Comparative decay resistance of plantation-grown and naturally-grown teak wood (*Tectona grandis* L.f.)

Photos 1.
a. A large teak (*Tectona grandis*) tree about 1,500 years old, with a height of 47.8 m, a circumference of 1,007 cm measured on June 18, 2000 before the top of tree was blown up by a storm, is now protected in the Ton Sak Yai National Park, Thailand. b. A row of teak trees along Route 117, Thailand contributes to the maintenance of good landscapes.
c. Plantation teak trees around 20 and 30 years old were harvested and stored in log-yard in Uttaradit Province, Thailand. All photos were taken during a teak expedition organized by Dr. Pipat Pattanaponpaiboon and Dr. Sasitorn Poungparn (Plant Ecology Laboratory), Faculty of Science, Chulalongkorn University in July 2023.
Photos K. Yamamoto.

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RÉSUMÉ

Comparaison de la résistance à la pourriture du bois de teck de plantation et du bois de teck naturel (*Tectona grandis* L.f.)

Le teck (*Tectona grandis* L.f.) est une des essences tropicales les plus largement utilisées en raison de sa durabilité naturelle. L'aubier, le duramen externe, moyen et interne et la moelle du teck de plantation (Indonésie) et du teck naturel (Myanmar) ont été testés pour leur résistance à la pourriture (composante majeure de la durabilité naturelle des bois), en appliquant un test de pourriture accélérée conformément à la norme JIS Z 2101 (1994) en présence de pourriture blanche (*Trametes versicolor*) et de pourriture brune (*Fomitopsis palustris*). Des blocs de bois de 20 × 20 × 10 mm ont été découpés dans des disques prélevés sur le rayon de la tige. Le pourcentage de perte de masse dû à la pourriture dans chaque bloc a été obtenu après 12 semaines d'incubation avec ces champignons. Les pertes de masse moyennes dues à *T. versicolor* sont les suivantes pour, respectivement, le teck de plantation, le teck naturel (n° 1) et le teck naturel (n° 2) : aubier 21,4 %, 7,1 % et « absence de données » ; duramen extérieur 0,6 %, 3,6 %, 6,6 % ; duramen moyen 2,3 %, 6,5 %, 5,7 % ; duramen intérieur 10,3 %, 9,6 %, 6,0 % ; moelle 13,0 %, 15,3 %, 8,2 %. Les pertes de masse dues à *F. palustris* sont, respectivement : aubier 7,5 %, 3,0 %, 7,5 % ; duramen externe 0,0 %, 2,5 %, 2,7 % ; duramen moyen 0,0 %, 2,2 %, 2,3 % ; duramen interne 4,9 %, 2,0 %, 3,4 % ; moelle 13,6 %, 8,4 %, 8,0 %. La durabilité a été classée en référence à Osborne (1970), en se basant sur le pourcentage moyen de perte de masse du duramen due à la pourriture fongique. Dans l'ensemble, parmi les échantillons de teck de plantation et de teck naturel, seuls les duramen externe et moyen étaient durables. La durabilité pour le duramen interne est modérée, mais faible pour la moelle. Aucune différence nette de résistance à la pourriture n'a été constatée entre le teck de plantation et le teck naturel.

Mots-clés : *Tectona grandis*, duramen, durabilité naturelle, résistance aux champignons lignivores, provenance, bois de teck, plantation tropicale, Indonésie, Myanmar.

ABSTRACT

Comparative decay resistance of plantation-grown and naturally-grown teak wood (*Tectona grandis* L.f.)

Teak (*Tectona grandis* L.f.) is one of the most popular tropical timber species for its natural durability. The sapwood, the outer, middle, and inner heartwood, and the pith of plantation-grown teak in Indonesia and naturally grown teak in Myanmar were tested for decay resistance (a major component of natural durability), applying an accelerated decay test according to JIS Z 2101 (1994), and using a white rot fungus (*Trametes versicolor*) and a brown rot fungus (*Fomitopsis palustris*). Wood blocks 20 × 20 × 10 mm in size were cut from discs across the radius of the stem. The percentage mass loss in each block caused by decay was obtained after 12 weeks of incubation with these fungi. Mean mass losses due to *T. versicolor* were respectively as follows for plantation-grown, naturally-grown (No. 1), and naturally-grown (No. 2) teak: sapwood 21.4%, 7.1%, "no data"; outer heartwood 0.6%, 3.6%, 6.6%; middle heartwood 2.3%, 6.5%, 5.7%; inner heartwood 10.3%, 9.6%, 6.0%; pith 13.0%, 15.3%, 8.2%. Mass losses due to *F. palustris* were, respectively: sapwood 7.5%, 3.0%, 7.5%; outer heartwood 0.0%, 2.5%, 2.7%; middle heartwood 0.0%, 2.2%, 2.3%; inner heartwood 4.9%, 2.0%, 3.4%; pith 13.6%, 8.4%, 8.0%. Durability was classified with reference to Osborne (1970), based on the mean percentage mass loss of heartwood caused by fungal decay. Only the outer and middle heartwood were generally durable in both plantation-grown and naturally grown teak specimens. The inner heartwood was moderately durable, but pith durability was low. No clear differences in decay resistance were found between plantation-grown and naturally-grown teak.

Keywords: *Tectona grandis*, heartwood, natural durability, decay resistance, provenance, teakwood, tropical plantation, Indonesia, Myanmar.

RESUMEN

Comparación de la resistencia a la descomposición de la madera de teca (*Tectona grandis* L.f.) de plantación y de crecimiento natural

La teca (*Tectona grandis* L.f.) es una de las especies de madera tropical más populares por su durabilidad natural. Se ensayó la resistencia a la descomposición (una componente importante de la durabilidad natural) de la albura, el duramen exterior, intermedio e interior y la médula de la teca de plantación de Indonesia y de la teca crecida naturalmente en Myanmar. Para ello se realizó un ensayo de descomposición acelerada según JIS Z 2101 (1994) utilizando un hongo de pudrición blanca (*Trametes versicolor*) y un hongo de pudrición parda (*Fomitopsis palustris*). Los bloques de madera de talla 20x20x10 mm se cortaron de discos a lo largo del radio del tronco. El porcentaje de pérdida de masa causada por la descomposición en cada bloque se obtuvo después de doce semanas de incubación con estos hongos. Las pérdidas de masa medias debidas a *T. versicolor* fueron respectivamente las siguientes para teca crecida en plantación, crecida naturalmente (nº 1), y crecida naturalmente (nº 2): albura 21,4 %, 7,1 %, "sin datos"; duramen exterior 0,6 %, 3,6 %, 6,6 %; duramen intermedio 2,3 %, 6,5 %, 5,7 %; duramen interno 10,3 %, 9,6 %, 6,0 %; médula 13,0 %, 15,3 %, 8,2 %. Las pérdidas de masa debidas a *F. palustris* fueron, respectivamente: albura 7,5 %, 3,0 %, 7,5 %; duramen exterior 0,0 %, 2,5 %, 2,7 %; duramen intermedio 0,0 %, 2,2 %, 2,3 %; duramen interno 4,9 %, 2,0 %, 3,4 %; médula 13,6 %, 8,4 %, 8,0 %. La durabilidad fue clasificada en referencia a Osborne (1970), según el porcentaje medio de pérdida de peso del duramen causada por descomposición fúngica. Solamente el duramen externo e intermedio eran generalmente duraderos tanto en ejemplares de teca provenientes de plantación como en ejemplares de teca de crecimiento natural. El duramen interno era moderadamente duradero, pero la durabilidad de la médula era baja. No se encontraron diferencias claras entre la resistencia a la descomposición de la teca proveniente de plantación o crecida naturalmente.

Palabras clave: *Tectona grandis*, duramen, durabilidad natural, resistencia a la descomposición, procedencia, madera de teca, plantación tropical, Indonesia, Myanmar.

Introduction

From the perspective of global warming countermeasures such as represented by the Sustainable Development Goals (SDGs), it is essential to curb the use of fossil resources and promote the better utilisation of natural resources, especially forest resources. It has been noted that wood-based products, as a representative of bio-based materials, should play an important role in the substitution of fossil resources to produce energy, fibre, and other manufactured goods (Verkerk et al. 2022). A prediction of the doubling of global resource use by 2050 would likely outstrip global sustainable supply and trigger negative impacts on biodiversity, climate, ecosystems, and human wellbeing (ITTO 2021). Wood resources are expected to play a leading role in the substitution of non-renewables because the increasing demand for goods in the construction sector and other sectors like plastics and textiles can partially be met by wood-based products (Held et al. 2021), though the carbon costs of 3.5-4.2 Gt CO_2e/year have been estimated as the increasing global wood harvests between 2010 and 2050 (Peng et al. 2023).

Tropical timbers have long been supplied to the rest of the world by timber-producing countries, but their supplies have significantly declined over the years because of unabated deforestation, forest alteration, and human settlement (Giam 2017). It is also mentioned that the boom-and-bust export pattern of tropical timber trade is rooted in tropical countries' own policies and unsustained-yield forestry (Vincent 1992). Demands for wood resources from plantation forests for the replacement of natural forest resources are steadily increasing in these years. It was predicted that increases in demand for paper products and construction-related materials would indicate fast-growing wood plantations playing a larger role in the future wood market (Elias and Boucher 2014). According to "The State of the World's Forests 2022" by FAO (2022), planted forests cover 294 million ha (7 percent of the global forest area), with the area increasing by a rate of just under 1 percent per year in 2015-2020, down from 1.4 percent per year in 2010-2015. There are many concerns about the environmental effects on plantations, particularly large-scale ones (Sawyer 1993). Although these timber plantations may have negative implications for biodiversity, ecosystem services, and local communities, integrated policies that strike a balance between reducing environmental impact and the necessity for forest products will maximise the potential benefit of both plantations and natural forests (Pirard et al. 2016).

The production of trees characterised by a higher growth rate, higher natural durability, and lower lignin content, among others, are important technological methods to contribute to the increasing demand for wood. The spread of wood species with high natural durability increases the value of timber products and also contributes to the SDGs thanks to the longer service life of the products (United Nations 2017). Fortunately, much research on the durability of wood, especially in tropics, has been carried out not only in producer countries (Foxworthy 1930; Eddowes 1977; Hong and Yamamoto 1990), but also in timber-importing countries (Chudnoff 1984; Timber Research and Development Association 1979; Gérard et al. 2017; Matsuoka 1970).

Teak (*Tectona grandis* L. f.) is one of the most popular tropical timber species in relation to its natural durability against decay fungi and especially termites on land. Because of its high value, the development of fast-growing teak plantations continues to expand in the tropics, and the planted teak area has increased significantly in Africa, Central America, and South America since 1995 (Kollert and Kleine 2017). The high natural durability of teak heartwood against wood-destroying fungi and termites is confirmed by many authors (Rudman et al. 1967; Bhat 1998; Thulasidas and Baillères 2017). Especially, there is great interest in the durability of short-rotation teak. Some studies showed fast-growing teak was not necessarily inferior in natural durability (Trockenbrodt and Josue 1999; Rodríguez-Anda et al. 2019; Martha et al. 2022), while others mentioned it was generally less durable than mature teak (Bhat et al. 2005; Thulasidas and Baillères 2017). Somewhat inconsistent results are attributed to the wide radial variation of natural durability (Da Costa et al. 1961), proportion of juvenile wood in heartwood (Bhat et al. 2001), and considerable variations of durability among provenances (Kokutse et al. 2016; Niamke et al. 2018). The content of extractives related to heartwood formation was also examined in plantation-grown and naturally-grown teak wood. The age of trees did not significantly influence the extractive concentration among 9, 15, 21 years old plantation-grown teak in Mexico (Rodríguez-Anda et al. 2019). In contrast, extractive contents, especially tectoquinone, were significantly higher in 100 years old naturally-grown teak from Myanmar than in 29 years plantation-grown teak from Panama (Haupt et al. 2003). A recent review of teak research presents the following key findings on natural durability (Thulasidas and Baillères 2017): (i) wood from fast-growing plantations is often less durable (Gérard et al. 2017), (ii) durability increases from the pith to the outer heartwood, and is largely determined by the various polyphenolic compounds especially particular individual chemicals, (iii) juvenile wood found near the pith offers less durability and teak does not reach maturity until 20-25 years of age, and (iv) it is advisable to retain teak trees for 60 years or more, disregarding the short-term investments and benefits on some occasions. Thulasidas & Baillères (2017) concluded that the key to growing teak is to improve the properties of the immature heartwood.

This paper aims to assess the difference in decay resistance between plantation-grown from Indonesia and naturally-grown teak from Myanmar. In addition, the comparative analysis of the fungal mass loss has been carried out across the radial transect (pith-to-sapwood) of tree stems in order to better understand the difference between plantation-grown and naturally-grown teak durability properties.

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Materials and Methods

A total of three discs of *Tectona grandis* wood with around 4 cm in thickness were obtained from a plantation forest in KPH Banyumas Barat, Central Jawa, Indonesia, and from a natural forest in Myanmar through the HOXAN CORPORATION, Japan in 1998 (table I). Sole plantation teak disc was 36 cm in diameter with 18 growth rings. One natural teak disc (No. 1) was 58 cm in diameter with 106 growth rings, and the other one (No. 2) was 64 cm in diameter with 245 growth rings. The heartwood percentage of sample discs was 69, 87, 88%, respectively. The height of the trunk at which these sample discs were obtained was not identified. Sample discs were grouped into nine radial parts from sapwood to the opposite sapwood across the radius of the stem via pith (figure 1). Heartwood was divided into three equal widths, except the pith. The nine parts consist of two sapwoods, two outer heartwoods, two middle heartwoods, two inner heartwoods, and one pith. Six wood block specimens of 20 × 20 × 10 (longitudinal) mm in size were cut from each part except sapwood of natural teak discs. The sapwood of natural teak discs almost disappeared, probably during the transportation of logs, only two specimens could be obtained from the inner part of the sapwood (intermediate wood) of each disc. Therefore, the data for the sapwood of natural teak discs were used as references. Each of three replicate wood specimens was subjected to the accelerated laboratory decay test by the white rot fungus *Trametes versicolor* and the brown rot fungus *Fomitopsis palustris*, respectively, according to JIS Z 2101 (1994) (figure 1).

Table I.
Characteristics of sampled discs and replicate numbers of the fungal test.

Sample discs	Number of trees and discs		Diameter and number of growth rings of the disc		Replicate number of specimens for each fungus	Origin****
	Trees	Discs	Diameter (cm)	Growth rings		
Plantation	1	1	36	18	3*	Central Jawa, Indonesia
Natural (No. 1)	1	1	58	106	3**	Myanmar
Natural (No. 2)	1	1	64	245	3***	Myanmar

* Three replications of each part for *Trametes versicolor* and *Fomitopsis palustris*.
** Three replications, except one replication of sapwood block for both fungi and one for the pith for *T. versicolor*.
*** Three replications, except one replication of sapwood block for both fungi.
**** Provenance from plantation- and natural trees is different. Landraces of Indonesian plantation teak trees showed a mixed pattern of various origins based on genetic diversity (Hansen et al. 2017)

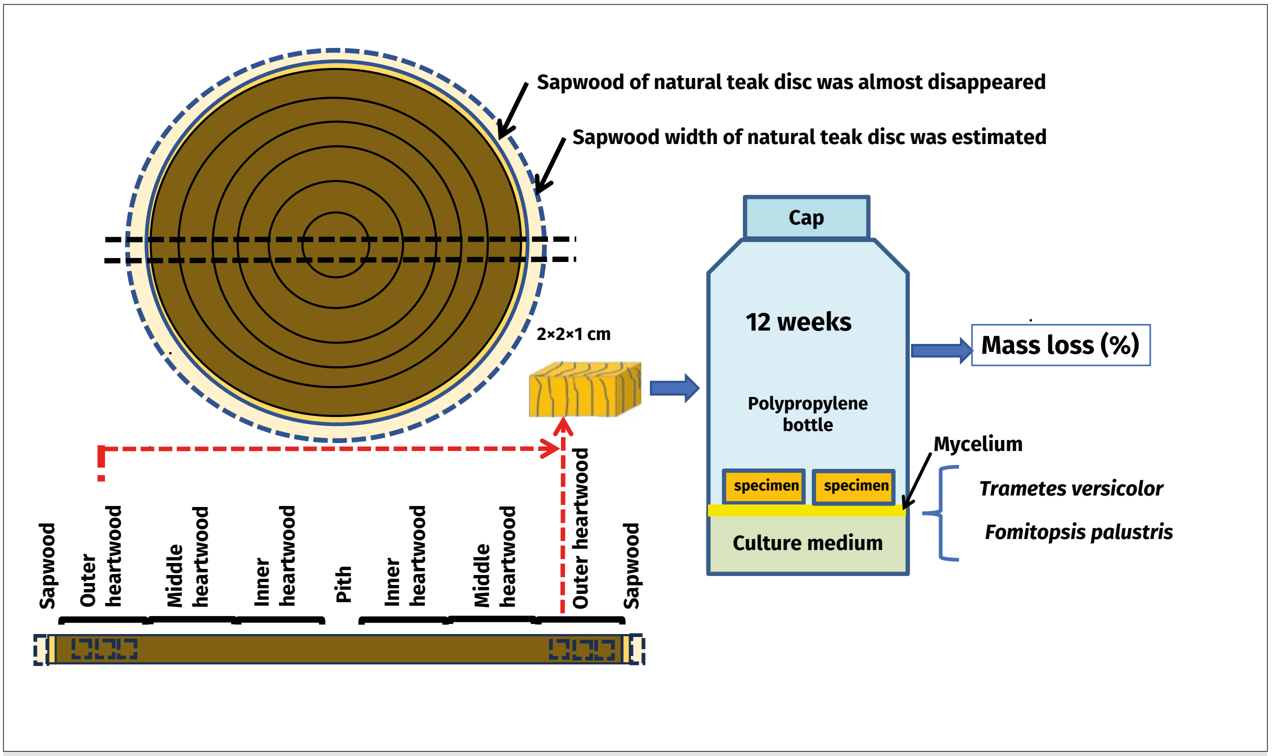

Figure 1.
Schematic diagram of wood specimen preparation and fungal decay test. Wood specimens were prepared across the radius of the stem via pith, and heartwood was divided into three equal widths except the pith (4 cm width).

Table II.
Mass losses of teak wood, *Tectona grandis* L.f., decayed by *Trametes versicolor* and *Fomitopsis palustris*.

Sample	Position	Mass loss (%) by *Trametes versicolor* (standard deviation)	Mass loss (%) by *Fomitopsis palustris* (standard deviation)
Plantation teak, *Tectona grandis* L.f.,	Sapwood	21.4 (3.2)	7.5 (7.3)
	Outer heartwood	0.6 (0.5)	0.0 (0.0)
	Middle heartwood	2.3 (2.0)	0.0 (0.0)
	Inner heartwood	10.3 (5.8)	4.9 (3.5)
	Pith	13.0 (4.3)	13.6 (9.3)
Natural teak (No. 1)	Sapwood***	7.1 (-)*	3.0 (-)*
	Outer heartwood	3.6 (1.8)	2.5 (1.2)
	Middle heartwood	6.5 (3.6)	2.2 (1.0)
	Inner heartwood	9.6 (3.1)	2.0 (2.8)
	Pith	15.3 (-)*	8.4 (1.4)
Natural teak (No. 2)	Sapwood***	**	7.5 (-)*
	Outer heartwood	6.6 (2.7)	2.7 (0.7)
	Middle heartwood	5.7 (1.9)	2.3 (2.3)
	Inner heartwood	6.0 (1.1)	3.4 (4.9)
	Pith	8.2 (4.3)	8.0 (5.2)
Reference: *Fagus crenata*	Sapwood	53.7	37.4

Number of replicate specimens was three unless otherwise noted.
* Replicate specimen was one. ** Test specimen was contaminated during the decay test, and the mass loss could not be determined efficiently. *** Data of sapwood of natural teak (No.1 and 2) were used as references because of the limitation of sample number and quality.

The percentage of mass loss in each specimen caused by decay was obtained after 12 weeks of incubation with these fungi. The reference wood species was the sapwood of *Fagus crenata* for hardwood and the sapwood of *Cryptomeria japonica* for softwood in the JIS. The mean mass loss of *F. crenata* was 53.7% by *T. versicolor* and 37.4% by *F. palustris*.

Classes of natural durability are usually determined by the mass loss ratios of test specimens to reference ones in EN 350 (2016), or by the mass loss values of test specimens in ASTM D 2017-05 (2005). When the EN or ASTM criteria were used as a reference, for instance, sapwood was classified as moderately durable or resistant in this study because the mean mass losses of teak wood, both sapwood and heartwood, were quite low compared with the mass loss of the reference species *F. crenata* sapwood (table II). Therefore, the durability class rating based on the mass losses measured by the laboratory decay test by Osborne (1970) for tropical rainforest timbers was referred to in this study. This rating adopted 4 classes: “durable” (less than 3% mean mass loss), “moderately durable” (3-10%), “slightly durable” (10-20%), and “nondurable” (more than 20%).

Result

The mean mass losses (%) of test specimens caused by *T. versicolor* and *F. palustris* are presented in table II. Mean mass losses of sapwood by *T. versicolor* were 21.4% in plantation wood, 7.1% in natural wood (No. 1), and no data (contaminations had occurred in the test device during the decay experiments) in natural wood (No. 2). Those of outer heartwood were 0.6%, 3.6%, 6.6%, middle heartwood were 2.3%, 6.5%, 5.7%, inner heartwood were 10.3%, 9.6%, 6.0%, and pith were 13.0%, 15.3%, 8.2%, respectively. Mean mass losses of sapwood by *F. palustris* were 7.5% in plantation wood, 3.0% in natural wood (No. 1), and 7.5% in natural wood (No. 2). Those of outer heartwood were 0.0%, 2.5%, 2.7%, middle heartwood were 0.0%, 2.2%, 2.3%, inner heartwood were 4.9%, 2.0%, 3.4%, and pith were 13.6%, 8.4%, 8.0%, respectively. These laboratory decay tests are comparative among the radial positions of heartwood and sapwood, between plantation wood and natural wood. The following results are obvious: (i) the outer and middle heartwood were more decay resistant than the inner heartwood for both in plantation wood and natural wood; (ii) the inner heartwood (juvenile wood), including the pith was less decay resistant both in plantation wood and natural wood; and (iii) there seem to be no distinctive differences in decay resistance between plantation wood and natural wood.

Discussion

Though the results of this preliminary study were based on a small quantity of tested samples and insufficient information on the origin of specimens, the following discussions about the classification of natural durability, proportion of heartwood, and variation of decay durability across the radius of the stem have been made.

Classification of natural durability

The usual methods to determine the natural durability of wood species are laboratory decay tests using wood-rotting fungi and field tests in ground contact (which exposes them to termites in the tropics) or above-ground conditions (EN 350 2016; JIS Z 2101 1994; ASTM D 2017-05 2005; AWPA E7-21 2023; AWPA E9-21 2023). Furthermore, studying wood durability in relation to heartwood formation has been increasing recently (Fernández-Sólis et al. 2018; Lukmandaru et al. 2021; Martha et al. 2022).

According to the rating system by Osborne (1970), only the outer and middle heartwood were "durable" in general for both plantation and natural teak specimens. However, the inner heartwood would be "moderately durable", and the pith would be "slightly durable" (table II). It has been well recognised for numerous tree species that the outer heartwood has more decay resistance than that of the inner heartwood near the pith because of its higher contents of extractives (Rowe 1989).

Proportion of heartwood at different ages

The heartwood percentage of discs with 18, 106, 245 growth rings was 69, 87, 88%, respectively, in this study. Bhat (1998) showed the heartwood percentage at breast height of fast, medium, and slow growth rates of teak at different ages of 13, 21, 55, and 65 years in India was around 38~58, 54~63, 81~82, and 81~85%, respectively, and evidently fast-growing genetically superior trees will produce either a higher or almost the same amount of heartwood as medium and slow-growing ones. The heartwood percentage of 18 growth rings plantation disc was 69% which was slightly larger than this literature, and that of 106 or 245 rings natural discs was not much different from 65 years plantation wood. The age of the tree had a distinctive influence on heartwood proportions, as indicated by the following expression: Heartwood proportion (%) = 68.569-518.416/age, it revealed, based on the data of ages 7, 11, 16, 21, 25, 32, and 50 years, that heartwood proportion was only 3, 12 and 27% for trees aged 7, 11 and 16 years, respectively (Hamza 1997). Prediction models were developed for sapwood thickness, heartwood radius, maximum heartwood height, heartwood percentage, and heartwood volume relative to tree age in plantation teak trees ranging from 2 to 22 years. These models showed Coefficients of Determination of 70%, 90%, 95%, 73% and 31%, respectively (Fernández-Sólis et al. 2018). Further improvements in prediction accuracy are expected, especially in heartwood percentage and heartwood volume in more mature plantation wood.

Variation of decay durability across the stem related to juvenile wood

Decay durability was variable depending on the radial positions of heartwood. The inner heartwood (juvenile wood), including the pith, was less decay-resistant than the outer and middle heartwood, both in plantation wood and natural wood (table II). The radius of inner heartwood was around 6, 9, and 10 cm in plantation wood, natural (No.1) and natural (No. 2) wood, respectively. From the many reviews on teak juvenile wood (Bhat et al. 2001), such juvenile wood properties were characterised by anatomical structures such as wide rings, short fibres, small cell diameter, or wide microfibrillar angle, while juvenility in plantation-grown teak extends up to 15 or 20-25 years, depending on growth rate and individual tree and plantation site (Bhat et al. 2001). The proportion of juvenile wood in plantation-grown teak at breast height is 80-100% and 25% at ages 20 and 60 years, respectively. It is important to be fully aware of the nondurable juvenile wood located in the central part of heartwood. If nondurable teak products enter the market, it would be a disadvantage to the brand power of teak products. It is said that teak is arguably the most economically important and most famous of the tens of thousands of tropical woods (Hartshorn and Peralta 2013). The branding of natural resources was discussed, as a case study of teak wood, exploring how teak has sustained its branding through the historical and geographical entanglements of the British Empire and Burma, as a former colony, which is a prime country for teak products (Bryant 2013).

Conclusions

The inner heartwood (juvenile wood), including the pith, was obviously less decay resistant than the outer and middle heartwood, and, based on this preliminary study, there seem to be no distinctive differences in the decay resistance of heartwood, both in plantation-grown and naturally-grown teak wood. This study needs to be reinforced by additional testing, including more trees from various plantations and forest areas. In the future, while small-sized, fast-grown teak wood will constitute a significant proportion of the international teak trade, some plantations should maintain a relatively long harvesting period of more than 60 years in order to secure or develop high brand value for teak products. It is also crucial that forest management techniques, including tree breeding and wood science, be pursued to improve the properties of the immature heartwood, not only for fungi but also for termites.

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Access to data

The data used is not freely accessible.

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