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Abstract

This study examined the wood properties, i.e., anatomical characteristics, chemical composition, physical and mechanical properties of seven-year-old plantation-grown *B. microphyllum* harvested from a research plot at the Forest Research Institute Malaysia. Microscopic analysis revealed diffuse-porous wood with very large solitary vessels, aliform to confluent parenchyma, medium-sized rays, and non-septate fibres. Fibre morphology showed a Runkel ratio below 1.0 and a slenderness ratio of 41.9, indicating favourable fibre flexibility and bonding potential. The absence of tyloses and silica suggests good treatability and machinability. Chemical analysis showed high holocellulose content (79.5–81.9%), α-cellulose (~44%), moderate lignin (22.6–23.9%), and low extractives (0.9–2.1%), indicating a substantial carbohydrate fraction with minimal non-structural compounds. Preliminary phytochemical screening detected flavonoids, tannins/polyphenols, and triterpenes/steroids as dominant constituents, supporting its traditional medicinal relevance. The wood density ranged from 441.4 to 606.8 kg m^{-3} (mean: 524.1 kg m^{-3}), classifying the timber as light to moderately heavy. Shrinkage at 15% moisture content was 2.2% (tangential), 1.2% (radial), and 0.6% (longitudinal), giving a tangential-to-radial ratio of 1.6 and indicating moderate dimensional stability. Despite being harvested at only seven years of age, *B. microphyllum* exhibited mechanical properties comparable to or superior to several commonly planted fast-growing species, such as *Eucalyptus nitens*, rubberwood (*Hevea brasiliensis*), and batai (*Paraserianthes falcataria*). In particular, the bending and shear strengths were considerably higher than those reported for some older plantation timbers. These findings suggest that *B. microphyllum* has strong potential as a fast-growing plantation timber with favourable strength characteristics and other promising properties, making it a suitable candidate for structural and value-added wood applications.

Keywords: wood anatomical properties; chemical composition; physical properties; mechanical properties; plantation timber; fast growing; *Brachypterum microphyllum*

Introduction

Brachypterum was long treated as a member of the genus *Derris* by numerous authors (Bentham 1860; Gagnepain 1916; How 1954; Hutchinson 1964; Thothathri 1982; Chen 1994; Kumar & Sane 2003; Schrire 2005; Chen & Pedley 2010). However, a comparative analysis of genera within the tribe Millettieae by Geesink (1984) reinstated *Brachypterum* as a genus distinct from *Derris*. Subsequent morphological and molecular phylogenetic studies strongly supported *Brachypterum* as a monophyletic group characterised by unique morphological traits, thereby confirming its generic status within Millettieae (Sirichamorn et al. 2012, 2014). Sirichamorn (2020) recognised approximately 12 species of woody climbers and trees in *Brachypterum*, distributed from Southeast Asia to northeastern Australia. According to Thothathri and Rugayah (1997) and Zhu (2023), *Brachypterum microphyllum* (syn. *Derris microphyllum*) occurs naturally in Sumatra, Peninsular Malaysia, Thailand, Burma (Myanmar), and possibly Indo-China. The species is also found in Java, where it is occasionally cultivated as a shade tree in cocoa, coffee, and tea plantations, particularly on poor soils.

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In addition to its use as green manure, the species is valued as an ornamental tree due to its abundant purple flowers.

In Malaysia, *Brachypterum microphyllum* Miq. (Fabaceae), locally known as *batai* by the Semai Orang Asli is traditionally used by their community in Ulu Geroh, Perak. In woody plants, the accumulation of secondary metabolites is closely associated with tissue differentiation and structural development. Phenolic compounds, including flavonoids and tannins, are commonly concentrated in lignified tissues and mature secondary cell walls, where they contribute to mechanical strength, pathogen defence, and environmental adaptation (Taiz et al. 2015). Likewise, extractive-rich tissues are typically associated with older and structurally robust plant parts and are known to contain diverse bioactive constituents such as triterpenes and steroids (Rowell 2012). These structure–chemistry relationships provide a plausible scientific explanation for the traditional preference for specific plant parts, particularly bark, in medicinal applications.

For this species most research attention has focused on the medicinal potential of the bark, leaving other parts of the tree less studies. Beyond its ethnomedicinal use, information on the utilisation and properties of *B. microphyllum* timber remains limited. Thothathri and Rugayah (1997) reported that the wood is used mainly as building material and firewood. Despite its restricted utilisation, further research on the basic properties of this species is warranted, as *B. microphyllum* is a pioneer species characterised by rapid growth. In the context of reducing pressure on natural forests and identifying alternatives to conventional commercial timbers, studies on fast-growing pioneer species are necessary to evaluate their potential for value-added products. Fundamental wood properties, including anatomical, physical, and mechanical characteristics, serve as key indicators for determining suitability for various end uses. In addition, chemical and phytochemical composition are also important to study in order to identify potential value-added applications of *B. microphyllum*.

Anatomical features such as cell structure and fibre morphology play a critical role in defining potential applications in the wood-based industry. For example, fibre morphology is a key indicator of suitability for pulp and paper production (Fazliana et al. 2024, Takeuchi et al. 2016), while fibre length and fibre wall thickness are important predictors of wood density and mechanical performance (Uetimane et al. 2011). Vessel size is also closely related to treatability, with larger vessels generally facilitating easier impregnation than smaller ones (Wang et al. 2023). Physical properties, particularly density and shrinkage, are widely recognised as important indicators of wood quality. Wood density is correlated with shrinkage behaviour, drying performance, machining characteristics, and mechanical properties (Igartua et al. 2003; Miyoshi et al. 2018). Shrinkage is another critical property, as it is associated with defects such as warping, cupping, checking, and splitting, which significantly affect wood performance and usability (Leif et al. 2025; Anwar et al. 2023).

In addition the chemical composition of woody species significantly influences durability, biological resistance, and potential pharmacological value. Although no detailed phytochemical investigation of *B. microphyllum* has been reported, related genera within the tribe Millettieae are known to produce diverse secondary metabolites, including flavonoids, isoflavonoids, rotenoids, and triterpenoids (Dewick 2009; Veitch 2013). Species formerly classified under *Derris* are particularly recognised for rotenoid compounds with documented insecticidal and bioactive properties (Zubairi et al. 2016). Given the close taxonomic relationship, it is reasonable to hypothesise that *B. microphyllum* may possess comparable biosynthetic potential.

In woody plants, extractives comprising phenolics, terpenoids, and other non-structural constituents are commonly deposited in heartwood and bark tissues and contribute to defence against fungi, insects, and environmental stress (Rowell 2005; Fengel & Wegener 2011). Phenolic compounds are frequently associated with antioxidant activity and enhanced natural durability (Scalbert 1991; Sjöström 1993). Moreover, extractive composition may influence wood colour, decay resistance, permeability, and dimensional stability (Hill 2007; Taylor et al. 2002). Understanding these structure-chemistry relationships is particularly relevant in species with traditional medicinal applications, where bark and mature tissues are often selectively utilised.

Given the absence of published phytochemical data for *B. microphyllum*, baseline chemical characterisation is required to support further pharmacological and ethnopharmacological research. Therefore, this study integrates anatomical, chemical composition, physical, mechanical properties to provide foundational data on the species. This multidisciplinary approach contributes to a more comprehensive understanding of its structure-property-chemistry relationships and supports both its ethnomedicinal relevance and its potential utilisation as a fast-growing timber resource.

Materials and Methods

Preparation of Materials

Click or tap here to enter text.Samples of *B. microphyllum* used in this study were obtained from the Forest Research Institute Malaysia research plot located at Selandar, Melaka. This plot forms part of an early planting trial established to explore the cultivation potential of the species and to support the development of sustainable raw material sources without relying on harvesting from natural forest populations. The planting materials originated from wild seedlings collected near Kampung Ulu Groh, Gopeng, Perak, where the species is traditionally used by the Semai Orang Asli community. After collection, local community members raised the seedlings before transferring them to the FRIM nursery, Kepong, Selangor for hardening prior to field planting at Selandar, Melaka.

For this study, four trees were selected from the open sub-plots. Individuals in this area generally showed better growth performance. At the time of harvesting, the trees were seven years old. Selection was based on a relatively larger diameter at breast height (dbh) and better stem form compared with other individuals within the plots. The range of diameter breast height (dbh), total bole height and merchantable bole height of the trees were 18-20 cm, 21-24 m and 6-11 m respectively.

Four 7-year-old trees were felled at approximately 15 cm above ground level. Two discs, each about 3 cm in thickness and billets of 2 m in length were obtained from each tree. The discs were used for anatomical and physical property analyses, while the 2 m billets were prepared for mechanical property testing. For chemical composition analysis, wood samples were air-dried, oven-dried at 60 ± 2 °C to constant mass, ground, and sieved to obtain particles between 40 and 60 mesh size. All determinations were conducted in triplicate and expressed on an oven-dry basis. For the phytochemical study, bark samples were collected and exhaustively extracted with methanol to obtain crude extracts.

Determination of Anatomical Properties

The study of anatomical characteristics was carried out following the procedure described by Schweingruber and Schulze (2006). Small wood blocks measuring 10 × 10 × 10 mm were prepared from the wood discs. These samples were immersed and boiled in distilled water until fully saturated and able to sink. Thin sections were subsequently obtained from the cross section, tangential, and radial planes using a sledge microtome, with section thickness maintained at approximately 25 μm. Each type of section was placed in separate petri dishes prior to staining. Staining was performed using a 1% safranin-O solution. The sections were then rinsed with 50% ethanol and progressively dehydrated through a graded ethanol series of 70%, 80%, 90%, and 95%. After dehydration, a drop of Canada balsam was applied, and the sections were mounted with a cover slip. The prepared slides were dried in an oven at 60 ºC for several days.

Fibre morphology was determined using the maceration method as outlined by Wheeler et al. (1989). Wood samples were first split into matchstick-sized pieces and subsequently macerated in a solution of 30% hydrogen peroxide and glacial acetic acid (1:1 ratio) at 45 ºC for 2–3 hours. The process was continued until lignin was completely dissolved, resulting in whitish cellulose fibres. Microscopic examination and measurements of anatomical features were conducted using a light microscope. Terminology and identification criteria were based on the International Association of Wood Anatomists (IAWA) list of microscopic features for hardwood identification (Wheeler et al. 1989). In addition, the slenderness ratio (fibre length/fibre diameter) and Runkel ratio (2 × wall thickness/lumen diameter) were calculated following Gülsoy et al. (2017) and Singh and Mohanty (2007).

Chemical Composition Analysis

Extractive content was quantified according to TAPPI T204 cm-07 (2007) by Soxhlet extraction of approximately 2 g of wood sample using ethanol-toluene (1:2, v/v) for at least 6 hours. The solvent was evaporated and the residue dried to constant weight. The extractive content was expressed as a percentage of oven-dry mass. Holocellulose content was determined using the sodium chlorite delignification method described by Wise et al. (1946). Extractive-free wood sample (~2 g) was treated with acidified sodium chlorite at 70-80 °C until lignin removal was complete, then washed to neutral pH, dried at 60 °C, and weighed. Holocellulose content was expressed as a percentage of oven-dry sample weight. Alpha-cellulose content was determined from the holocellulose fraction following TAPPI T203 om-93, in which holocellulose was treated with 17.5% NaOH at room temperature to remove hemicelluloses. The insoluble residue was washed, neutralised, dried, and weighed. The α-cellulose content was calculated relative to the original oven-dry sample, while hemicellulose content was estimated as the difference between holocellulose and α-cellulose. Lignin content was determined as acid-insoluble lignin in accordance to TAPPI T222 om-02 by hydrolysing extractive-free samples (~1 g) with 72% H_2SO_4, followed by dilution and refluxing to remove carbohydrates. The insoluble residue was then filtered, washed and dried at 105 °C to constant weight. Lignin content was expressed as a percentage of oven-dry sample weight.

Determination of preliminary phytochemical screening, the bark of the plant was exhaustively extracted using methanol to obtain the crude extracts. Preliminary phytochemical screening was performed to detect the presence of major classes of secondary metabolites commonly associated with plant biological and ecological functions, including alkaloids, saponins, flavonoids, tannins, triterpenes, and steroids. All analyses were conducted using standard qualitative phytochemical methods as described by Harborne (1998), Sofowora (2008), and Trease and Evans (2009). Alkaloids were detected using Mayer’s reagent following acid extraction, where the formation of a white precipitate indicated a positive result (Harborne, 1998). Saponins were detected using the froth test, in which the persistence of stable foam indicated the presence of saponins (Sofowora, 2008). Flavonoids were detected using the ammonia test, with yellow coloration indicating a positive reaction (Trease & Evans, 2009). Tannins and polyphenols were identified using ferric chloride, producing blue-black or greenish-brown coloration depending on tannin type (Harborne, 1998). Triterpenes and steroids were detected using the Liebermann–Burchard reaction, a widely accepted qualitative test for terpenoid compounds (Sofowora, 2008). The intensity of colour development or precipitate formation was recorded semi-quantitatively as weak (+), moderate (++), or strong (+++).

Determination of Physical Properties

Physical properties were tested using ISO 13061 2014: Physical and Mechanical Properties of wood–Test methods for small clear wood specimens. Samples of size 20 mm in radial × 20 mm in longitudinal × 40 mm in tangential directions were cut from the woods for the analyses of density and shrinkage. Density was determined on the basis of oven dry weight and green volume. The shrinkage test was conducted in green to air-dry conditions. The tangential, radial and longitudinal sections of each sample were marked and measured with a pair of digital vernier callipers to the nearest 0.01 mm. Shrinkage was calculated using the following equations:

$$Sa\ (\%) = \left(\frac{Di\ -\ Da}{Di}\right) \mathrm{X}\ 100$$

where S_a = shrinkage from green to air-dry conditions, D_i = initial dimension (mm) and D_a = air-dry dimension (mm).

Determination of Mechanical Properties

The timber was processed into samples and divided into two groups, according to the timber gathered from the bottom section or middle section of the tree trunk. All the samples were conditioned to moisture content between 12 to 14% prior to testing. The tests were conducted in accordance with ISO 13061 2014: Physical and Mechanical Properties of wood–Test methods for small clear wood specimens namely static bending test (central loading method), compression test (parallel to the longitudinal grain), shear test (parallel to the longitudinal grain), and hardness test (Janka indentation test). The size of the samples followed the 2 cm standard of the testing methods (Table 1). The modulus of rupture (MOR) and modulus of elasticity (MOE) were determined in the bending test. The moisture content of the samples at the time of test was also determined using oven-dry method.

Table 1. Size of test samples in accordance with 2 cm standard of ISO 13061 2014.

	Number of samples (for each bottom or middle section group)	**Dimensions (cm) (depth × width × length)**
Static bending	30	2 × 2 × 30
Compression	30	2 × 2 × 6
Moisture content	30	2 × 2 × 6
Shear	60*	2 × 2 × 2
Hardness	60**	2 × 2 × 6

*30 samples each for plane of shear failure parallel to the radial and tangential direction respectively. **30 samples each for the load applied on the radial and tangential surface respectively.

Statistical Analysis

Statistical analysis was performed using Statistical Analysis System (SAS). Analysis of variance (ANOVA) was used to determine whether or not the differences in means was significant. If the differences were significant, Least Significant Difference (LSD) test was used to determine which of the means were significantly different from one another.

Results and Discussion

Anatomical Properties

The anatomical features of 7-year-old plantation-grown *B. microphyllum* are shown in Figure 1. The anatomical features of *B. microphyllum* are describe for their identification and are an important indication on the suitability of the timber in terms of its potential usage. The following description of timber is based on microscopic features of 7–years-old *B. microphyllum*. **Cross section:** Growth ring indistinct. Diffuse porous, vessels exclusively solitary, with simple perforation, very large-sized of 296 to 310 µm and very few in vessels numbers, 4 per mm^2. Tyloses and deposit absent. Axial parenchyma is aliform and confluent. **Tangential section:** Rays of 3 to 4 seriate and height range from 173 to 193 µm. All rays storied, ripple marks present**. Radial section:** All ray cells procumbent. Fibres non-septate. Crystal and silica grains absent.

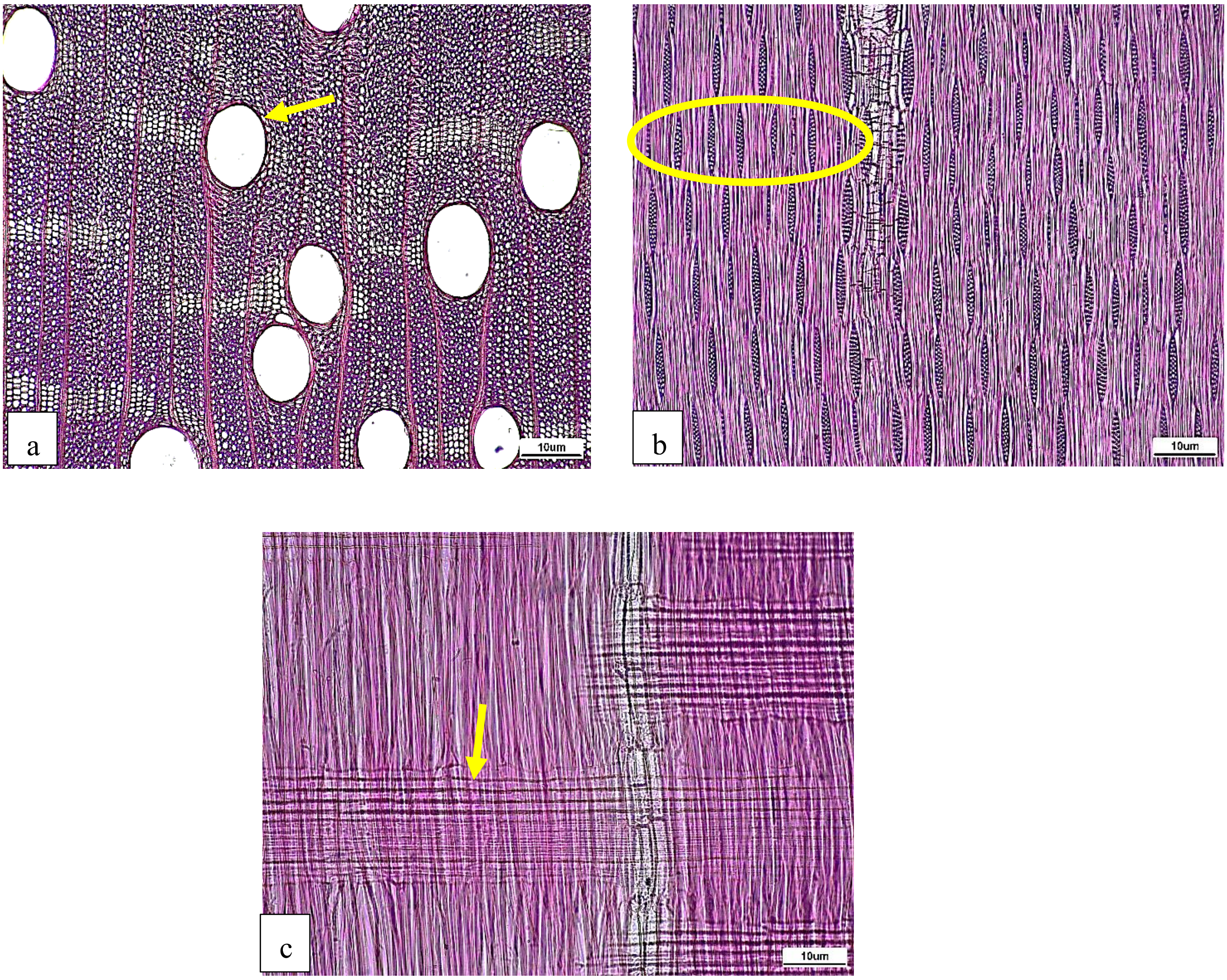

Figure 1. a) **Cross section:** Diffuse porous, vessels exclusively solitary (arrow). b) **Tangential section:** Rays of 3-4 seriate. All rays storied (circle). c) **Radial section:** All ray cells procumbent (arrow). Fibres non-septate.

Table 2 summarises the anatomical properties of *B. microphyllum* in comparison with selected plantation timbers, namely batai, kelempayan, rubberwood and *Eucalyptus* which were 15-years-old. In Malaysia, these species have been recognised by the Malaysian Timber Industry Board (MTIB) as major fast-growing trees capable of producing quality timber for plantation forests. Besides, the result of anatomical properties at the bottom part of the *B. microphyllum* tree were significantly higher at ($p \leq 0.05$) compared to the middle portion, except fibre wall thickness, runkel ratio and number of vessels which shows no significant difference between bottom and middle portion.

Table 2. Anatomical properties of *B. microphyllum* and other plantation species.

Species	**Tree height**	**Fibre length (µm)**	**Fibre diameter (µm)**	**Fibre lumen diameter (µm)**	**Fibre wall thickness (µm)**	**Runkel ratio**	**Slenderness ratio**	**Vessel diameter (µm)**	**Number of vessels/ mm^{2}**
B. microphyllum	Bottom	1150.0^{a}	26.8^{a}	21.8^{a}	2.5^{a}	0.3^{a}	42.8^{a}	310^{a}	4.0^{a}
		(69.0)	(3.5)	(2.6)	(0.8)	(0.1)	(3.7)	(35)	(0.5)
	Middle	978.0^{b}	23.0^{b}	17.5^{b}	2.6^{a}	0.3^{a}	41.0^{b}	296^{b}	4.0^{a}
		(72.0)	(2.6)	(3.1)	(0.6)	(0.1)	(5.7)	(29)	(0.4)

Mean	1014 (92.0)	24.4 (2.8)	18.6 (3.3)	2.9 (0.7)	0.3 (0.1)	41.9 (4.8)	303 (33)	4.0 (0.5)
Batai* (*Pareserianthes falcataria*)	1182	33	27	3.0	0.27	36.4	290	2.0
Kelempayan** (*Neolamarckia cadamba*)	1512	37	23	3.0	0.57	43.2	250	4.0
Rubberwood*** (*Hevea brasiliensis*)	1270	29.7	21.8	3.9	-	-	260	5.0
Eucalyptus hybrid ****	1187	22.4	12.6	4.9	0.38	52.9	150–250	7–11

Note: Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05. *Hamdan et al. (2020), **Nordahlia et al. (2020), ***Marasigan & Alipon (2026), ****Nordahlia & Zairul (2021).

As timber plantations are primarily established to supply raw material for the pulp and paper industry, fibre parameters such as the fibre length, Runkel ratio and slenderness ratio are key indicators of performance (Nordahlia et al. 2011; Adi et al. 2025). The fibre length of *B. microphyllum* exceeded 1000 µm, indicating suitability of this timber for pulp, paper and composite panel production (Bowyer et al. 2003; Cicekler & Uzum 2023). According to Takeuchi et al. (2016), fibres with a Runkel ratio below 1.0 are suitable for pulp production with good strength properties, whereas higher values indicate stiff and less flexible fibres that produce bulkier paper with a lower bonded area (Shmulsky & Jones 2019). The mean Runkel ratio of *B. microphyllum* was below 1.0 (Table 1), suggesting its potential to produce good-quality paper. Paper tearing strength and folding endurance are influenced by the slenderness ratio (Adi et al. 2025), with higher values indicating better fibre bonding and improved sheet formation (Rodriguez et al. 2016). The slenderness ratio of *B. microphyllum* was 41.9, comparable to that reported for *Eucalyptus* hybrid (52.9), a commonly preferred species for pulp and paper production (Adi et al. 2025).

The anatomical of timbers such as vessels, rays, present of tylosis and silica of wood determine the processing and use of timber. Their size, quantity, and structure are closely related to the physical properties of the timber and directly determine the value of timber use (Wang et al. 2021). Anatomically, *B. microphyllum* is characterised by very large vessels according to the classification of Wheeler et al. (1989). Large vessels are typically associated with light-weight timber and coarse texture suitable for general utility applications (Phongkrathung et al. 2016). The absence of tyloses and gum deposits further indicates good treatability through impregnation processes (Adeniyi et al. 2013) and suitability for veneer and plywood manufacture, as gums may interfere with adhesive bonding. Additionally, the absence of silica suggests improved machinability, particularly ease of cutting and sawing (Lim et al. 2016; Nordahlia et al. 2023). The rays are medium-sized and homocellular, a feature that favours good nailing performance (Wang et al. 2021, Wang et al. 2023).

Chemical Composition

The chemical composition of *B. microphyllum* (Table 3) indicates that holocellulose is the dominant component, comprising 79.5% in the bottom portion and 81.9% in the middle portion of the stem, with an average of 80.7%. This level is comparatively higher than that reported for several fast-growing plantation species, such as kelempayan (72.1%) and batai (74.86-76.21%), and substantially exceeds that of rubberwood (58.58%) (Rushdan et al., 2020; Kurniawan et al., 2024; Zaki et al., 2012). A high holocellulose fraction reflects a greater proportion of structural carbohydrates, which is advantageous for fibre-based and lignocellulosic applications.

Table 3. Chemical composition of *B. microphyllum* and other plantation species.

Species	Tree height	Holocellulose (%)	α-Cellulose (%)	Lignin (%)	Extractives (%)
B. microphyllum	Bottom	79.5^{a}	44.5^{a}	22.6^{a}	2.1^{a}

		(4.64)	(1.13)	(0.35)	(0.46)
	Middle	81.9^{b} (0.44)	44.2^{a} (0.81)	23.9^{a} (1.23)	0.9^{b} (0.62)
Mean		80.7 (3.03)	44.4 (0.97)	23.3 (0.79)	1.5 (0.54)
Kelempayan* (*Neolamarckia cadamba*)		72.1	41.2	23.0	-
*Batai*** (*Paraserianthes falcataria*; sengon)		74.86-76.21	47.99-48.91	26.58-30.81	5.23-6.01
Rubberwood*** (*Hevea brasiliensis*)		58.58	41.41	16.59	-
Eucalyptus hybrid****		-	-	25.9 - 29.4	2.3 - 3.0
		57.0	-	29.15	-

Note: Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05. *Rushdan et al. (2020), **Kurniawan et al. (2024), ***Zaki et al. (2012), ****Vieira et al. 2021; 2023.

The α-cellulose content (44.2-44.5%) falls within the typical range for hardwoods and is comparable to kelempayan and rubberwood, though slightly lower than sengon (Kurniawan et al., 2024). Lignin content (22.6-23.9%) is moderate, aligning with values reported for kelempayan but lower than sengon and higher than rubberwood. Such levels are favourable for processing, as excessive lignin can hinder chemical pulping efficiency.

Total extractives were relatively low (0.9-2.1%), comparable to Eucalyptus hybrids but lower than sengon. From a processing perspective, reduced extractive content is beneficial, as it minimises interference with pulping and adhesive performance. Nevertheless, the qualitative composition of these extractives remains significant.

Phytochemical screening (Table 4) confirmed the presence of multiple classes of secondary metabolites, particularly flavonoids, tannins/polyphenols, and triterpenes or steroids, with alkaloids and saponins detected in smaller or inconsistent amounts. These compounds represent the functional constituents of the extractive fraction. The dominance of phenolic compounds is consistent with their known association with lignified tissues, where they contribute to structural integrity and defence mechanisms (Taiz et al., 2015).

Table 4. Preliminary phytochemical screening of *B. microphyllum.*

Phytochemical Class	Result	Intensity
Alkaloids	Present	+ / ++
Saponins	Present	+
Flavonoids	Present	+++
Tannins/Polyphenols	Present	++ / +++
Triterpenes/Steroids	Present	++

In addition, secondary metabolites such as tannins and triterpenes are widely linked to protective functions, including resistance to biological degradation and environmental stress (Rowell, 2012). Their distribution, particularly in the basal region, corresponds with observed variations in mechanical properties, suggesting a close relationship between chemical composition, tissue structure, and functional performance. Beyond their structural role, these bioactive constituents may enhance durability and provide added value for bio-based applications due to their antioxidant and other functional properties. Taken together, the chemical and phytochemical characteristics of *B. microphyllum* demonstrate its suitability for a broad range of uses, from conventional wood products and engineered composites to fibre-based materials and higher-value bioproducts such as biofuels and biochemicals.

Physical Properties

Results for density and shrinkage of *B. microphyllum*, in comparison with selected plantation timbers, are presented in Table 5. There is no significant difference in terms of the shrinkage in the bottom and middle portion, whereas for the density is significantly higher at ($p \le 0.05$) in the bottom portion compared to the middle. Based on its density, *B. microphyllum* is classified as a light to moderately heavy timber (Wong, 2019). The density ranges from 441.4 to 606.8 kg/m^3, with a mean value of 524.1 kg/m^3 which the density is higher compared to batai, kelempayan and rubberwood which their age is 15-year-old, but comparable to *Eucalyptus* hybrid. Owing to *B. microphyllum* relatively low density, according to Phongkrathung et al. (2016) the light timber is suitable for light construction, furniture, picture frames, and general utility products.

Table 5. Physical properties of *B. microphyllum* and other plantation species **Mechanical Properties.**

Species	Tree height	Density (Kg/m^3)	Shrinkage from green to air dry %				Shrinkage from green to oven dry %			
			Tangential	Radial	Longitudinal	T/R	Tangential	Radial	Longitudinal	T/R
B. microphyllum	Bottom	568.4^{a}	2.2^{a}	1.4^{a}	0.6^{a}	1.6^{a}	4.9^{a}	3.3^{a}	0.8^{a}	1.50^{a}
		(65.9)	(0.7)	(1.0)	(0.4)	(0.2)	(1.0)	(1.5)	(0.4)	(0.2)
	Middle	464.5^{b}	2.2^{a}	1.3^{a}	0.7^{a}	1.7^{a}	4.6^{a}	3.0^{a}	1.0^{a}	1.53^{a}
		(63.9)	(0.7)	(1.2)	(0.5)	(0.3)	(1.5)	(1.4)	(0.5)	(0.2)
	Mean	524.1 (82.7)	2.2 (0.7)	1.37 (1.2)	0.6 (0.3)	1.61 (0.1)	4.8 (1.2)	3.2 (1.4)	0.9 (0.4)	1.50 (0.2)
Batai* (*Pareserianthes falcataria*)		293	3.0	2.4	0.8	-	-	-	-	-
		(78.0)	(0.9)	(0.9)	(0.4)	-	-	-	-	-
Kelempayan** (*Neolamarckia cadamba*)		493	2.4	1.5	0.5	-	-	-	-	-
		(35.0)	(0.6)	(0.8)	(0.1)	-	-	-	-	-
Rubberwood*** (*Hevea brasiliensis*)		480	-	-	-	-	2.81	4.52	0.50	-
Eucalyptus hybrid ****		559	4.8	2.5	0.3	1.0	9.8	4.9	0.4	2.1

Note: Note: Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05. *Hamdan et al. (2020), **Nordahlia et al. (2020), ***Marasigan et al. (2026), ****Zairul et al. (2021).

The shrinkage of *B. microphyllum* is rated as average, based on tangential shrinkage from green to air-dry condition (Wong, 2019). At 15% moisture content, tangential shrinkage was 2.2%, while radial shrinkage was lower at 1.2%, indicating moderate dimensional movement. The medium ray size (Elaieb et al., 2019) also supports the observed average shrinkage behaviour. However, the longitudinal shrinkage (0.6% at 15% moisture content) was relatively high, which is attributed to the presence of juvenile wood. In comparison, longitudinal shrinkage of normal mature wood in most species typically ranges between 0.1% and 0.2% and rarely exceeds 0.4% (Schmulsky & Jones, 2019).

Based on the results obtained (Table 5), the T/R ratio of *B. microphyllum* at 15% moisture content was 1.6, indicating moderate dimensional stability. In general, values close to 1.0 represent highly stable timbers indicates uniform shrinkage and greater dimensional stability, values between approximately 1.3 and 1.8 indicate moderate stability, and values exceeding 1.8 correspond to unstable timbers prone to warping, cupping, twisting and surface checking during seasoning (Bowyer et al., 2003). Because drying defects are directly associated with anisotropic shrinkage, the T/R ratio is frequently used to evaluate the suitability of a species for high-precision products such as furniture components, flooring, veneers, laminated products, and musical instruments (Wong, 2019). Species with low T/R ratios are preferred for applications requiring tight dimensional tolerances, whereas species with higher ratios require careful drying schedules and design allowances (Hon & Shiraishi, 2001; Dinwoodie, 2000). Consequently, the T/R ratio serves not only as a physical property descriptor but also as a practical index for predicting processing performance and end-use quality (Zairul et al., 2021).

The mechanical properties of the timber are shown in Table 6. The mean results showed that most of the mechanical properties of the samples obtained from the bottom trunk of the trees were significantly higher at ($p \leq 0.05$) than the middle portion, except for the MOE values. Similar trend was also observed in other study on *Acacia mangium* (Moya & Muñoz, 2010); kelempayan (Nordahlia et al., 2020); sentang (Nordahlia et al., 2011); and *Khaya ivorensis* (Nordahlia & Lim, 2018). Higher density is typically associated with higher mechanical properties of timber (Dinwoodie, 2000).

Table 6. Mechanical properties of *B.* *microphyllum* and other plantation species.

	Moisture content (%)	Tree height	Bending		Compressive strength (N/mm^2)	Shear strength (N/mm^2)	Hardness (kN)
			MOR (N/mm^2)	MOE (N/mm^2)			
B.microphyllum	12–14	Bottom	94.80^{a} (15.22)	9427^{b} (1649)	44.89^{a} (4.84)	12.31^{a} (2.07)	3.91^{a} (1.03)
		Middle	76.88^{b} (14.81)	9610^{a} (1777)	40.13^{b} (5.63)	10.86^{b} (1.46)	3.20^{b} (0.70)
Rubberwood* (*Hevea brasiliensis*) Clone PB 260	12	Bottom	54.08 (19.08)	6100 (1640)	25.32 (5.06)	6.13 (0.79)	3.25 (0.86)
		Middle	57.92 (11.86)	6990 (930)	26.62 (5.48)	6.07 (0.82)	2.84 (0.49)
Batai** (*Paraserianthes falcataria*)	Air-dry	-	36.9 (14.1)	5143 (1453)	22.9 (4.8)	5.8 (1.3)	-
Kelempayan*** (*Neolamarckia cadamba*)	15.61	-	53.90 (9.47)	6031 (1102)	27.71 (4.90)	6.87 (1.70)	1.80 (0.50)
Eucalyptus nitens ****	8.2–10.5	-	53.0 (7.8)	10377 (1692)	42.8 (4.9)	5.5 (2.2)	-

Note: Note: Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05. *Marasigan & Alipon (2026), **Hamdan et al. (2020), ***Mohamad Omar et al. (2020), **** Derikvand et al. (2019).

Table 6 shows comparison of test results of other timber species from fast-growing tree plantation of other studies. The mechanical properties of *B. microphyllum* samples in this study showed higher strength values compared to the other species. In comparison with the age of the trees, which the test samples were produced, *B. microphyllum* (7-year-old) were very much younger than the timber species from the other studies such as rubberwood (25-year-old), *Paraserianthes falcataria* (15-year-old), and kelempayan (15-year-old). The bending MOR and shear strength of *B. microphyllum* were approximately 78% and 123% respectively higher than *Eucalyptus nitens*, while the bending

MOE and compressive strength parallel to the grain were comparable. The mechanical properties of middle section *B. microphyllum* were higher than the rubberwood. When compared to another species i.e *Paraserianthes falcataria* in the study by Hamdan et al. (2020), the younger *B. microphyllum* was overwhelming stronger. This shows the potential of *B. microphyllum* to be used as material for structural uses due to its fast-growing with superior mechanical properties when compared to timber from other plantation species.

Conclusion

This study provides the first integrated evaluation of the anatomical, chemical composition, physical and mechanical properties of plantation-grown *B. microphyllum* in Malaysia. The species is characterised by diffuse-porous wood with very large vessels, medium rays, and flexible fibres with a Runkel ratio below 1.0 and relatively high slenderness ratio, indicating favourable fibre bonding and processing performance. Chemical analysis revealed high holocellulose contents (79.5-81.9%), consistent α-cellulose (44.2-44.5%), moderate lignin (22.6-23.9%), and low extractive content (0.9-2.1%), indicating a substantial carbohydrate fraction with minimal non-structural compounds. Preliminary phytochemical screening detected flavonoids, tannins/polyphenols, and triterpenes/steroids as dominant constituents, supporting the relationship between tissue structure and secondary metabolite accumulation, and providing a scientific basis for its traditional use.

The timber exhibited light to moderately heavy density and moderate shrinkage with a T/R ratio of 1.6, indicating acceptable dimensional stability for general utilisation. These properties support its suitability for light construction, furniture components, veneers, composite products, and pulp-related applications. *B. microphyllum* showed higher density and superior mechanical properties compared to more mature timber from other plantation species. Rather than waiting more than 10 years for fast-growing plantation species to reach harvest maturity, *B. microphyllum* represents a promising timber source due to its favourable mechanical properties at a harvesting age of seven years, as demonstrated in this study. In summary, *B. microphyllum* demonstrates strong potential as an alternative fast-growing plantation species for value-added wood products, while also possessing bioactive chemical constituents of potential pharmacological interest.

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