are rich in these compounds (Conceição et al., 2020). As constituents of cell membranes, lipids help prevent excessive water loss and offer resistance against diseases (Taiz and Zeiger, 2021; Tiago et al., 2020). Plants that inhabit stressful environments tend to invest in the storage of lipids and carbohydrates (Liang et al., 2023).

Adaptation and resistance manifest themselves through changes in plant cell metabolism, including the production of defense proteins, regulated by specific genes (Fonseca, 2022). The induced expression of these proteins increases the survival rate of plants in adverse environmental conditions, improving their adaptation and resilience to sequential stressors (Appu et al., 2021). These plant defense proteins have great potential for medical and agricultural applications, such as in the development of biopesticides (Ruszczyńska & Sytykiewicz, 2024).

There is growing interest in the structural and pharmacological study of phenolic compounds, whose biomolecules are found in plants (Borges & Amorim, 2020). Phenolic compounds decrease light absorption by epidermal cells, protecting leaves from overheating and light damage, while also influencing plant-animal interactions by reducing herbivory (Accioly, 2022).

Phenolic compounds also have various biological activities, such as antioxidant, antimutagenic, antibacterial, atherosclerosis, coronary heart disease, or anticancer effects (Deus et al., 2019). The encapsulation of phenolic bioactives is of great importance to the pharmaceutical, food, and cosmetics industries.

Lignin plays a key role in plant growth and adaptation, being one of the main components of the plant cell wall (Bezerra, et al., 2020). In addition to its structural relevance, lignin can be used by the pharmaceutical industry for the development of health-oriented bioproducts. This phytochemical compound has antioxidant, neuroprotective, and anticancer properties (Oliveira et al., 2023). It is also capable of inhibiting lipid peroxidation and the generation of oxygen radicals, which are responsible for oxidative stress and cellular damage (Korányi et al., 2020).

In addition to lignin, another plant phenolic polymer with defensive properties is tannin. According to Fraga-Corral et al. (2020), tannins have several biological activities useful for medical, pharmaceutical, and veterinary applications. The main bioactivities involve antioxidant, antimicrobial, anthelmintic, antiviral, and anti-inflammatory properties (Maia, 2021). When associated with proteins, tannins help defend plants against attacks by insects, fungi, and bacteria.

In several plant species, alkaloids are synthesized in response to stress, especially saline stress, and play an important role in defending against cellular damage (Sytar et al., 2018). The production of alkaloids in response to light stress varies according to the species, growth stage, and physiological condition of the tissue (Ghosh et al., 2018). In the pharmaceutical industry, alkaloids are used for their various pharmacological properties, which depend on their different chemical structures. They regulate, induce, and stimulate various functions, in addition to having cytotoxic, antifungal, antiparasitic, and antibacterial activities, and can act on the central nervous system (Rodrigues, 2018; Galvão, 2024).

These compounds identified in *M. guianensis* corroborate the species' characteristic of having high natural durability against xylophagous and degrading organisms, as well as influencing its natural resistance. The secondary metabolites present in plants encompass various substances with widely diverse profiles. Many of these metabolites can have significant biological effects when used by humans, making them an important focus of study for researchers interested in isolating and identifying these biologically active substances.

5. CONCLUSION

The anatomical characteristics of the leaves of this species explain its ability to adapt to environments with high light intensity. *M. guianensis* can be characterized by the presence of branched multicellular trichomes, paracytic stomata, and a thick cuticle, which function as mechanisms to minimize water loss. The anatomical analysis performed can contribute to the identification of the plant.

The results of the histochemical analysis revealed that the plant contains primary and secondary compounds, which may be evidence supporting its medicinal use. Anatomical and histochemical characterization is essential in the identification of species with medicinal potential, as it allows the identification of sites of secretion and/or accumulation of biologically active products. In addition, the identified compounds have potential for pharmaceutical applications, which may encourage research aimed at developing new drugs, as well as strategies for conserving the species, promoting its sustainable use.

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AUTHOR CONTRIBUTIONS

Rodrigues, LC: Conceptualization; Data curation; Formal analysis; Writing – original draft; Writing – review & editing. Rebouças NPB: Formal analysis; Writing – original draft. Pinto FR: Formal analysis; Methodology. Santos, VAHF dos: Formal analysis; Methodology; Writing – original draft. Ferreira, DL: Formal analysis; Methodology; Writing – original draft.

DATA AVAILABILITY

The entire dataset supporting the findings of this study has been published within the article.

7. REFERENCES

Accioly, A. D. (2022). *Morphological and anatomical studies of leaves from species in the Brazilian semi-arid region: an ecological perspective* (Master's thesis). Federal University of Pernambuco.

Alexandre, A. S., Fachin-Espinar, M. T., & Nunez, C. V. (2023). Triterpenes, steroids, and phenolics isolated from *Minquartia guianensis* Aubl. (Coulaceae) and antibacterial activity. *CLIum, 23*(3), 883-895. https://doi.org/10.53660/CLM-920-23B61

Andrade, C. G. C., Silva, M. L., Torres, C. M. M. E., Ruschel, A. R., Silva, L. F., Andrade, D. F. C., & Reis, L. P. (2017). Diametric growth and time of passage of *Minquartia guianensis* after logging at Tapajós National Forest, Brazil. *Pesquisa Florestal Brasileira, 37*(91), 299–309. https://doi.org/10.4336/2017.pfb.37.91.1406

Antezana-Vera, S. A., & Marenco, R. A. (2021). Sap flow rates of *Minquartia guianensis* in the central Amazon during the prolonged dry season of 2015–2016. *Journal of Forestry Research, 32*, 2067–2076. https://doi.org/10.1007/s11676-020-01193-9

Appezzato-da-Glória, B., & Carmello-Guerreiro, S. (2022). *Plant anatomy*. (4th ed.). Editora UFV.

Appu, M., Ramalingam, P., Sathiyanarayanan, A., & Huang, J. (2021). An overview of plant defense-related enzymes responses to biotic stresses. *Plant Gene, 27*, 100302. https://doi.org/10.1016/j.plgene.2021.100302

Bezerra, J. D. C., França, S. A., Nascimento Junior, J. R. S., Castro, F. M., Silva, N. V., & Barbosa, S. N. (2020). Lignin biosynthesis in plants subjected to water deficit. *Revista Pubvet, 14*(9), 1-14. https://doi.org/10.31533/pubvet.v14n9a653.1-14

Borges, L. P., & Amorim, V. A. (2020). Secondary metabolites of plants. *Revista Agrotecnologia, 11*(1), 54-67.

Camargo, J. L. C., & Ferraz, I. D. K. (2004). Amazonian seed manual (Fascicle 4) *Minquartia guianensis* Aubl. [Internet]. INPA Publishing House.

Camargo, M. A. B., & Marenco, R. A. (2011). Density, size, and distribution of stomata in 35 rainforest tree species in Central Amazonia. *Acta Amazonica, 41*(2), 205-212. https://doi.org/10.1590/S0044-59672011000200004

Casas, L. P. (2016). *Bioprospecting of endophytic fungi of Minquartia guianensis Aubl. (OLACACEAE)* (Master's Thesis). Amazonas State University.

Chandra, S., Rawat, D., Verma, S., & Uniyal, P. (2019). Diversity of trichomes of the Caryophyllaceae family of the Western Himalayas and their taxonomic implication. *Town Planning Review, 6*, 397-407. https://doi.org/10.22271/tpr.2019.v6.i3.049

Conceição, L. O., Aoyama, E. M., Furlan, M. R., & Hering-Rinnert, C. (2020). Anatomy and histochemistry of the stem of species known as quebra-pedra from the Euphorbiaceae and Phyllanthaceae families. *Acta Biológica Catarinense, 7*, 65–80. https://doi.org/10.21726/abc.v7i4.22

Costa-Lima, J. L., & Chargas, E. C. O. (2024). Coulaceae in Flora and Funga of Brazil. Rio de Janeiro Botanical Garden. https://floradobrasil.jbrj.gov.br/FB19958

Cutler, D. F., Botha, T., & Stevenson, D. W. M. (2011). *Plant anatomy: An applied approach.* Artmed Editora.

Daningsih, E., Fransiska, N., & Mardiyyaningsih, A. (2023). Thickness of leaf anatomical tissue of dicotyledonous ornamental plants under different light intensities. *International Journal of Scientific Research and Management (IJSRM), 11*(02), 203–213. https://doi.org/10.18535/ijsrm/v11i02.b01

Dardengo, J. F. E., Rossi, A. A. B., Silva, I. V., Pessoa, M. J. G., & Silva, C. J. (2017). Analysis of the influence of light on the anatomical aspects of leaves of *Theobroma speciosum* Willd ex Spreng. (Malvaceae). *Ciência Florestal, 27*(3), 843–851. https://doi.org/10.5902/1980509828634

Deus, V. L., Santos, A. P. C., Walker, J. F., Neta, L. S., & Souza, L. S. (2019). Phenolic compounds in vegetables grown in conventional and organic systems: a review. *Brazilian Journal of Health and Pharmacy, 1*(1), 70-84. https://revistacientifica.crfmg.emnuvens.com.br/crfmg/article/view/89

Dickison, W. C. (2000). *Integrative plant anatomy*. Harcourt/Academic Press.

Driesen, E., Van den Ende, W., De Proft, M., & Saeys, W. (2020). Influence of environmental factors light, CO_2, temperature, and relative humidity on stomatal opening , and development: A review. *Agronomy, 10*(12), 1975. https://doi.org/10.3390/agronomy10121975

El Babili, F., Rey-Rigaud, G., Rozon, H., & Halova-Lajoie, B. (2021). State of knowledge: Histolocalisation in phytochemical study of medicinal plants. *Fitoterapia, 150*, 104862. https://doi.org/10.1016/j.fitote.2021.104862

Fahn, A. 1990. *Plant Anatomy.* Pergamon Press, Oxford.

Revista ÁRVORE
ISSN 1806 – 9088

Flora of Brazil. (2024). Coulaceae in Flora and Fungi of Brazil. Rio de Janeiro Botanical Garden. https://floradobrasil.jbrj.gov.br/FB19958

Fonseca, A. S. D. (2022). *Biochemical characterization of Coffea canephora Pierre ex A. Froehner accessions in interaction with the fungus Hemileia vastatrix Berk. & Br* (Doctoral thesis). Federal University of Rondônia Foundation.

Frade, S. R. P. (2017). *Comparative leaf anatomy of jequitibá-rosa (Cariniana legalis) cultivated in vitro and ex vitro* (Course Completion Paper). Forestry Institute of the Federal Rural University of Rio de Janeiro.

Fraga-Corral, M., García-Oliveira, P., Pereira, A. G., Lourenço-Lopes, C., Jimenez-Lopez, C., Prieto, M. A., & Simal-Gandara, J. (2020). Technological application of tannin-based extracts. *Molecules, 25*(3), 614. https://doi.org/10.3390/molecules25030614

Franklin, G. L. (1946). A rapid method of softening wood for microtome sectioning. *Australian Journal of Botany, 33*, 393-408.

Freitas, B. M. S. (2023). *Population dynamics of Minquartia guianensis Aubl. over 30 years in an exploited forest in the Eastern Amazon* (Final Course Project). Federal Rural University of Amazonia.

Galeriani, T. M., & Cosmo, B. M. N. (2020). Notions of plant physiology: Germination, transpiration, photosynthesis, and cellular respiration. *Revista Agronomia Brasileira, 4,* 1-6. https://doi.org/10.22407/rab.v4n1.a1

Galvão, L. R. L. (2024). *Chemical characterization of the aqueous extract of Pseudobombax simplicifolium A. Robyns and evaluation of its acute toxicity and biological activities.* (Final Course Project). Federal University of Pernambuco.

Ghosh, S., Watson, A., Gonzalez-Navarro, O. E., Ramirez-Gonzalez, R. H., Yanes, L., Mendoza-Suárez, M., Simmonds, J., Wells, R., Rayner, T., Green, P., Hafeez, A., Hayta, S., Melton, R. E., Steed, A., Sarkar, A., Carter, J., Perkins, L., Lord, J., Tester, ... & Hickey, L. T. (2018). Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. *Nature Protocols, 13*(12), 2944–2963. https://doi.org/10.1038/s41596-018-0072-z

Gonçalves, L. B. (2022). *Anatomical, histochemical, and phytochemical characteristics of Cybistax antisyphilitica (Mart.) Mart. (Bignoniaceae).* (Master's thesis). Federal Institute of Goiás.

Jansen, M. R. A., Romero, F. M. B., & Junior, M. D. J. V. L. (2024). Influence of light intensity on the development of *Minquartia guianensis* Aubl. seedlings. *Revista Delos, 17*(58), e1653-e1653. https://doi.org/10.29020/delos.v17i58.1653

Jardim, R. I. L., Melo Júnior, J. C. F., & Silva, M. M. (2018). Effect of light gradient on structural responses of *Hyeronima alchorneoides* (Phyllanthaceae) in a forest environment. *Revista Brasileira de Geografia Física, 11*(3), 913-922. https://periodicos.ufpe.br/revistas/index.php/rbgfe/article/view/234297

Karabourniotis, G., Liakopoulos, G., Nikolopoulos, D., & Brestic, M. (2020). Protective and defensive roles of non-glandular trichomes against multiple stresses: Structure function coordination. *Journal of Forestry Research, 31*, 1-12. https://doi.org/10.1007/s11676-019-01034-4

Kraus, J. E., & Arduin, M. (1997). *Basic manual of methods in plant morphology*. Edur.

Korányi, T. I., Fridrich, B., Pineda, A., & Barta, K. (2020). Development of 'lignin-first' approaches for the valorization of lignocellulosic biomass. *Molecules, 25*(12), 2815. https://doi.org/10.3390/molecules25122815

Lemos, V. O. T., Lucena, E. M. P., Bonilla, O. H., Chaves, B. E., & Freitas, M. A. (2020). Ecological leaf anatomy of *Myrcia guianensis* (Aubl.) DC. in Restinga Cearense. *Ciência Florestal, 30*(2), 307-322. https://doi.org/10.5902/1980509830997

Liang, Y., Huang, Y., Liu, C., Chen, K., & Li, M. (2023). Functions and interaction of plant lipid signalling under abiotic stresses. *Plant Biology, 25*(3), 361–378. https://doi.org/10.1111/plb.13507

Lopes, A. B., Silva, M. M., & Júnior, J. C. F. M. (2019). Functional strategies of *Vanilla chamissoni* (Orchidaceae) in shrubby and forested sandbank environments. *Revista Brasileira de Geografia Física, 12*(2), 355-364. https://doi.org/10.26848/rbgf.v12.2.p355-364

Lourenço, L. F. G. (2023). *Effects of flooding and water suspension on the morphology and physiology of young plants of Peltophorum dubium (Spreng) Taubert (Fabaceae).* (Master's Thesis). State University of Maringá.

Lucena, D. D. S. (2021). *Taxonomic studies on Olacaceae s.l. in Brazil, with emphasis on the genera Cathedra Miers. and Heisteria Jacq.* (Doctoral thesis). Federal University of Pernambuco.

Maia, D. R. (2021). *Tannin-based extract from the bark of Azadirachta indica A Juss. and its antioxidant and antibacterial potential* (Course Completion Paper). Federal University of Rio Grande do Norte.

Matos, F. S. (2020). *Dry leaf: Introduction to plant physiology.* (E-book). Appris Publishing House.

Metcalfe, C.R.; Chalk, L. *Anatomy of the dicotyledons: leaves, stem and wood in relation to taxonomy with notes on economic uses* 2nd ed. Oxford: Clarendon Press, 1979. v.1.

Morais, F. L. (2021). *Plant tissue culture of Minquartia guianensis Aubl. (Olacaceae) and isolation of trans-decosyl-4-hydroxy-3-methoxycinnamate.* (Master's thesis). Federal University of Rio Grande do Norte.

Natividade, M., Sampaio, J., Pereira, W., Leal de Sousa, I., Cardoso Júnior, C., Souza Carvalho, C., & Melo, L. (2018). Forest structure and dynamics before and after timber extraction in a forest management area in the Tapajós National Forest. *Revista Agroecossistemas, 10*(2), 113¬124. http://dx.doi.org/10.18542/ragros.v10i2.5183

Nickrent, D. L., Malécot, V., Vidal-Russell, R., & Der, J. P. (2010). A revised classification of Santalales. *Taxon, 59*(2), 538-558. https://doi.org/10.1002/tax.592019

Oliveira, B. P. S. (2023). *Leaf anatomy and its importance in the phylogenetic relationships of the Chapada Diamantina Clade (Eupatorieae, Asteraceae)* (Master's Thesis). Federal University of Bahia.

Oliveira, K. S. P., da Silva, J. M. L., Silva, C. M., da Silva, V. R., & de Ávila Medeiros, T. (2023). Vetiver (*Vetiveria zizanioides* L.): A plant of interest for the production of green cosmetics. *Ciência Atual – Multidisciplinary Scientific Journal of the São José University Center, 19*(2).

Reyes, M. G., Carmoga, G. S. L., & Fernández, M. E. (2018). Physiological and utilization aspects of Acacia mangium Willd. A review. *Revista Colombiana de Ciencias Hortícolas, 12*(1), 244-253. https://doi.org/10.17584/rcch.2018v12i1.7340

Rocha, R. D. C., Edson-Chaves, B., Rodrigues, A. C., & Oliveira, F. M. C. (2024). Building protocols for teaching plant anatomy through accessible laboratory practices. *Science & Ideas Journal, 15*, 1–20. https://doi.org/10.22407/2176-1477/2024.v15.2440

Rodrigues, A. T. (2018). *Pharmacognosy* (1st ed.). Editora e Distribuidora Educacional S.A.

Ruszczyńska, M., & Sytykiewicz, H. (2024). New insights into involvement of low molecular weight proteins in complex defense mechanisms in higher plants. *International Journal of Molecular Sciences, 25*(15), 8531. https://doi.org/10.3390/ijms25158531

Santos, M. de F., Ruas, N. R., Ferreira, A. N., Ferrante, M., Gavilanes, M. L., & Carvalho, E. E. N. (2022). Stomatal analysis in leaves of *Siparuna guianensis* Aubl. (Siparunaceae). *Research, Society and Development, 11*(1), e17111124722. https://doi.org/10.33448/rsd-v11i1.24722

Silva, D. B. (2019). *Treatment of wastewater from cassava processing to obtain butanol.* (Doctoral thesis). State University of Campinas.

Silva, F., & Garcia, D. L. (2020). Ecological interpretations of the leaf anatomy of *Acacia mangium* Willd (Fabaceae-Mimosoideae). *Biosphere Encyclopedia. 17*(31).

Silva, J. M., Costa, D. A., & Oliveira, R. M. (2023). Plant anatomy from the perspective of higher education students in the Biological Sciences course. *Revista Docência do Ensino Superior, 13*, 1–24. https://doi.org/10.35699/2237-5864.2023.45706

Silva, P. A. (2018). *Chemical study and evaluation of the biological activity of extracts of Minquartia guianensis Aubl. (Olacaceae)* (Master's Thesis). Amazonas State University.

Soares, M. M. P. (2016). *Anatomical and histochemical characterization of the vegetative organs of Ruellia paniculata L. (Acanthaceae) in the municipality of Cuité-PB* (Final Course Project). Federal University of Campo Grande.

Sytar, O., Mbarki, S., Zivcak, M., & Brestic, M. (2018). *Salinity responses and tolerance in plants. In The involvement of different secondary metabolites in salinity tolerance of crops* (1st ed., pp. 21-48). Springer Cham. https://doi.org/10.1007/978-3-319-90318-7_2

Taiz, L., Zeiger, E., Moller, I. M., & Murphy, A. (2021). *Fundamentals of plant physiology* (1st ed.). Artmed.

Tiago, P. V., Larocca, D., Silva, I. V. da ., Carpejani, A. A., Tiago, A. V., Dardengo, J. de F. E., & Rossi, A. A. B.. (2020). Morphoanatomical, phytochemical, and histochemical characterization of *Hymenaea courbaril* (Leguminosae), occurring in the Southern Amazon. *Rodriguésia, 71*, e02182018. https://doi.org/10.1590/2175-7860202071063