Unlocking the potential of fast-growing species from Indonesia: durability and sorption aspects

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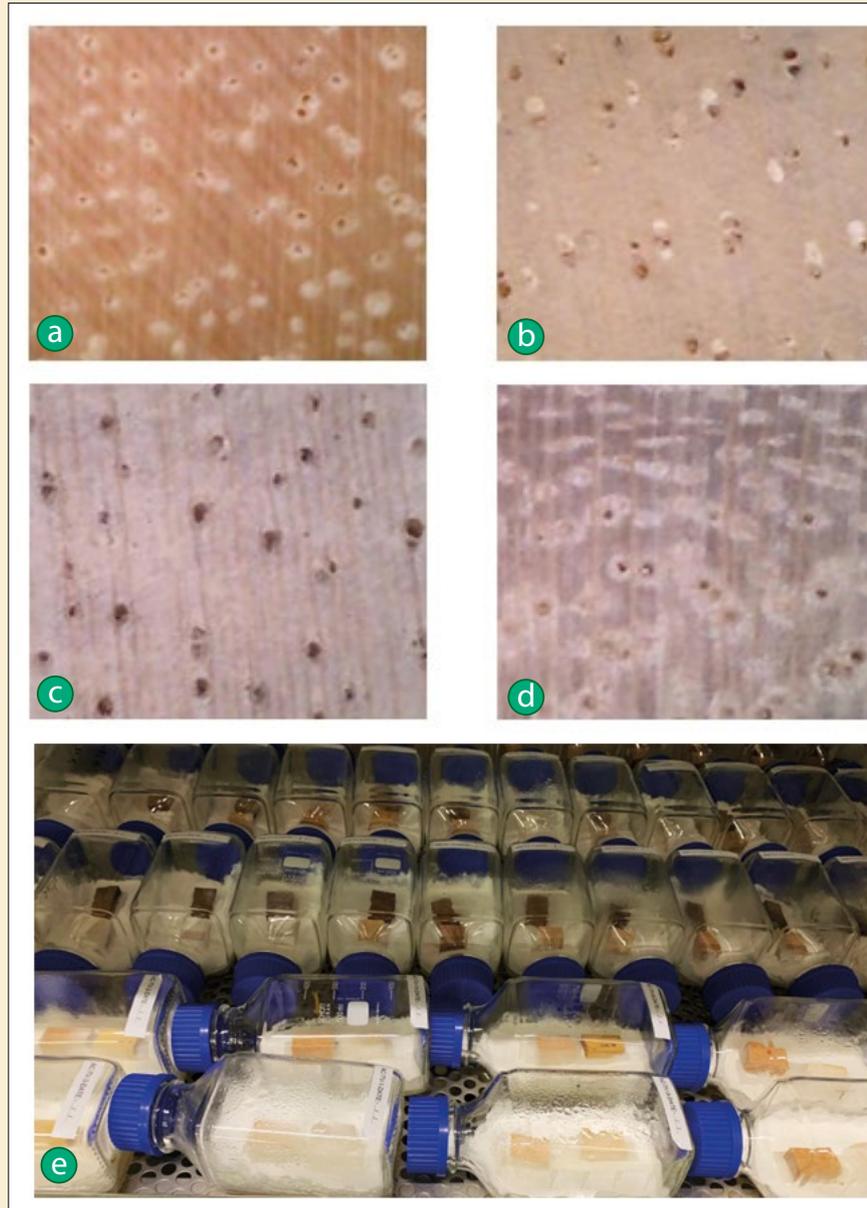
Photos 1.
Cross sections of *Acacia mangium* (a), *Anthocephalus cadamba* (b),
Paraserianthes falcataria (c), and *Paulownia tomentosa* (d) woods.
Wood durability and resistance tests against basidiomycete fungal attack (e).
Photos S. Fauziyyah.

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RÉSUMÉ

Exploiter le potentiel des espèces à croissance rapide d'Indonésie : durabilité et sorption

La foresterie sociale ou communautaire a été promue comme une piste intégratrice pour atténuer le changement climatique, dans le cadre du programme REDD+ de la CCNUCC (Réduction des émissions dues à la déforestation et à la dégradation des forêts). Les essences à croissance rapide sont peu exploitées en foresterie communautaire en Asie du Sud-Est, alors que leur potentiel pourrait contribuer à satisfaire la demande de bois de sciage en forte croissance. En 2016, le gouvernement indonésien s'est fixé pour objectif de céder des concessions totalisant 12,7 millions d'hectares à la foresterie communautaire, objectif qui reste fortement soutenu au niveau national. Si les essences commerciales de plantation, principalement le sengon (*Paraserianthes falcataria* L. Nielsen) et le jabon (*Anthocephalus cadamba* Roxb.), sont en forte demande, le potentiel d'autres essences, telles que l'acacia (*Acacia mangium* Willd.), mérite d'être exploré. Le paulownia (*Paulownia tomentosa* (Thunb.) Steud.) a également été utilisé dans cette étude. Physiologiquement, les essences à croissance rapide diffèrent des bois durs à longue rotation par leur qualité, notamment vis-à-vis de leur résistance à la biodétérioration. Dans cette étude, la durabilité naturelle des espèces à croissance rapide susmentionnées a été étudiée en laboratoire, en utilisant des monocultures de basidiomycètes. Des échantillons de bois ont été exposés à la pourriture brune (*Coniophora puteana*) et blanche (*Trametes versicolor*) pendant 16 semaines. Des paramètres tels que la perte de masse, la dureté de la surface, les propriétés de sorption et les caractéristiques anatomiques après exposition aux champignons ont été déterminés. Les temps de mesure de la sorption à haute température étaient plus rapides et l'hystérésis plus faible. Différents niveaux d'humidité relative ont affecté les modifications de la surface totale des vaisseaux. Parmi les essences à croissance rapide, *A. cadamba, P. falcataria* et *P. tomentosa* ont été classées comme peu durables à non durables, tandis que *A. mangium* a été classé comme durable. Les données concernant les échantillons exposés à *C. puteana* se sont avérées très variables. La dureté axiale restante des échantillons de bois incubés avec *T. versicolor* était inférieure à celle de *C. Putanea*. L'observation EDX (spectroscopie de rayons X à dispersion d'énergie) a montré que K (potassium) était le cation principal dans les échantillons atteints de pourriture.

Mots-clés : basidiomycetes, durabilité inhérente, résistance à l'humidité, bois dur tropical, Asie du Sud-Est.

ABSTRACT

Unlocking the potential of fast-growing species from Indonesia: durability and sorption aspects

Social or community-managed forestry has been promoted as an inclusive way of mitigating climate change, under the UNFCCC's REDD+ programme (Reducing Emissions from Deforestation and forest Degradation). Fast-growing wood species are one of the least tapped social forestry commodities in Southeast Asia, and they have the potential to be upscaled to meet the surge in demand of sawn timber. In 2016, the Government of Indonesia aimed to hand over concession rights to 12.7 million hectares for community forestry, and support at the national level is currently strong. The highly demanded commercial species from plantations are sengon (*Paraserianthes falcatria* L. Nielsen) and jabon (*Anthocephalus cadamba* Roxb.), another interesting species to explore is acacia (*Acacia mangium* Willd.). Paulownia (*Paulownia tomentosa* (Thunb.) Steud.) was also used in this study. Physiologically, fast-growing wood species differ from long-rotation hardwoods in their quality, i.e. their resistance to biodeterioration. In this study, the natural durability of the aforementioned fast-growing species was investigated by laboratory testing, using basidiomycete monocultures. Wood specimens were incubated with brown rot (*Coniophora puteana*) and white rot (*Trametes versicolor*) fungi for 16 weeks. Parameters such as mass loss, surface hardness, sorption properties, and anatomical characteristics after exposure to the fungi were determined. Sorption measurement times at high temperature were faster with lower hysteresis. Different relative humidity levels affected the changes in the total vessel area. The fast-growing wood species *A. cadamba*, *P. falcataria*, and *P. tomentosa* were classified as slightly durable to non-durable, except for *A. mangium,* which was classified as durable due to portions of heartwood in the samples. The data for specimens exposed to *C. puteana* were found to be highly variable. The remaining axial hardness of wood specimens incubated with *T. versicolor* was lower compared to *C. Putanea*. EDX observation (energy-dispersive X-ray spectroscopy) showed K (potassium) as the major cation in decayed specimens.

Keywords: basidiomycetes, inherent durability, moisture performance, tropical hardwood, South-East Asia.

RESUMEN

Explotación del potencial de las especies de crecimiento rápido de Indonesia: aspectos de durabilidad y sorción

La silvicultura social o comunal se ha promovido como una forma inclusiva de atenuar el cambio climático, según el programa UNFCCC's REDD+ (reducción de emisiones de la deforestación y degradación forestal). Las especies madereras de crecimiento rápido se utilizan poco como recurso forestal comunitario en el sudeste asiático, a pesar de que su potencial podría ayudar a satisfacer el aumento en la demanda de madera aserrada. En 2016, el Gobierno de Indonesia se marcó como objetivo transferir los derechos de concesión de 12,7 millones de hectáreas para silvicultura comunitaria, y este objetivo a nivel nacional se mantiene en la actualidad. A pesar de la elevada demanda de especies comerciales procedentes de plantación, como el sengon (*Paraserianthes falcataria* L. Nielsen) y el jabon (*Anthocephalus cadamba* Roxb.), el potencial de otras especies, como la acacia (*Acacia mangium* Willd.), merece ser explorado. También se utilizó la paulonia (*Paulownia tomentosa* Thunb.) en este estudio. Fisiológicamente, las especies madereras de crecimiento rápido difieren de las maderas duras de rotación larga en su calidad, por ejemplo, la resistencia al biodeterioro. En este estudio, la durabilidad natural de las especies de crecimiento rápido mencionadas anteriormente se investigó mediante pruebas de laboratorio, utilizando monocultivos de basidiomicetos. Los ejemplares de madera se incubaron con hongos de pudrición parda (*Coniophora puteana*) y de pudrición blanca (*Trametes versicolor*) durante 16 semanas. Se determinaron parámetros como pérdida de masa, dureza superficial, propiedades de sorción y características anatómicas después de la exposición a los hongos. Los tiempos de medición de sorción a elevada temperatura fueron más rápidos con menor histéresis. Diferentes niveles de humedad relativa afectaron a los cambios en la superficie total de los vasos. Las especies madereras de crecimiento rápido *A. cadamba, P. falcataria* y *P. tomentosa* se clasificaron de no muy duraderas a no duraderas, excepto *A. mangium*, que se clasificó como duradera. Se encontró que los datos para las muestras expuestas a *C. puteana* eran altamente variables. La dureza axial remanente de las muestras incubadas con *T. versicolor* fue inferior comparada con las de *C. Putanea*. Las observaciones mediante EDX (espectrometría por dispersión de energía de rayos X) mostraron que K (potasio) era el catión principal en las muestras descompuestas.

Palabras clave: basidiomicetos, durabilidad inherente, rendimiento con humedad, madera dura tropical, Sudeste Asiático.

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Introduction

Wood as a construction material offers many benefits. Despite its environmental lead as a sustainable material for construction, lignocellulosic materials such as wood are characterised by their hygroscopic and anisotropic behaviour, as well as their varying natural durability. Wood can be particularly affected by biological deterioration agents such as wood-destroying fungi, which are negatively affecting the service life of wooden components in outdoor use. In Indonesia, the core mitigation plan in the forestry sector under the Ministry of Environment and Forestry is the development of social forestry with an emission reduction target of up to 100,930 GgCO$_{2eq}$ (MoEF 2017). The implementation of the social forestry programme as a climate mitigation action plan aimed to reduce deforestation rate, forest degradation, and enhance carbon sink (REDD+) with co-benefits on poverty alleviation and improvement of governance for empowering the local economy. Per July 2022, more than 1,000 units of forest management permits through forestry partnerships have been established, which cover a total of 571,053.42 ha of forested land for more than 150 thousand households (MoEF 2022).

Agroforestry practices under the social forestry programme are often adapted by communities around forested land to maintain the soil nutrient cycle and improve the microclimate. Among different types of tree species, deciduous trees are largely planted in Indonesia. In 2001, Indonesia ranked third among all Asian countries, with a forest plantation area of 9.9 million ha. The majority of the Indonesian plantations are dedicated to rubber, teak, pines, and *Acacia mangium* (Enters and Durst 2004). The deciduous tree species planted by community farmers in one of Sumatera's regions are Sengon/Albasia. (*Paraserianthes falcataria* Nielsen), Jabon (*Anthocephalus cadamba*

Roxb.), Teak (*Tectona grandis* L.), *Ficus microcarpa* and non-woody species such as *Calamus manan* and *Bambusoideae* (Pratiwi et al. 2021). These species are planted along with coffee and cocoa plants, which have been the major export commodities from various provinces in Sumatra. Soerianegara et al. (1993) reported that the mean annual increment (MAI) for the 8–12-year-old *P. falcataria* rotation is around 10–25 to 30–40 m³/ha. Another major species is Acacia, as about 67% of the total reported area of *A. mangium* plantations in the world are located in Indonesia (Krisnawati et al. 2011). Further deciduous lightwood species utilised in community forests and their distribution are presented in table I.

Fast-growing species resourced by regional social forestry schemes are capable of taking a prominent position in the advancing climate agenda. However, such wood species often have relatively inferior material properties, including low biological durability. When six-year-old *A. cadamba* or *P. falcataria* trees are harvested, 100% of their formed wood is, of course, juvenile (Rahayu et al. 2014). However, there are notable differences in durability between juvenile and mature wood, which makes juvenile wood questionable for use as constructive timber. As far as durability is concerned, mature wood has higher concentrations of extractives compared to juvenile wood (Forest Products Laboratory 2010). Consequently, juvenile wood usually has lower natural durability compared to mature wood. Thus, the inherent resistance against biodeterioration is critical for any future use (Brischke et al. 2012). In addition, fungal degradation rates depend on wood moisture content, on the prevalent temperature, and on the inherent durability of a given wood piece (Zabel and Morrell 2012).

Table I.
Distribution of notable low-density deciduous wood species in five major islands in Indonesia adapted from Martawijaya (2004).

Wood species	Specific gravity	Natural forest					Plantation				
		Sumatra	Java	Borneo	Sulawesi	Papua	Sumatra	Java	Borneo	Sulawesi	Papua
Paraserianthes falcataria (L.) Nielsen syn. *Albizia falcataria* (L.) Fosberg and *Albizia falcata* (L) Becker	0.33 (0.24–0.49)	x	x	x	x			x		x	x
Acacia mangium Willd.	0.50 (0.46–0.52)								x		x
Anthocephalus chinensis (Lamk.) A. Rich, ex Walp. Syn. *Anthocephalus cadamba* Miq.	0.42 (0.29–0.56)	x	x	x	x	x		x	x		
Dyera costulata Hook	0.43 (0.22–0.56)	x		x							
Macaranga hypoleuca (Reichb. F.et Zoll.) M.A syn. *Nappa hypoleuca* (Reichb.F.et Zoll.)	0.34 (0.21–0.47)	x		x							
Toona sureni	0.39 (0.27–0.67)						x	x	x	x	x
Aleurites moluccana (L.) Wild	0.31 (0.23–0.44)						x	x		x	x
Gmelina arborea Roxb.	0.47 (0.46–0.63)							x			

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Table II.
Wood species used in the experiment, mean wood density (standard deviation in parentheses), and origin.

No	Species	Density (g/cm³)	Origin
1	Sengon (*Paraserianthes falcataria*)	0.29 (0.06)	Java
2	Jabon (*Anthocephalus cadamba*)	0.48 (0.04)	Java
3	Acacia (*Acacia mangium*)	0.70 (0.12)	Borneo
4	Paulownia (*Paulownia tomentosa*)	0.30 (0.01)	Austria
5	Beech (*Fagus sylvatica*)	0.68 (0.06)	Austria

For determining the expected service life of wooden components in hot-humid environments, knowledge about the inherent natural durability is required. Therefore, preventive actions such as preservation or modification measures can be applied, to assure sufficient service life. Work has been done on the durability of fast-grown wood against termite and insect attacks, but records regarding durability against decay fungi are scarcely offered (Hadi et al. 2020; Jusoh et al. 2014). Generally, cities and regencies in Java have a high to very high decay hazard index, according to Scheffer (1971), with 47% of the cities and regencies in Java having a high decay Scheffer index and 40% of the cities in the rest of Java being classified as a moderate decay hazard region (Priadi 2011). The overall purpose of this research is to assess the suitability of three fast-grown Indonesian wood species to be potentially used for engineered wood products. In particular, this paper focuses on the vapor sorption characteristics and the inherent durability of solid wood samples.

Material & Methods

Wood origin

Various wood species (1–3, table II) were attained from different plantations in Java and Borneo, Indonesia. The tree's age ranged between five and seven years. Logs were debarked and sawn into boards. For each board, defect-free samples were cut to a size of 25 × 25 × 300 (w × h × l) mm³, and shipped to Austria in oven-dried condition. While most of the samples consisted of sapwood only, a larger proportion of heartwood was found for the *A. mangium* samples, thus some adjustments were made for decay specimens further specified in the methodology. Additional samples from Austrian-grown *Paulownia tomentosa* (Thunb.) Steud. and beech (*Fagus sylvatica* L.) were obtained from the University of Natural Resources and Life Sciences Vienna, Austria. Information about the studied wood species is displayed in table II.

Material characterization

Wood moisture dynamics

Oven-dried wood specimens with a dimension of 25 × 25 × 50 (w × h × l) mm³ were sanded using multiple sandpaper grit starting from 120 grit to 600. Dust residues were removed using pressurised air. Thin slices of sapwood were then sawn using a circular saw (Format-4 Formatkreissäge Kappa 550) from the cross-section planes, having a size of 25 × 25 × 1 (w × h × l) mm³. The two final specimens were then cut to size 10 × 10 × 1 (w × h × l) mm³ using razor blades and stored inside a desiccator prior to measurement. Sorption measurements were carried out in a DVS Advantage 1 (Surface Measurement Systems). The initial dry weight was determined at 0% RH (relative humi-

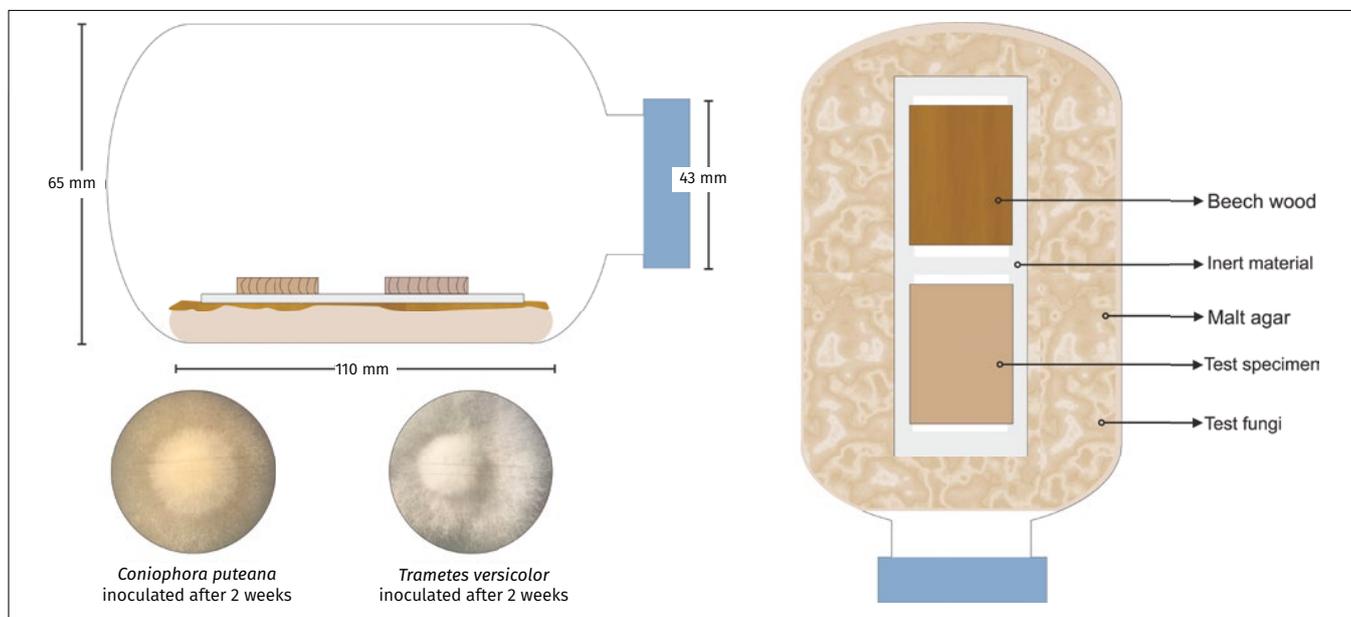65 mm

43 mm

110 mm

Coniophora puteana
inoculated after 2 weeks

Trametes versicolor
inoculated after 2 weeks

→ Beech wood
→ Inert material
→ Malt agar
→ Test specimen
→ Test fungi

Figure 1.
Illustration of the conducted decay tests.

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dity). RH levels were applied at 10% increment, from 0–90% were set, with a total of 19 RH measurement points. As soon as the dm/dt criterion of 0.002 was reached, which is the weight change over time, the next humidity level was set. Measurements were done at three different temperatures (15, 25, 35 °C) to observe potential temperature effects on the sorption properties of the materials, and the total air gas flow was set to 200 cm³/s. Changes in vessel area were determined through image analysis, by using the public domain software ImageJ (Schneider et al. 2012).

Table III.
Durability classes (DC) of wood according to EN 350 (2016).

Durability class	Description	Median percentage mass loss (ML)
DC 1	Very durable	ML ≤ 5
DC 2	Durable	5 < ML ≤ 10
DC 3	Moderately durable	10 < ML ≤ 15
DC 4	Slightly durable	15 < ML ≤ 30
DC 5	Not durable	30 < ML

Table IV.
Testing forces for Brinell axial hardness test.

Wood species	Test fungus	Maximum load (N)
Anthocephalus cadamba	Trametes versicolor	400
	Coniophora puteana	30
	Control	1,000
Acacia mangium	Trametes versicolor	400
	Coniophora puteana	30
	Control	1,000
Paraserianthes falcataria	Trametes versicolor	30
	Coniophora puteana	30
	Control	1,000
Paulownia tomentosa	Trametes versicolor	400
	Coniophora puteana	30
	Control	1,000
Fagus sylvatica	Trametes versicolor	400
	Coniophora puteana	30
	Control	1,000

Decay resistance against basidiomycetes

The assessment of the biological durability of wood specimens of the selected fast-growing species was performed according to EN 113-2 (2016), using the white rot fungus *Trametes versicolor* (CTB 836 A) and the brown rot fungus *Coniophora puteana* (CBS 230.87), respectively. Both fungal strains were obtained from the culture collection of the Institute of Forest Entomology, Forest Pathology, and Forest Protection at the University of Natural Resources and Life Sciences Vienna. Before incubation, the wood specimens were sterilised using a Cobalt 60 Gammatron 1500 following EN ISO 1348 (2016) and ISO 11137 (2018). Wood test specimens (n = 13) and moisture content test specimens (n = 5) were incubated in an alternative type 1 test vessel, as shown in figure 1, for 16 weeks at 22 ± 2 °C and 70 ± 5% RH, all stored inside a Phytotron (Heraeus-Vötsch, type VB 0714). Fluctuations in temperature and RH were monitored in real-time using the Simpati® software.

Beech (*F. sylvatica* L.) wood was used for virulence control of the two test fungi, which have to lead to a minimum mass loss of 20% after 16 weeks of incubation. All test specimens were produced from sapwood, except for *A. mangium,* which also contained larger portions of heartwood. To comply with the standard dimension, specimens were made with as little heartwood as possible. After incubation, the specimens were cleaned from adhering mycelium, oven-dried at 103 ± 2 °C, until a constant weight was reached. Mass loss was determined by weighing the oven-dry specimens before and after incubation. The inherent durability was classified according to EN 350 (2016) (table III).

Brinell hardness test

Brinell hardness tests were performed according to EN 1534 (2020). After mass loss evaluation, the specimens were stored at 20 °C and 65% RH for approximately one month, until weight constancy was reached. The test was performed with a universal testing machine Zwick Roell Z020. With an element length of less than 200 mm based on the testing norm, one testing point on the axial plane or face element was performed on each of the exposed as well as the control specimens. The hold and release of the hardness indenter were set to 30 seconds. The Brinell hardness (HB) was calculated using Equation 1:

$$HB = \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})} \qquad \text{(Equation 1)}$$

where F is the maximum load (N), D is the diameter of the indentation ball (mm), and d the diameter of residual indentation (mm). A list of predetermined forces used for the measurements is shown in table IV.

Characterization of fungal decay

The level of fungal degradation after incubation on decayed specimens was observed using the digital microscope Olympus DSX 1000 and a scanning electron microscope (SEM Hitachi HT3030). Samples were prepared using a sliding microtome, by cutting tangential and longitudinal sections. Traces of fungal decay were preliminarily
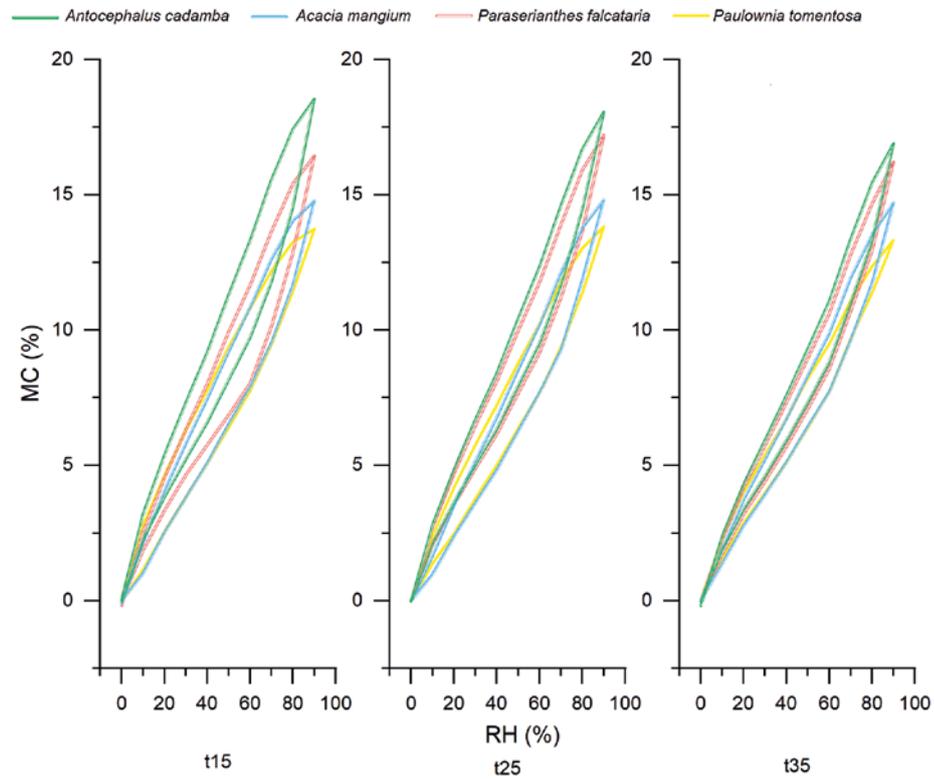
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Figure 2.
Sorption isotherms of wood species at different temperatures of 15, 25, and 35 °C.
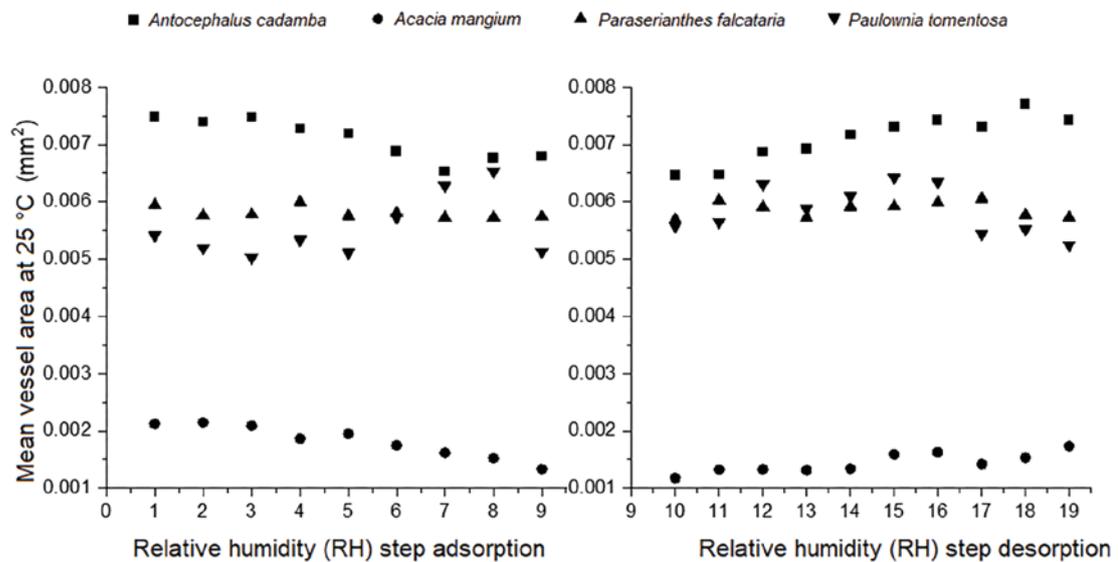
Figure 3.
Mean vessel area of wood specimens at different relative humidity (RH) steps.

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observed using an energy-dispersive X-ray spectrophoto-meter (EDX), which was implemented in the SEM. The EDX was used to perform elemental analysis on the specimens.

Results and Discussion

The exploration of unutilized fast-growing wood species from secondary forests in Kalimantan has been studied to understand their fibre characteristics and potential utilisation in various wood products, including construction materials (Adi et al. 2014). Fast-growing wood species generally have lower density and shorter fibre length compared to slow-growing wood species (Kojima et al. 2009). They have a higher proportion of early wood, which is more susceptible to moisture movement, leading to splitting and cracking (Gril et al. 2017). Nevertheless, as an oriented strand board, they meet minimum requirement for OSB/2 properties (Dumitrascu et al. 2020). Before utilising wood species as local building materials, information regarding their properties such as strength, dimensional stability, and inherent durability in relation to sorption isotherms is vital for efficient practical use (Wegner et al. 2010). The variability of the sorption iso-therm, which helps us understand how wood will absorb and release moisture, can have an impact on the durability of fast-growing wood species (Lee et al. 2021; Zhang and Richman 2021).

In this study, sorption isotherms show total vapour adsorbed by the samples as a function of relative vapour pressure (Nopens et al. 2019). All four examined fast-growing wood species showed similar characteristics, by following the IUPAC classification type II isotherm. In figure 2, smaller hysteresis were noted at the higher tem-perature levels. Thus, results indicated that temperature and wood species had a significant influence on wood hysteresis and sorption isotherm. This is in accordance with Krupińska et al. (2007), who also found that wood became less hygroscopic when measurement temperature increased, as indicated by decreased moisture content. This phenomenon resulted from enhanced reaction rates due to higher water activity (Panchariya et al. 2001). Moreo-ver, the width of the hysteresis loop depends on inter-nal bonding between and among the cell wall polymers (Irbe et al. 2006). Higher measurement temperatures also reduced the sorption hysteresis of all wood samples, especially in the high humidity range, with a maximum hysteresis seen at 60–70% RH. The highest to lowest moisture contents at 90% RH were found in the following order: *A. cadamba* (highest), *P. falcataria*, *A. mangium*, and *P. tomentosa* (lowest). Total time to achieve equilibrium required the longest period at the RH 90%, for all mea-sured temperatures and across all wood species. The total running times of the four-wood species were different at each set temperature, with the longest sorption period found for *A. mangium*, followed by *A. cadamba*, *P. falcata-ria*, and by *P. tomentosa*.

In this study, vessel area changes have been obser-ved during swelling and shrinking at the different RH levels (figure 3). The changes in vessel area were following wood activity, depending on the adsorption and desorp-tion stages. The graph shows that the mean vessel area was decreasing during the adsorption cycle, while on the desorption cycle, it tended to increase. Different moisture contents were recorded, and a relationship between ini-tial mass and moisture contents was made at the end of each RH step. A previous study on cell wall structure and sorption properties using different drying methods, i.e. air drying and oven drying, showed that the higher shrinkage corresponded to a smaller surface area. In this study, the surface area of the cell wall was correlated to the total pore volumes (Broda et al. 2021).

With respect to the species resistance against decay, the specimens were classified as slightly durable to not durable (DC 4–5). The average mass losses of wood spe-cimens exposed, from highest to lowest, irrespective of fungal species, were as follows: *A. cadamba*, *P. falcataria*, *P. tomentosa*, and *A. mangium* (table V). This is expec-ted for fast-growing wood species, which have a high proportion of juvenile wood within the sapwood (Dar-mawan et al., 2013). Fast-growing wood species with short rotation periods contain high portions of juvenile wood, which means lower resistance against decay, due to fewer extractives and lower technological properties. The high proportion of juvenile wood negatively impacts wood quality and durability against biodeterioration agents (Hadi et al. 2015; Lasserre et al. 2009).

Acacia mangium behaved differently since the samples also included smaller portions of heartwood. Heartwood-free samples were not available when the specimens were procured with small-diameter acacia. To comply with the requirement of a minimum sample dimen-sion based on EN 113-2 (2021), specimens had to be made with sapwood close to heartwood. In the literature, mass losses of *Acacia* hybrid, *A. mangium*, and *A. auriculiformis* due to decay by *T. versicolor* were 10.2%, 11.2%, and 7.3%, respectively (Jusoh et al. 2014). Those results were higher compared to the data found in this study, which had a mass loss of only 2.7% after exposure to the same white rot species. An even greater mass loss value of 14.3% was presented by another study on *A. mangium,* as exposed to *T. versicolor* (Wahab et al. 2017). *Acacia mangium* used in this study had a slightly higher wood density (0.70 g/cm³), compared to *A. mangium* from Malaysia forest plantations (0.29–0.58 g/cm³). Similar results as in the present study were found by Krisnawati et al. (2011), who found that *A. mangium* from natural forest in Indonesia had a density ranging between 0.45–0.69 g/cm³, at 15% moisture content.

Figure 4 shows mass losses of the wood specimens due to decay caused by the white rot fungus *T. versico-lor* and the brown rot fungus *C. puteana* after 16 weeks of exposure, including the mass losses of wood specimens of *F. sylvatica,* which were included in order to prove the virulence of the used test fungi. There was no notable difference in durability classes between brown-rot and white-rot decay; however, brown-rot exposure resulted in

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Table V.
Mean density (ρ), mean moisture content before (μMC_{be}) and after incubation (μMC_{ae}), mean mass loss (μML) and durability classes (DC) based on median ML of wood specimens (standard deviation in brackets).

Wood species	Fungal species	Measured parameters				
		ρ (g/cm3)	µMCbe (%)	µMCae (%)	µML (%)	DC
Anthocephalus cadamba	*Trametes versicolor*	0.50 (0.04)	6.56 (0.79)	78.10	34.4 (7.7)	5
	Coniophora puteana	0.48 (0.06)	6.63 (0.61)	70.00*	27.6 (4.3)	4
Acacia mangium	*Trametes versicolor*	0.78 (0.05)	7.81 (0.9)	51.81	2.7 (2.5)	1
	Coniophora puteana	0.76 (0.08)	8.4 (0.88)	68.53	2.1 (0.1)	1
Paraserianthes falcataria	*Trametes versicolor*	0.29 (0.06)	5.29 (0.72)	71.67	29.2 (7.4)	4
	Coniophora puteana	0.31 (0.06)	2.7 (9.91)	70.00*	15.1 (12.3)	4
Paulownia tomentosa	*Trametes versicolor*	0.30 (0.01)	6.26 (0.68)	76.60	23.6 (8.9)	4
	Coniophora puteana	0.29 (0.02)	6.2 (0.02)	70.00*	10.6 (18.8)	3v
Fagus sylvatica	*Trametes versicolor*	0.71 (0.04)	4.11 (0.46)	54.62	35.9 (9.5)	Virulence
	Coniophora puteana	0.70 (0.02)	3.9 (0.29)	71.72	53.3 (3.5)	Virulence

* waterlogged test specimens; "v" indicates the species exhibits high level of variability.

higher mass loss variation within the species. High data variability was recorded on *P. falcataria* and *P. tomentosa* exposed to *C. puteana,* with standard deviations between 12.3% and 18.8%. A former study indicated that the variation in mass loss data could be due to internal factors such as natural resistance across the wood specimens and the selectivity of the decaying fungi (Sharapov et al. 2018).

The results of the Brinell hardness tests on the wood samples are presented in figure 5. Axial hardness values before and after exposure were significantly different ($p < 0.05$). Species exposed to *T. versicolor* had considerably lower axial hardness compared to *C. puteana*. Species with the highest axial hardness values after incubation with basidiomycetes were from high to low: *A. mangium, A. cadamba, P. falcataria,* and *P. tomentosa,* regardless of decay type. When compared to control specimens, the axial hardness of specimens decayed by *T. versicolor* was reduced by 0.07%, 69.04%, 45.61%, and 55.34% for *A. mangium, A. cadamba, P. falcataria,* and *P. tomentosa,* respectively. Specimens exposed to *C. puteana* had slightly lower percentages of axial hardness reduction of 0.04%, 57.74%, 17.30%, and 22.24%. Brinell axial hardness is strongly influenced by the density of the surface layer, while variation in density within the sample did not influence these properties (Rautkari et al. 2013).

Test specimens exposed to brown rot revealed noticeable degradation compared to white rot in the wood substrate. Even though brown rot is causing more visible damage, the average mass loss of specimens decayed by *T. versicolor* was higher compared to *C. puteana*. Lignin plays a major role in wood degradation caused by fungi. It provides biological protection by generating enzymes to avoid fungal penetration (Arantes et al., 2011). Lignin in gymnosperms consists mostly of guaiacyl units, while angiosperms are composed of syringyl and guaiacyl units in varying ratios (Whetten and Sederoff 1995; Wool 2005). Thus, hardwood possesses lower resistance to white rot decay, which mainly attacks lignin. Additionally, fungal selectivity in degrading wood substrates is different depending on species. *T. versicolor* initially attacks hemicellulose and lignin, which causes strength reduction, whereas brown rot fungi only decompose hemicellulose or cellulose selectively (Qi et al. 2022).

Decay and active hyphae from fresh incubated specimens are shown in figure 6. White-rot decay activity has produced more porous zones in wood tissue, which led to the disintegration of wood samples (figure 6a). Fungal access to adjacent cells most likely took place via pit apertures or through direct penetration via cell walls (Schwarze 2007). In this study, hyphae spread through adjacent vessels (figure 6b), with the vessels filled with fungal mycelia. Cracks often occur between the radial cell walls close to the vessels. In figure 6b it is seen that hyphae grew inside the cell lumina with close contact to the cell walls. Here, active hyphae excrete degrading enzymes, causing a reduction in wall thickness over time (Schmidt 2006).

In figures 6d-f, characteristics of wood decay by *C. puteana* are displayed. The interface of *C. puteana* in *P. falcataria*'s lumen can be seen in figure 6d. Changes in
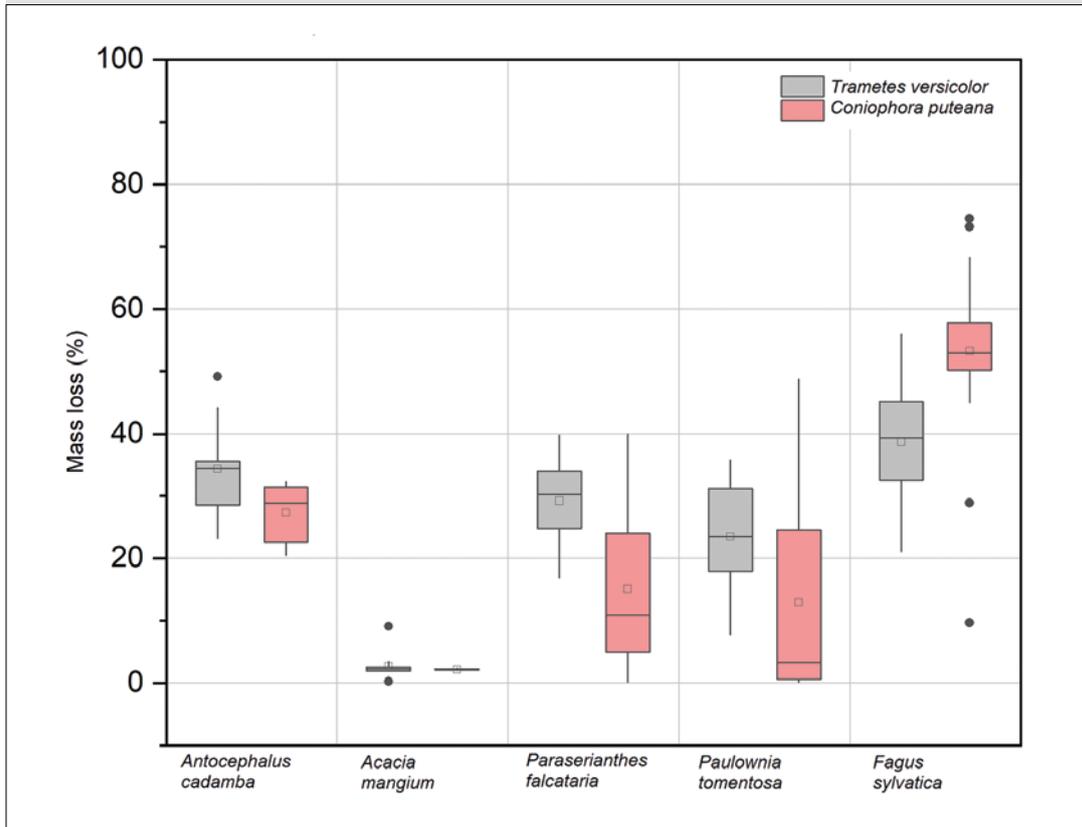
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Figure 4.
Mass loss results of white rot and brown rot decay after 16 weeks exposure.
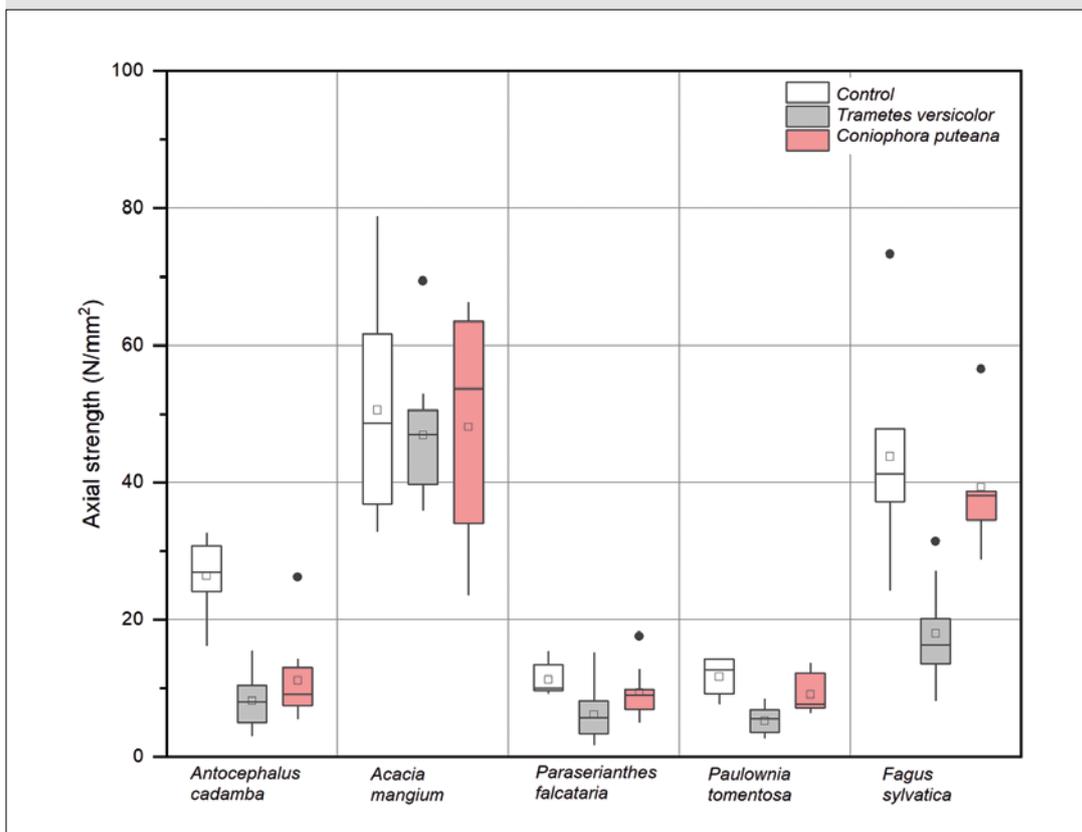
Figure 5.
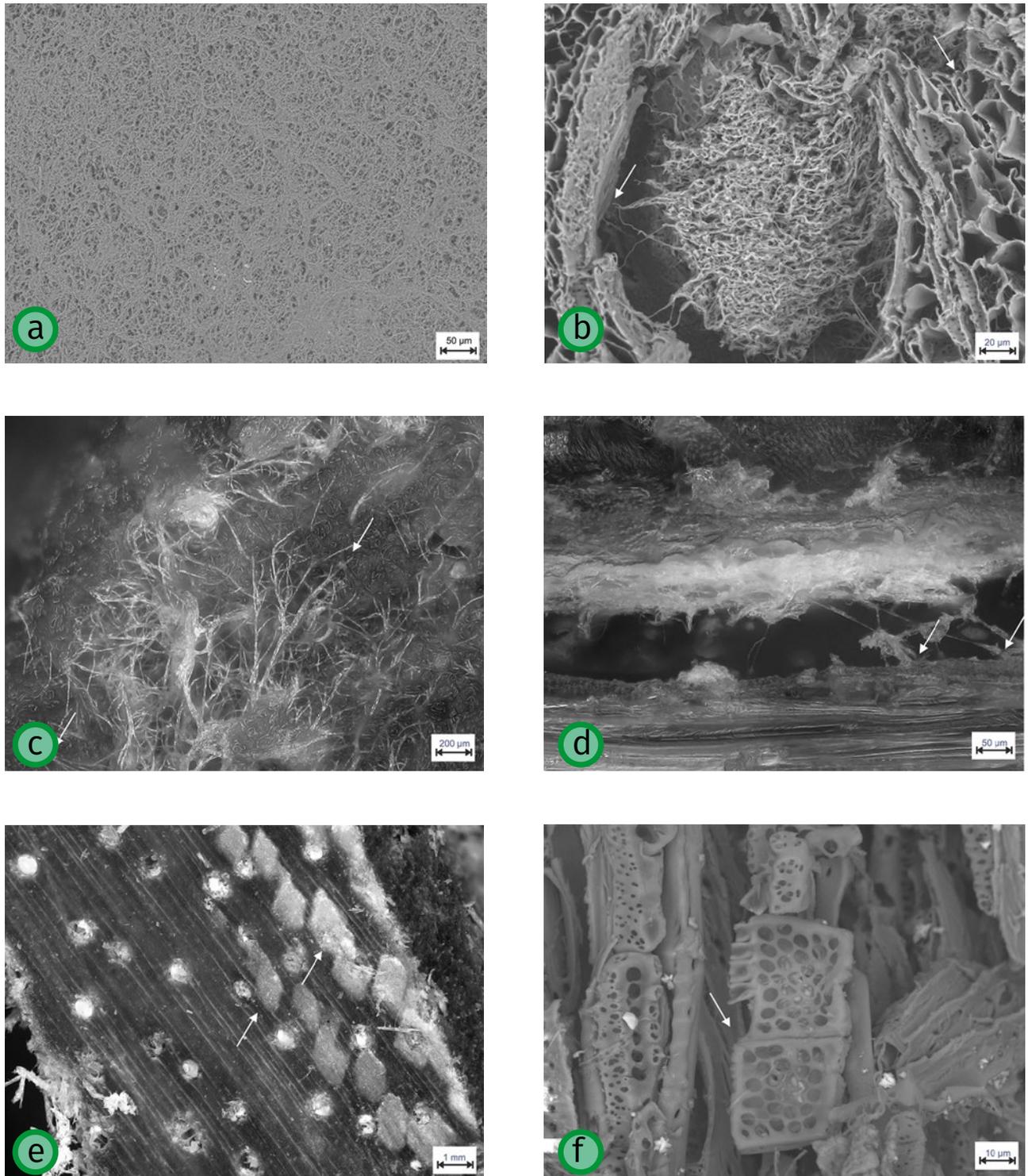Changes in axial hardness of decayed test specimens after 16 weeks exposure.

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Figure 6.
Mycelium mats of *Trametes versicolor* on *Paraserianthes falcataria* 200x magnification (a), bundles of *T. versicolor* on *P. falcataria* 100x magnification (b), hyphae of *T. versicolor* on *P. falcataria* 40x magnification (c), *Coniophora puteana* mycelium adherence interface on *P. falcataria* (d), structural changes on *P. falcataria* decayed by *C. puteana* 40x magnification (e) and cuboid cells on *Anthocephalus cadamba* decayed by *C. puteana* 600x magnification (f).
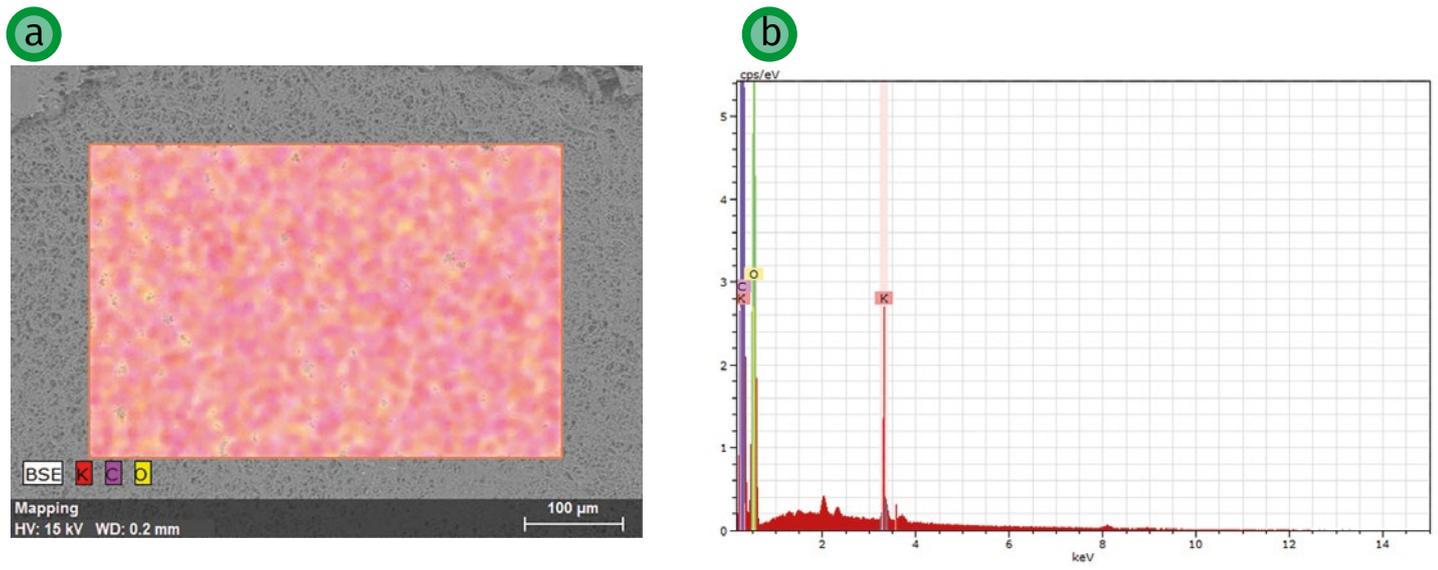
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Figure 7.
EDX analysis on a sample degraded by *Trametes versicolor*.

wood occurred due to the degradation of wood components by degrading enzymes of brown rot (figures 6e-f). Disintegration of cell walls is a result of extensive degradation of cellulose and hemicelluloses, subsequently causing the formation of holes and cracks (Moskal-del Hoyo et al. 2010). Changes in components degraded by white-rot decay caused severe changes in impact bending due to significant carbohydrate losses (Bari et al. 2015). Brown-rot decay is causing a significant decrease in the weight and mechanical properties of a given wood piece (Bouslimi et al. 2014). According to Pandey and Pitman (2004), decay by *C. puteana* causes the lignin content to increase with exposure time, in parallel with a mass loss as the carbohydrates are selectively removed.

Using the EDX method, major portions of K (potassium) cations were found on decayed wood specimens degraded by *C. puteana* or *T. versicolor* (figure 7). Higher concentrations of Ca (calcium), Mn (manganese), and Fe (iron) in decayed wood were also found in the study of Jellison et al. (1992). Ostrofsky et al. (1997) reported that Ca and K tend to increase with fungal exposure, as seen in red spruce. A higher K cation concentration is also associated with a decrease in the electrical resistance of decaying wood (Gao et al. 2019). Increased cation concentrations are correlated with mass loss and the progression of wood decay (Soge et al. 2021). Fungal activity on wood includes the transport of ions towards the infected regions. Recent findings suggested an increase in Fe concentration in brown rot decayed specimens, with significant movement of Ca from sound wood cell walls into the area colonised by fungal mycelium (Kirker et al. 2017).

Engineered wood products, such as glued laminated timber (glulam) or oriented strand boards (OSB), can be derived from tropical fast-growing wood species. For example, Hadi et al. (2021) studied polystyrene-impregnated glulam made from tropical wood species and found mechanical properties such as MOE and MOR to be inferior, which means they did not meet the required standards. Baskara et al. (2022) tested OSB made from the tropical fast species *Paraserianthes falcataria*, *Maesopsis eminii*, and *A. mangium.* It was found that with sufficient isocyanate resin as the binder for OSB, most of the physical and mechanical properties did meet the standard.

The use of tropical fast-growing wood species in engineered wood products is an important area of research, given the potential for these species to serve as a valuable resource. In their solid form, wood durability, axial hardness, and sorption properties are important factors to consider when selecting fast-growing wood species for practical applications commensurate to its service life (Barbu et al. 2022; Missio et al. 2016). Wood durability is affected by its natural resistance to decay, which varies among species. Meanwhile, sorption properties are an important analytical tool for the characterization of wood or any construction materials where the impact of humidity is important to material performance. The moisture content of wood is an important parameter influencing almost all mechanical properties of wood, and strength properties of wood increase as its moisture content decreases (Cao et al., 2021). The information regarding inherent durability and sorption properties leads to a better understanding of the provision of engineered wood products made from fast-growing species, which will be the avenue for the next research activities.

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Conclusions

In this study, fast-growing wood species showed low resistance to decay by basidiomycetes. Tested low-density wood had a high affinity for water. Moreover, higher temperatures during vapour sorption have led to faster running times and less expressed sorption hysteresis. The longest time period to reach moisture equilibrium was found at a relative humidity of 90%. Among the observed wood species, *Anthocephalus cadamba* had the highest moisture content. Changes in vessel area at different relative humidity (RH) levels were in accordance with the adsorption and desorption stages. Concerning decay resistance, specimens exposed to brown rot (*Coniophora puteana*) showed a higher mass loss variation within the tested species, compared to white rot (*Trametes versicolor*). Based on the obtained results, durability classes of wood were classified into durability classes 4–5 (slightly durable–nondurable), with the exception of *Acacia mangium*, which was rated as very durable (class 1). The unexpected result for *A. mangium* was due to the small proportions of heartwood present in the specimens. Specimens exposed to *T. versicolor* exhibited significantly lower axial hardness, whereas those exposed to *C. puteana* showed visibly extensive degradation compared to *T. versicolor*. High K ion concentrations were detected in decayed regions of the wood specimens. These results are crucial in determining further steps employing strategies to improve observed wood species properties for structural components in various conditions.

Data access
Following the FAIR (Findable, Accessible, Interoperable, and Reusable) principle, the data used in this article is available based on request and downloadable on doi: https://doi.org/10.5281/zenodo.8430111

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Writing – Review & Editing	S. Fauziyyah, C. Brischke, R. Wimmer, E. Halmschlager