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ANATOMICAL VARIATION AND WOOD PROPERTIES OF *AQUILARIA CRASSNA* AND *GYRINOPS WALLA* FOR TIMBER AND AGROFORESTRY APPLICATIONS

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Abstract. This study evaluates the anatomical and mechanical properties of *Aquilaria crassna* and *Gyrinops walla*, two agarwood-producing tree species. Samples were collected from eight-year-old plants grown at Marambekanda Estate, Sadaharitha Plantation (Pvt) Ltd., Sri Lanka, and analyzed at the State Timber Corporation, Battaramulla, Sri Lanka. Anatomical features were examined using a trinocular microscope and a handheld digital microscope, with measurements obtained through Micrometrics SE Premium 4 Software. Mechanical properties were tested using a universal testing machine. Results showed that both species exhibit fine wood texture, with *G. walla* having a lower density (435 kg/m³) compared to *A. crassna* (512 kg/m³) at 12% moisture content. The mean vessel diameters of *A. crassna* (70.63 μm) and *G. walla* (68.95 μm) showed no significant difference ($p = 0.642$), indicating comparable vessel sizes between the two species. Despite their low durability, both species are recommended for light construction purposes with preservative treatments, consistent with their current applications in picture frames, agricultural tools, toys, blackboards, and firewood. Main purpose of this study compares the anatomical and mechanical properties of *Aquilaria crassna* and *Gyrinops walla*, showing that both species have fine wood texture and low density, making them suitable for light construction and various products when treated for preservation.

Key words: *Aquilaria crassna*, *Gyrinops walla,* anatomical properties, mechanical properties, wood density.

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АНАТОМИЧЕСКИЕ ИЗМЕНЕНИЯ И СВОЙСТВА ДРЕВЕСИНЫ *AQUILARIA CRASSNA* И *GYRINOPS WALLA* ДЛЯ ПРИМЕНЕНИЯ В ЛЕСОЗАГОТОВКАХ И АГРОЛЕСОВОДСТВЕ

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Аннотация. В исследовании оцениваются анатомические и механические свойства *Aquilariacrassna* и *Gyrinopswalla*, двух видов агаровых деревьев. Образцы были собраны с восьмилетних растений, выращенных в поместье Марамбеканда, плантация Садахарита (Pvt) Ltd., Шри-Ланка, и проанализированы в Государственной лесопромышленной корпорации, Баттарамулла, Шри-Ланка. Анатомические особенности были исследованы с помощью тринокулярного микроскопа и ручного цифрового микроскопа, измерения были получены с помощью программного обеспечения MicrometricsSEPremium 4. Механические свойства были проверены с помощью универсальной испытательной машины. Результаты показали, что оба вида демонстрируют тонкую текстуру древесины, при этом *G. walla* имеет более низкую плотность (435 кг/м³) по сравнению с *A. crassna* (512 кг/м³) при содержании влаги 12 %. Средний диаметр сосудов *A. crassna* (70,63 мкм) и *G. walla* (68,95 мкм) не показал значительной разницы (p = 0,642), что указывает на сопоставимые размеры сосудов между двумя видами. Несмотря на их низкую прочность, оба вида рекомендуются для получения легких конструкций с консервирующей обработкой, что соответствует их текущему применению при производстве рам для картин, сельскохозяйственного инвентаря, игрушек, классных досок и дров. Основная цель этого исследования – сравнить анатомические и механические свойства *Aquilaria crassna* и *Gyrinops walla*, показав, что оба вида имеют тонкую текстуру древесины и низкую плотность, что делает их подходящими для легких конструкций и различных изделий, когда необходима обработка для консервации.

Ключевые слова: *Aquilaria crassna*, *Gyrinops walla*, анатомические свойства, механические свойства, плотность древесины.

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Introduction

Aquilaria crassna and *Gyrinops walla* are aromatic tree species renowned for their production of agarwood, a highly valued resin used in perfumery, incense, and traditional medicine [5]. *A. crassna*, commonly known as agarwood, produces resinous heartwood in response to fungal infection, while *G. walla*, found in Southeast Asia, also yields agarwood. The fragrance industry heavily relies on these trees for their distinctive scent, which drives their commercial significance [5].

The anatomical properties of both *A. crassna* and *G. walla* have been described in previous studies, revealing similar structural features that contribute to their fine wood texture. Both species exhibit a diffuse-porous wood anatomy, with vessels evenly distributed across growth rings. The vessels are mostly solitary or occasionally arranged in short radial multiples, and the axial parenchyma is paratracheal, appearing as scanty lines around the vessels. The rays are uniseriate to multiseriate and homogenous, consisting predominantly of procumbent cells. These anatomical features are typical of the Thymelaeaceae family, known for its fine-textured and uniform wood, which influences both workability and aesthetic appeal [1].

The anatomical and mechanical strength properties of these trees are fundamental in determining their suitability for various applications. Anatomical properties, such as cell structure and tissue arrangement, influence the wood's resilience, strength, and adaptability to environmental conditions [2]. Strength properties, including bending strength, compressive strength, and flexibility, define the timber's capacity to withstand external forces, making these traits critical for both natural adaptation and practical usage. Understanding these properties is essential not only for the cultivation and for management of *A. crassna* and *G. walla* but also for expanding their applications beyond agarwood production, such as in light construction [4; 9].

The economic value of agarwood is substantial, with first-grade agarwood commanding one of the highest commercial values among natural raw materials [11]. Agarwood is sold in various forms, including woodchips, powder, and incense, contributing to its widespread market presence. However, the overexploitation and limited natural distribution of both *A. crassna* and *G. walla* pose serious sustainability challenges, threatening the availability of natural agarwood. This highlights the urgent need for sustainable resource management to preserve these valuable species.

This research aims to address the gap in understanding the anatomical and mechanical properties of *A. crassna* and *G. walla*, offering insights that can optimize the agarwood industry, innovate fragrance and medicinal applications, and guide sustainable resource management. By examining the wood's structural characteristics and strength properties, this study informs practices in the wood and fiber industries, aids in climate adaptation, and contributes to conservation efforts. Furthermore, the findings support the development of sustainable cultivation practices, promoting the economic viability of plantations and reducing dependence on wild agarwood sources. Ultimately, the research has broad implications for industries, communities, and environmental conservation, demonstrating the importance of these species in both local and global contexts.

Materials and methods

Study Location. The study was conducted at the State Timber Corporation (latitude 6.81185° or 6° 48' 43'' north, longitude 79.88092° or 79° 52'), Battaramulla, Sri Lanka, during the period from August to October 2023.

Sampling. Timber samples were obtained from the Marambekanda Estate, which is managed by Sadaharitha Plantation (Pvt) Ltd, located in Avissawella within the Colombo District of the Western Province, Sri Lanka. The research site, positioned at a latitude of 6° 95' and a longitude of 80° 20', falls under the Low Country Wet Zone (WL4) climatic classification. The elevation of the site is recorded at 35.32 meters above sea level. Meteorological data indicate an average annual rainfall of approximately 2262 mm and an average annual temperature of 29°C. The predominant soil type in the area is red-yellow podzolic soil. For the study, five samples were collected from eight-year-old plants of each species.

Species. The common names agarwood and wallapatta are associated with the botanical names *Aquilaria crassna* and *Gyrinops walla*, respectively. Both species are classified under the family Thymelaeaceae. Known for their high value, these plants are often cultivated for their aromatic resin. The production of this resin, used in perfumes and incense, is induced naturally or artificially in the wood of these trees.

Wood section cutting. The selected wood samples were soaked in water for two weeks until air spaces inside the wood were occupied by water. Each wood species was cut into blocks measuring 2 cm × 2 cm × 3 cm to prepare microscopic slides. Using a microtome (Model LEICA SM 2000 R), transverse, radial, and tangential sections in the range of 10–15 μm thickness were taken. During the wood section cutting, the piece of timber specimen and knife were soaked in 30% ethanol for 10 minutes to facilitate fine sectioning and prevent infection by microorganisms.

Staining and mounting. Transverse, radial, and tangential sections were mounted permanently using Canada balsam. Using a Petri dish, separated wood sections were dipped in 50% alcohol for 5 minutes to ensure dehydration. They were then flooded in safranin with 50% alcohol for 15 minutes for further removal of the moisture and the color. The wood samples were subsequently rinsed with 70% alcohol for 5 to 10 minutes to facilitate further dehydration and then immersed in 90% alcohol for an additional 10 minutes. Wood sections were again kept with absolute alcohol for 10 minutes for further dehydration (during the process evaporation was avoided with covering). Then wood sections were kept in xylene with absolute alcohol for 10 minutes. Milkiness occurs at this stage, indicating incomplete dehydration. Thus, samples were again rinsed in absolute alcohol and xylene for

10 minutes. Then wood sections were mounted with Canada balsam to fix the wood sections. Finally, the slides of wood sections were observed through the microscope. Transverse (T.S.), tangential (T.L.S.), and radial (R.L.S.) wood sections were placed on a slide in the below manner. Slides were kept in the laboratory of the State Timber Corporation.

Anatomical identification of wood species. Quantitative wood anatomical features such as mean diameter of vessel lumina, vessels per square millimeter, ray height, ray width, rays per 25 square millimeters, and fiber length were measured. Qualitative parameters such as vessel shape and arrangement were also recognized. One set of slides from each species was employed to take the measurements. All of the quantitative and qualitative information on the anatomical characteristics was tabulated.

Microscopic examination. Anatomical observations on quantitative and qualitative features were made under a light microscope at 4 × 10 magnification. Measurements and anatomical images were made with Micrometrics SE Premium 4 Software available at the research division of the State Timber Corporation. Quantitative wood anatomical features and qualitative wood anatomical features were measured according to the IAWA list (1989).

Anatomical observation with a handheld digital microscope. Microscopic images of cross-sectional wood samples from each species were captured and analyzed using a handheld digital microscope. Observations were made at 20 × magnification, and the numbers of rays and vessels per 25 mm^2 wood area were recorded.

Determination of the density. Determination of the density of wood was carried out using Archimedes' principle for various species. Timber samples, each measuring 2 cm × 2 cm × 2 cm, were cleaned of impurities, including sawdust and mud, and labeled accordingly. To saturate the vessels with water, the samples were submerged in water for approximately 30 minutes. The weight of a beaker filled with water (W1) was measured using an electronic balance. After three days, the samples were placed in a desiccator to stabilize the temperature, and their dry weights were recorded. The samples were then oven-dried at 103°C for three days to ensure all moisture was removed. A water-saturated sample was subsequently immersed in the beaker at a consistent depth using a thin stick attached to a stand, and the final weight of the beaker (W2) was noted. The wet weight of the wood sample was calculated using a specific equation (1):

$$\text{Timber weight (W)} = \text{Final beaker weight (W2)} - \text{Initial beaker weight (W1)}. \quad (1)$$

To determine density at 0% moisture level, equation (2) was used:

$$\text{Density at 0\% moisture} = \frac{\text{Oven dry weight of timber sample}}{\text{Weight of timber sample (W)}} \times \text{Density of Water} \; (1000 kgm^{-3}). \quad (2)$$

Density at 12% moisture level was determined using equation (3):

$$\text{Density at 12\% moisture level} = \frac{\text{Density at 0\% moisture level)}}{100} \times 112 (kgm^{-3}). \quad (3)$$

Determination of the moisture content of wood samples. The moisture content of the samples was measured at 12% condition using a moisture meter available at the Wood Science Laboratory in the State Timber Corporation.

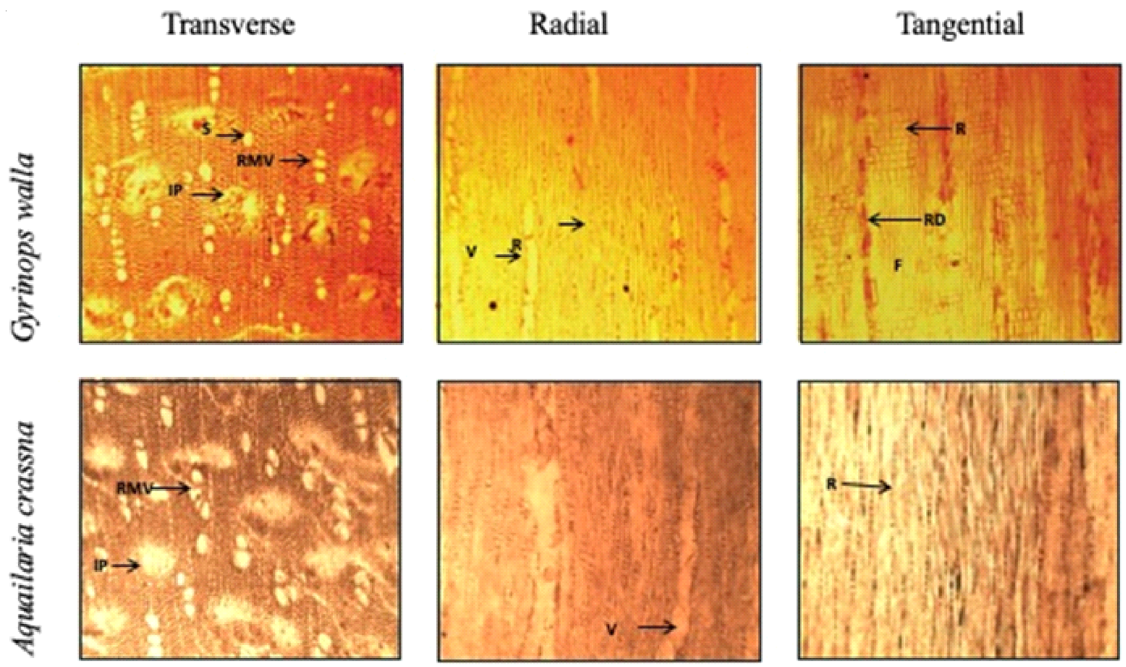
Fiber length measurements. Fiber length measurements were conducted to assess the anatomical characteristics of *Aquilaria crassna* and *Gyrinops walla*. Samples were prepared by macerating thin wood sections in a solution of glacial acetic acid and hydrogen peroxide (1:1 ratio) at 60°C for 24 hours to separate individual fibers. The macerated fibers were then washed thoroughly, mounted on glass slides, and examined under a trinocular microscope (Accu-scope 3000 series). Fiber lengths were measured using Micrometrics SE Premium 4 Software, with at least 30 fibers randomly selected per sample to ensure statistical reliability. The measurements provided insights into the structural attributes influencing the wood's mechanical properties and potential applications.

Results and discussions

Figure illustrates the key anatomical features of *Gyrinops walla* and *Aquilaria crassna*, two agarwood-producing species, with a scale bar of 100 µm for reference. The figure highlights several important components of the wood structure, including Included Phloem (IP), which is responsible for nutrient transport in the bark; Solitary Vessels (SV), individual vascular elements aiding water and nutrient transport; and Radial Multiple Vessels (RMV), which are groups of vessels arranged in a radial pattern. The ray parenchyma (R) consists of horizontal cells that contribute to the lateral transport of water and nutrients, as well as store starch and other substances. Fibers (F), which provide mechanical support to the wood, are elongated cells that contribute to the overall strength and stiffness of the wood. Vessels (V) are larger water-conducting cells that facilitate water movement, while resin deposits (RD) are characteristic of both species, contributing to the resinous nature and aromatic qualities of agarwood. These anatomical features, detailed at a microscopic level, form the basis for understanding the wood's texture, workability, and functionality.

In addition to the anatomical features, the study measured mean vessel diameter, mean ray height, mean ray width, and average fiber length for both species. The mean vessel diameter provides insights into the wood's porosity, which influences its texture and strength. The mean ray height and mean ray width are crucial for understanding the organization of the wood's vascular tissue and its lateral nutrient transport capacity. Finally, the average fiber length is an important parameter for assessing the mechanical properties of the wood, with longer fibers typically enhancing the wood's strength and flexibility. These measurements help characterize the structural qualities of *A. crassna* and *G. walla*, which are essential for evaluating their potential uses in applications such as light construction, artisanal crafts, and the production of agarwood. Understanding these features also aids in optimizing cultivation practices, processing methods, and conservation strategies for these economically valuable species.

The anatomical features observed in *Gyrinops walla* and *Aquilaria crassna*, such as vessel diameter, ray height, and fiber length, play a crucial role in determining the wood's texture, strength, and suitability for various applications. The lack of significant differences between the



Anatomical features of *Gyrinops walla* and *Aquilaria crassna*

Scale bars: 100 мм. Abbreviations: IP – Included Phloem, SV – Solitary Vessel, RMV – Radial Multiple Vessel, R – Ray Parenchyma, F – Fiber, V – Vessel, RD – Resin Deposit. Source: State Timber Corporation of Sri Lanka.

species' vessel diameters suggests that both species share similar structural characteristics, which may influence their potential for light construction and artisanal products. Despite their low durability, the fine texture and mechanical properties, such as fiber length, suggest that both species can be effectively utilized when treated with preservatives. These insights not only contribute to the optimization of agarwood production but also support sustainable use and conservation efforts, ensuring the economic viability of these species for both local and global industries.

The results, presented in Table, were categorized based on IAWA feature numbers 40 to 43, with Category 01 denoting vessels with a diameter of ≤ 50 µm, Category 02 ranging from 50 to 100 µm, Category 03 spanning 100 to 200 µm, and Category 04 including vessels with a diameter ≥ 200 µm. Table presents the anatomical features of *Aquilariacrassna* and *Gyrinopswalla*, comparing key structural characteristics based on various parameters. Both species exhibit diffuse-porous wood, indicating an even distribution of vessels throughout the growth rings, which is characteristic of their wood anatomy. The vessel arrangement in *A. crassna* predominantly consists of radial multiples of 2–3 vessels, with more complex patterns, while *G. walla* has radial and multiple vessels, though a few solitary vessels are also present. The vessel density is similar for both species, with approximately 350 vessels per 25 square mm in A. crassna and 348 vessels in *G. walla*, suggesting comparable vascular structures. The mean vessel diameters are also similar, with *A. crassna* having a slightly larger average diameter of 70.63 µm compared to 68.95 µm in G. walla, indicating only minor differences in vessel size. Both species show tyloses and resin deposits in their vessels, a common feature in agarwood-producing species, which contributes to their aromatic qualities.

The ray characteristics of both species show similar dimensions in mean ray width (27 µm) and mean ray height (around 280 µm for *A. crassna* and 284 µm for *G. walla*). Although *A. crassna* has a slightly higher ray density, with 212.5 rays per 25 mm^2 compared to 183 rays in *G. walla*, the ray arrangement in *A. crassna* is both uniseriate and biseriate, whereas *G. walla* features exclusively uniseriate rays. Both species exhibit included phloem, which is scattered and isolated, contributing to the vascular complexity of the trees. Finally, fiber length is measured at 786.0 µm for *A. crassna* and 731.1 µm for *G. walla*, indicating that *A. crassna* has slightly

Anatomical features of *Aquilaria crassna* and *Gyrinops walla*

No	Anatomical feature	*Aquilaria crassna*	*Gyrinops walla*	IAWA feature no
		Vessels		
1	Porosity	Wood diffuse-porous	Wood diffuse-porous	5
2	Vessel arrangement	Radial multiples of 2–3 more were commons	radial and multiple, but a few solitary vessels are also present	10
3	Vessels per 25 square mm	350 ± 31 (mm^2)	348± 9.5 (µm^2)	48,49
4	Mean vessel diameter of lumina	70.63 ± 1.9 (µm)	68.95 ± 2.8 (µm)	40
5	Tyloses and deposits in vessels	Yes	Yes	134
		Rays		
6	Mean Ray width	27 .12(µm)(µm)	27(µm)(µm)	97
7	Mean Ray height	280 ± 12 (µm)	284.1 ± 13 (µm)	
8	Rays per 25 square millimeter	212.5 ± 16 (mm^2)	183 ± 28 (mm^2)	115
9	Ray arrangement	Uniseriate/Biseriate	Exclusively uniseiate	
		Cambialvariants		
10	Included Pholem	Included phloem, diffuse (scattered isolated phloem)	Included phloem, diffuse (scattered isolated phloem)	133
		Fiber		
11	Average Fiber length	786.0 (µm)	731.1 (µm)	

longer fibers, which may affect its mechanical properties and strength. Overall, these anatomical features reveal the structural similarities and subtle differences between the two species, which are important for their potential applications in wood processing and agarwood production.

The categorization of vessel diameters based on IAWA (International Association of Wood Anatomists) feature numbers 40 to 43 provides valuable insights into the anatomical variability of *Aquilaria crassna* and *Gyrinops walla*. As shown in Table, the vessels in these species predominantly fell into Categories 02 and 03, indicating a diameter range of 50–200 μm. This distribution is consistent with the diffuse-porous wood anatomy typically observed in members of the Thymelaeaceae family [6].

The preponderance of smaller vessel diameters (≤ 200 μm) suggests adaptations for maintaining hydraulic conductivity while minimizing the risk of embolism, a common trait in species thriving in tropical climates. The anatomical traits linked to vessel size also play a crucial role in determining the mechanical properties and processing behavior of the wood. Smaller vessels contribute to fine-textured wood, enhancing its workability and suitability for artisanal applications like carving and toy making [10].

Furthermore, the results align with prior studies that reported similar vessel diameter ranges in agarwood-producing species, reinforcing the functional and ecological significance of these features. This categorization method provides a standardized framework for comparing the wood anatomy of economically significant species and supports their classification for practical applications.

The mean vessel diameter values for *A. crassna* and *G. walla* were found to be 70.63 μm and 68.95 μm, respectively. Remarkably, statistical analysis revealed no significant difference between the mean vessel diameters of the two species, with a *p*-value of 0.642 at a 0.05 probability level. This lack of significant difference implies that, within the observed parameters and measurement criteria, the mean vessel diameters of *A. crassna* and *G. walla* trees remain comparable.

The results of the vessel diameter analysis for *Aquilaria crassna* and *Gyrinops walla* showed that the mean vessel diameters for *A. crassna* (70.63 μm) and *G. walla* (68.95 μm) were closely comparable, with no significant statistical difference between the two species (p-value = 0.642, $\alpha = 0.05$). This finding suggests that, within the parameters of this study, the vessel diameter of these agarwood-producing species is similar, despite the differences in their ecological and morphological traits.

The lack of significant difference in vessel diameter supports earlier studies indicating that species within the Thymelaeaceae family often exhibit similar vessel size ranges, regardless of their geographic or environmental variation [8]. Vessel size is a key anatomical trait affecting the hydraulic efficiency and overall wood density of a species [3; 12]. The comparable vessel diameters observed in *A. crassna* and *G. walla* may suggest similar strategies for water transport and structural efficiency in these species.

Furthermore, the absence of a significant difference aligns with findings in other hardwood species where vessel diameter variability is often minimal across closely related taxa [7]. This indicates that while vessel size can influence the mechanical properties of wood, factors such as fiber length, density, and growth conditions may play more prominent roles in differentiating the wood properties of *A. crassna* and *G. walla*.

These findings suggest a degree of similarity in the anatomical characteristics of vessel diameters between the two species. This may have implications for wood quality, hydraulic conductivity, and overall tree physiology. The non-significant difference prompts further exploration into the factors influencing vessel diameter variations within and between these two species.

Results depicted in Table with regard to mean ray heights were recorded in micrometers, and the findings revealed a mean statistical analysis unveiled no significant difference between the treatment means at the 0.05 probability level. The similarity in mean ray height between the two species or the non-significant difference observed emphasizes the need for further exploration into the factors influencing ray height variations, contributing to a comprehensive understanding of the anatomical features of these tree species. This statistical non-significance indicates that, within the measured parameters, the mean fiber lengths of *A. crassna* and *G. walla* trees are comparable in terms of mean ray height, mean ray width, rays per 25 mm², vessels per 25 mm², and mean fiber length.

The vessel diameter range for *A. crassna* was found to be 44 to 90 µm, while the corresponding range for *G. walla* was 47 to 88 µm. According to the classification table and the observed vessel diameter ranges, both species fall within the fine texture category, as their vessel diameters are consistently less than 100 µm. This classification has significant implications for understanding the wood properties of *A. crassna* and *G. walla*. Fine-textured wood is often associated with certain desirable characteristics, including a smoother appearance, uniformity, and potential applications in high-value products. The consistency in vessel diameter within the fine texture category aligns with the potential utilization of both species in applications that value these specific wood properties.

A notable and statistically significant difference in mean density between *Gyrinops walla* and *Aquilaria crassna* species was observed (p-value = 0.029). In accordance with the timber classification, wood density was categorized into four groups based on Timber Density at 12% moisture level (kg/m³). *Gyrinops walla* was categorized into the "Light density wood" category, indicating a density less than 500 kg/m³, while *Aquilaria crassna* was placed in the "Medium density wood" category, representing timber density ranging from 500 kg/m³ to 640 kg/m³, according to STC classification. This categorization aligns with the general association of low density with lower strength. The density chart further corroborates this distinction, indicating that *Gyrinops walla* exhibits lower strength compared to *Aquilaria crassna*. Additionally, both timber species were classified as having very low durability, making them susceptible to deterioration from insect damage. As a result, these timber species are typically recommended for light constructions, especially when treated with preservatives such as Boron, which proves effective in protecting against termites.

Conclusion

The research findings reveal that there are no significant differences in the mechanical properties, including compression (perpendicular to grain), bending, modulus of elasticity, and modulus of rupture, between *Aquilaria crassna* and *Gyrinops walla* timbers. Both species exhibit fine wood texture, with mean vessel diameters below 100 µm, categorizing them within the fine texture group. While *G. walla* has an exclusively uniseriate ray arrangement, *A. crassna* shows a combination of uniseriate and biseriate rays. In terms of density, *G. walla* is classified as light-density wood (less than 500 kg/m³), whereas *A. crassna* is categorized as medium-density wood (500–640 kg/m³). Despite these similarities, both species exhibit low durability, which limits their suitability for construction applications. However, they remain viable for use in light construction and other specific industries. In conclusion, although their low durability restricts broader use, the unique anatomical and mechanical properties of *A. crassna* and *G. walla* make them valuable resources for applications. The findings suggest opportunities for further research into their sustainable utilization, though improvements through treatments and processing are necessary to enhance their performance in more demanding uses.

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