Natural durability of 8 tropical species suitable for structural roundwood: laboratory screening tests for resistance to fungi and termites

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Photo 1.
(a) Fungal and (b) termite's laboratory screening tests carried out on 8 Guianese wood species.
Photo K. Candelier.

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RÉSUMÉ

Durabilité naturelle de 8 essences tropicales utilisables en bois rond pour la construction : tests rapides en laboratoire de leur résistance aux champignons et aux termites

Les connaissances sur les propriétés des bois tropicaux sont encore relativement limitées, de sorte que leur exploitation se concentre sur quelques essences abondantes et de grand diamètre. Les arbres de petit diamètre sont très peu connus, alors qu'ils pourraient être utilisés directement comme bois rond pour la construction. L'objectif de cette étude est de déterminer la durabilité naturelle de 8 essences potentiellement utilisables en bois rond pour la construction en Guyane française : *Goupia glabra, Licania alba, Hymenopus heteromorphus, Lecythis persistens, Oxandra asbeckii, Pouteria bangii, Simarouba amara, Tachigali melinonii et Virola surinamensis*. Des échantillons de leur bois ont été exposés à la pourriture blanche (européenne et tropicale), à la pourriture brune (européenne) et aux termites souterrains européens (à l'aide de tests sans choix et à choix multiples) dans des conditions de laboratoire, puis soumis à des tests rapides adaptés des normes européennes. Seules deux espèces ont été classées comme durablement résistantes à la fois aux champignons et aux termites : *L. alba* et *P. bangii*, ce qui signifie qu'elles peuvent être utilisées sans traitement comme bois d'œuvre en climat tropical ou tempéré. Les autres essences testées ont été classées (1) durables mais avec des différences notables observées quant à leur résistance aux champignons et aux termites respectivement (*G. glabra, L. persistens, O. asbeckii*), (2) moyennement durables (*H. heteromorphus*), (3) peu durables à sensibles (*T. melinonii, S. amara, V. surinamensis)*, ce qui signifie que les normes européennes actuelles n'autoriseraient pas la mise en œuvre de ces dernières dans des structures extérieures sans protection, malgré leur utilisation par la population locale dans la construction traditionnelle. Cependant, elles pourraient être utilisées pour la construction moyennant des systèmes de protection appropriés (y compris protection du bois). Nos résultats pour la résistance à la pourriture du bois apportent des informations essentielles pour évaluer le potentiel de ces huit essences dans le secteur de la construction en Guyane française.

Mots-clés : Termites, champignons, durabilité naturelle, bois de petit diamètre, bois rond, Guyane française.

ABSTRACT

Natural durability of 8 tropical species suitable for structural roundwood: laboratory screening tests for resistance to fungi and termites

Knowledge of the wood properties of tropical tree species is still relatively limited, so timber extraction focuses on a few abundant, large-diameter species. Very little is known about small-diameter trees, although they could be used directly as roundwood for construction. The aim of this study was to determine the natural durability of 8 candidate species for use as structural roundwood in French Guiana: *Goupia glabra*, *Licania alba*, *Hymenopus heteromorphus*, *Lecythis persistens*, *Oxandra asbeckii*, *Pouteria bangii*, *Simarouba amara*, *Tachigali melinonii* and *Virola surinamensis.* Samples of their wood were exposed to white rot (European and tropical), brown rot (European), and European subterranean termites (using non-choice and multi-choice tests) in laboratory conditions and subjected to screening tests adapted from European standards. Only two species were classified as durable against both fungi and termites: *L. alba* and *P. bangii,* which means they can be used without treatment as building material in tropical or temperate climates. The other species tested were classified (1) as durable but with notable differences observed in their resistance to fungi and termites respectively (*G. glabra, L. persistens, O. asbeckii*), (2) moderately durable (*H. heteromorphus*), (3) low durability to sensitive (*T. melinonii, S. amara, V. surinamensis*), meaning actual European standards would not let use these last species in outdoor structures without protection, despite their use by local population in traditional building. However, they could be used for building purposes with appropriate protection systems (including wood protection). The results we obtained for resistance to wood decay provide essential information to assess the potential of these eight tree species in French Guiana's construction sector.

Keywords: Termites, fungi, natural durability, small-diameter wood, roundwood, French Guiana.

RESUMEN

La durabilidad natural de ocho especies tropicales apropiadas para madera en rollo estructural: pruebas rápidas de cribado de laboratorio sobre la resistencia a hongos y termitas

El conocimiento de las propiedades de la madera de especies de árboles tropicales es todavía relativamente limitado, de manera que la extracción de madera se centra en unas pocas especies abundantes de gran diámetro. Se conoce muy poco sobre árboles de pequeño diámetro, a pesar de que se podrían utilizar directamente como madera en rollo para construcción. El objeto de este estudio era determinar la durabilidad natural de ocho especies candidatas para usar como madera en rollo en la Guayana Francesa: *Goupia glabra*, *Licania alba*, *Hymenopus heteromorphus*, *Lecythis persistens*, *Oxandra asbeckii*, *Pouteria bangii*, *Simarouba amara*, *Tachigali melinonii* y *Virola surinamensis.* Las muestras de sus maderas se expusieron a pudrición blanca (europea y tropical), pudrición parda (europea) y termitas subterráneas europeas (utilizando tests sin selección y con selección múltiple) en condiciones de laboratorio mediante pruebas rápidas de cribado adaptadas según los estándares europeos. Solamente dos especies se clasificaron como resistentes simultáneamente a hongos y termitas: *L. alba* y *P. bangii*, lo que significa que se pueden utilizar sin tratamiento como material de construcción en climas tropicales o templados. Las demás especies ensayadas se clasificaron como (1) duraderas, aunque se observaron diferencias notables en su resistencia a hongos y termitas (*G. glabra, L. persistens, O. asbeckii*); (2) moderadamente duraderas (*H. heteromorphus*); (3) de poco duraderas a delicadas (*T. melinonii, S. amara, V. surinamensis*), lo que significa que los estándares europeos actuales no permitirían que las últimas especies se incluyeran en estructuras exteriores sin protección, a pesar de su uso por la población local en construcciones tradicionales. Sin embargo, podrían utilizarse en construcción con sistemas de protección apropiados (incluyendo tratamientos de la madera). Los resultados que obtuvimos para la resistencia a la descomposición de la madera proporcionan información esencial para evaluar el potencial de estas ocho especies de árboles en el sector de construcción de la Guayana Francesa.

Palabras clave: termitas, hongos, durabilidad natural, madera de pequeño diámetro, madera en rollo, Guayana Francesa.

Introduction

The Guiana Shield is one of the largest continuous areas of lowland tropical rainforest in the world. The forest cover reaches 8 million hectares in French Guiana (1/3 of the French forest) and shelters a unique biodiversity. Forestry operations are, therefore, subject to strict rules, designed to preserve the resilience of the ecosystem, maintain a high level of biodiversity, and ensure the recovery of wood and carbon stocks. It is therefore essential to target the species to be harvested and optimise their processing in order to maximise the added value of the final products. Nowadays, about 90 vernacular timber species (ca. 250 botanical species), out of the 1,800 species of trees inventoried in French Guyana, are considered technologically relevant and therefore of potential commercial value (Guitet et al. 2014). Among this large tree diversity, less than 30 wood species were exploited over the last decades by the local wood industrial chain (Détienne et al. 1989; ITTO 2019). Moreover, 4 timbers (*Louro vermelho*, *Basralocus*, *Mandioqueira* and *Pau roxo*) constitute 75% of the volume harvested (SOMIVAL 2020). Local timber production thus only focuses on a few abundant species (associated with a long renewal period) and values only the old large-sized trees (with a diameter greater than 50 cm). In the context of the growing need for timber, such a production chain can no longer meet the demand while preserving the forest ecosystem. With wood demand expected to triple by 2030 (Houël et al. 2022; SOMIVAL 2020), it is therefore essential to broaden our knowledge about the potentialities of the Guyanese forest resource in order to identify new tree species of interest for timber production.

Small-diameter trees represent an abundant resource in the Amazonian rainforest (Sellan et al. 2023). This resource, unexploited, could constitute an interesting alternative for the construction sector. The most abundant species identified within the diversity of small-diameter trees (from 5 to 10 cm) are slow-growing shade-tolerant species. They produce dense wood (Ramananantoandro et al. 2016; Lehnebach et al. 2019), providing the material interesting mechanical performances suitable for log building, as evidenced by traditional Palikurs constructions (Ogeron et al. 2018). Besides density and mechanics, the choice of the timber in the design of a wooden construction also strongly depends on natural durability, as the intended end-uses (e.g. poles, framings, etc.) do not require the same durability performances (Pilgram 1983). Durability is one of the most important concerns related to the use of timber in construction, whatever the construction system used. Providing more information about this property, as well as other technological characteristics, can help in predicting service life, designing buildings, performance evaluation, and life cycle assessment of wood structures (Brischke et al. 2014). In addition, durability property is a good indicator of the activity of the secondary metabolite constituents and can provide useful leads for wood's valorization through green chemistry applications (Royer et al. 2010; Perrot et al. 2018). To determine the most suitable applications for small-diameter species, it is crucial to address the existing knowledge gap concerning the natural resistance of these woods to biological agents, such as fungi and termites.

Natural durability is an inherent property of wood defined by its resistance to wood-destroying agents. It results from a combination of different parameters like chemical composition (mainly extractives compounds) and anatomical characteristics that are linked to the genetic determinants (Gouveia et al. 2021). The resistance of wood against destroying organisms is complex but can be assessed through a variety of test protocols, whether at a laboratory level or under field conditions (Kutnik et al. 2017). When investigating new species, a first approach may be to evaluate their resistance to specific organisms using reproducible and standardised laboratory-scale tests to allow comparison with more common species already used in construction.

The objective of this research work was to determine the durability of 8 selected Guyanese wood species (table I), with small diameters identified as abundant and undervalued local resources, against European and tropical fungal strains and *Reticulitermes flavipes* termites under laboratory conditions. This property is crucial for discussing the possible uses of these 8-timber species in local log building within the Guyanese construction market.

Material and Methods

Wood Species and Trees Selection

Eight Guyanese tree species were selected because of their rather homogeneous abundance on the whole French Guiana's territory (Jolivot et al. 2008), and their very slender and flawless morphology, answering the objective of providing a low-cost local building material. A ninth wood species was used as a control to test termite and fungal resistance (table I).

The diameter distribution of the selected species, resulting from local inventories[1, 2], is detailed in figure 1. The choice of the species studied results from a combination of different criteria, such as size at maturity, abundance in natural forests, and the potential sylvicultural models of these species. Thus, 5 species were selected: *Hymenopus heteromorphus, Licania alba, Lecythis persistens, Oxandra asbeckii*, and *Pouteria bangii*, whose size at maturity in natural stands does not exceed 30 cm in diameter (with the exception of *L. alba*, i.e. 42 cm), which is the reason why the forestry sector has never been interested in harvesting them. However, for a given geometry, their high wood density suggests good mechanical performance for use as roundwood. These 5 species could complement the

[1] https://paracou.cirad.fr/
[2] https://dataverse.cirad.fr/dataverse/paracou

Table I.
Genus, species, and family names of the selected studied trees, their vernacular names (Molino 2022) in Creole and Bushinengue (Jaouen et al. 2022), and their pilot's name (ATIBT 2016).

Scientific name	Family	Creole name	Bushinengue name	Pilot name (ATIBT)
Goupia glabra Aubl., 1775	Goupiaceae	Goupi, Bois caca	Kopi	Cupiuba
Hymenopus heteromorphus (Benth.) Sothers & Prance, 2016 *var. heteromorphus*	Chrysobalanaceae	Gaulette	Boliken koko	Grigri
Lecythis persistens Sagot, 1885	Lecythidaceae	Mahot rouge	Lebi loabi	Sapucaia
Licania alba (Bernoulli) Cuatrec., 1964	Chrysobalanaceae	Koko, Gaulette	Lebi koko	Grigri
Oxandra asbeckii (Pulle) R.E.Fr., 1931	Annonaceae	n.c.	Muamba	Lancewood
Pouteria bangii (Rusby) T.D.Penn., 1990	Sapotaceae	Balata pomme	Bakuman	n.c.
Simarouba amara Aubl., 1775	Simaroubaceae	Simarouba, Acajou blanc	Asumaripa	Marupa
Tachigali melinonii (Harms) Zarucchi & Herend., 1993	Fabaceae (Caesalpinioideae)	Cèdre Remi	Diaguidia	Tachi
Virola surinamensis (Rol. ex Rottb.) Warb., 1897	Myristicaceae	Yayamadou marecage	n.c.	Virola

n.c.: not communicated.

harvesting of large-sized timber trees in natural forests. *Goupia glabra* was also selected. It is a canopy's species, which consequently reaches a much larger size at maturity, i.e. 62 cm. This long-lived, densely-wooded heliophilic species is already harvested by local logging when mature, but it is also very abundant in small-diameter classes in moderately disturbed forests. It therefore accounts for a substantial proportion of the small-stem volumes resulting from forest clearing and could be valued as roundwood. The last two species selected were *Simarouba amara* and *Tachigali melinonii*. Unlike the others, they have light wood, but their vernacular uses suggest that they could be good candidates for the construction of temporary structures or emergency habitats for which a low-weight material with satisfactory mechanical performance and low resistance to rot is sufficient. In addition,

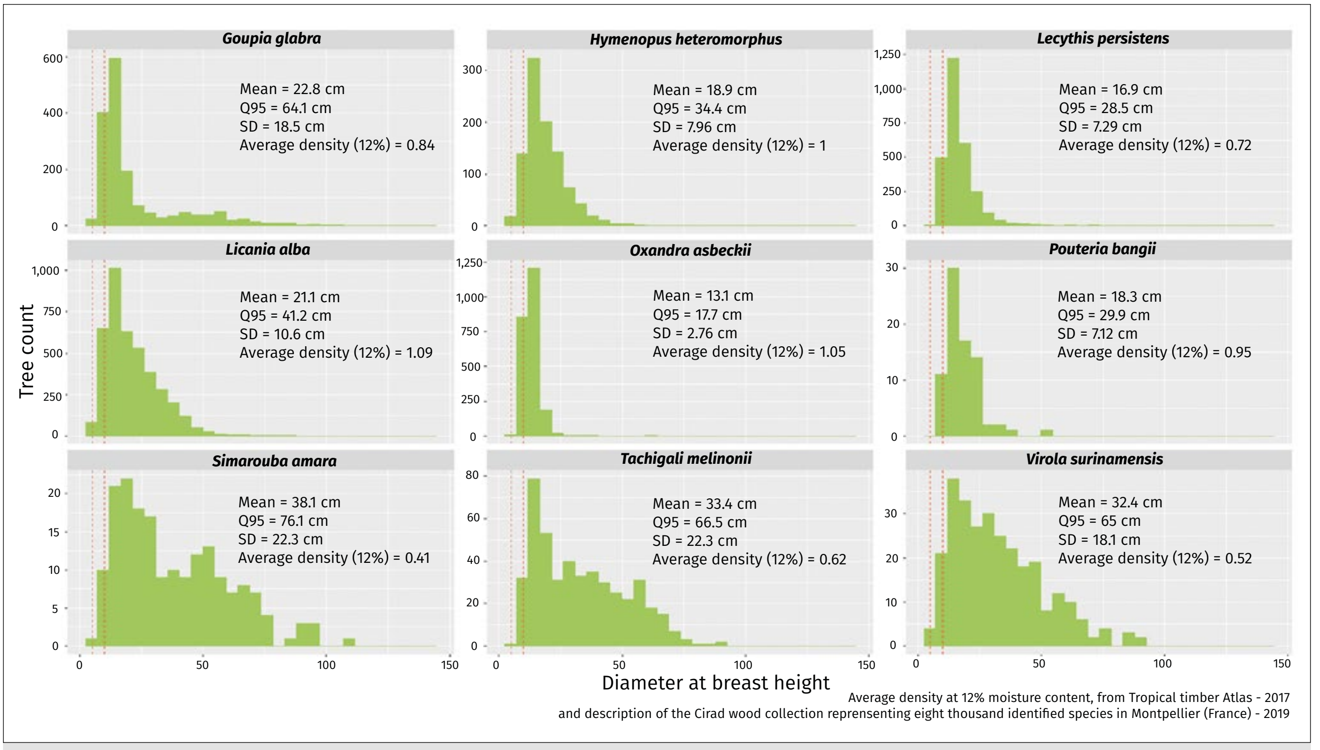

Figure 1.
Distribution of the diameter at breast height of the selected wood species in natural plots. Data are issued from the Guyafor Data Dictionary (https://paracou.cirad.fr/, and https://dataverse.cirad.fr/dataverse/paracou). The values for the average density at 12% are issued from Gerard et al. (2017) and Langbour et al. (2019).

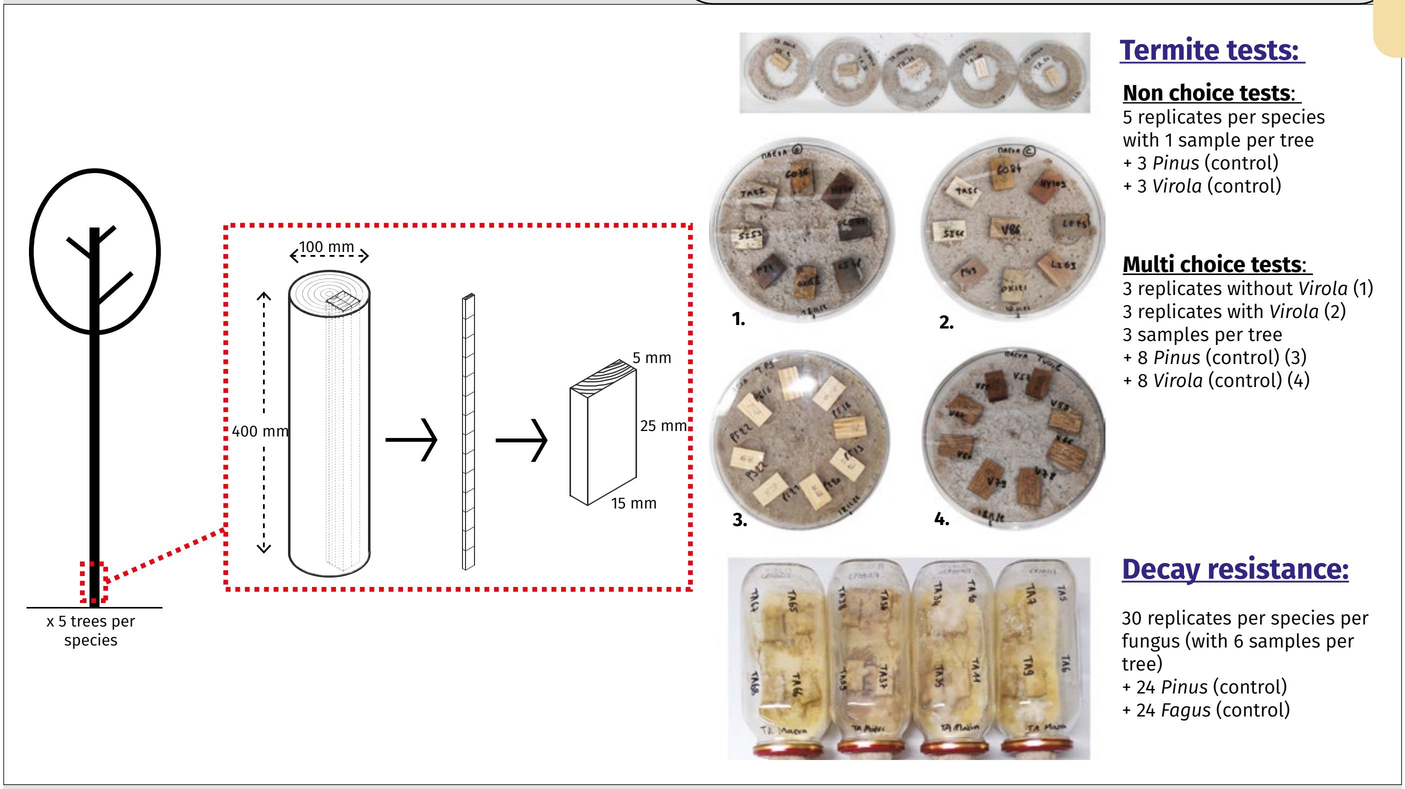

Figure 2.
Sampling plan for each tree and summary of required samples for each experiment (termite or decay tests). Five different trees per species were used to obtain a 40 cm-long stem per tree. 26 samples were cut in each stem, avoiding pith or knots, with dimensions 400 × 15 × 5 mm (L × R × T). Photos M. Leroy.

for example, *S. amara* and *T. melinonii* seem to be rather resistant against insect attack compared to other wood species during sawmill storage. However, their low density is one of the properties that makes their processing (except for the wood with a high content of silica) and implementation relatively easy, as well as their impregnation with anti-fungal and anti-termite bio-treatments. According to Gérard et al. (2017) *S. amara* is classified in treatability class 1 (treatable), whereas *Tachigali* sp. can be classified until treatability class 3 (poorly treatable) according to the genus. It should be noted that *S. amara*, *T. melinonii*, and *G. glabra*, due to their heliophilic temperament and high growth rates, could also be produced as roundwood through short-rotation planting or as a complement to longer-lasting plantations.

For termite and fungal resistance tests, an additional species, *Virola surinamensis*, known for its poor natural durability (Neves et al. 2002), has been added to be tested as a virulence control.

Five trees per species were identified and collected near the Paracou experimental research station[3], in French Guyana (5°16'27''N; 52°55'26''W). This site is a “terra firme” natural forest belonging to the Caesalpiniaceae facies (Sabatier and Prevost 1989), a typical forest type of French Guiana. A total of 45 trees (5 per species) of 6-10 cm diameter were sampled, with the most cylindrical trunks and the longest useful lengths, in order to dedicate the whole tree to other characterization experiments required for round wood uses in building (drying, cracking, mechanical properties, durability field tests, etc.).

Preparation of natural durability tests samples

A 40 cm-long stem portion was collected from the lower part of each selected tree. Several wood pieces longitudinally oriented, 400 × 15 × 5 mm (L × R × T), were sawn from each stem portion. The pieces in the middle of the radial profile were selected in order to maximise heartwood proportion while avoiding the presence of juvenile wood. Finally, pieces were longitudinally cut into 25 × 15 × 5 mm (L × R × T) test samples (figure 2).

To obtain a representative sampling of the exploitable wood, samples exhibiting peculiarities such as knots, slope grain, or reaction wood were discarded (ISO 4471 1982). As the number of samples per tree is limited by the small size of the stem, preference was given to natural durability screening tests (Bravery 1978; Salman et al. 2017), which involve small-sized samples with reduced biological exposure durations, over European standards. In addition, as the objective was to assess the natural durability of the log as a whole, sapwood was not cleared from the samples. From each stem, 26 samples were randomly selected (figure 2): 18 samples to assess the fungal resistance (6 samples per fungus) and 8 samples to assess the termite resistance (5 samples for non-choice tests and 3 samples for choice tests).

[3] https://paracou.cirad.fr/

Resistance against fungal degradation by screening tests

The resistance against wood-destroying rots was tested according to the guidelines of Bravery (1978), i.e. a screening tests adapted from EN 113-2 (2020) for the sample size and the fungal exposure duration.

Glass bottles of 720 ml volume were filled with 65 ml of sterile culture medium [malt extract (40 ± 0.5 g) (Quaron) and agar (20 ± 0.5 g) (Biomérieux) in deionized water (1 l)], inoculated with two small pieces (1 × 1 cm) of a 7-day-old culture mycelium of one brown rot [*Coniophora puteana* (CP) (Schumacher ex Fries) Karsten (BAM Ebw. 15)], one white rot [*Trametes versicolor* (TV) (L.) Lloyd (CTB 863A)], or one white tropical rot [*Pycnoporus sanguineus* (PS) (L.) Murrill, 1904] and then closed with carded cotton to enable air circulation. The inoculated glass bottles were stored for 2 weeks in a climatic chamber regulated at 22 ± 2 °C and 70 ± 5% Relative Humidity (RH) for TV and CP, or 27 ± 2 °C and RH > 75% for PS, until reaching the full colonisation of the medium by the mycelium.

Surface sterilisation of the wood samples before the decay resistance test was performed by ultraviolet radiations (20 minutes per face).

A batch of 10 samples per species was treated separately to calibrate the estimation of the theoretical anhydrous mass of each species tested (m_1). This batch was stabilised (20 ± 2 °C and 65 ± 5 % RH) and weighed (m_s), then oven dried at 103 °C for 48 h and weighed (m_a). The theoretical anhydrous mass (m_1) was calculated using the averaged stabilised mass to oven-dried mass ratio of the batch (k), according to Equation 1 and Equation 2.

$$k=\frac{m_s}{m_a} \quad (1)$$

$$m_1=k*m_s \quad (2)$$

The test samples (4 wood samples of the same species per inoculated glass bottle) were incubated for 8 weeks in a climatic chamber (22 ± 2 °C and 70 ± 5% RH for CP and TV; 27 ± 2 °C and RH > 75% for PS). Once the fungal exposure was completed, samples were carefully cleaned. All samples were then oven dried at 103 °C for 48 h and weighed (m_2). The degradation of each sample was assessed by computing the mass loss (ML%) as (Equation 3):

$$ML(\%)=\frac{m_1-m_2}{m_1}\times 100 \quad (3)$$

Pine sapwood (*Pinus sylvestris*) and beech (*Fagus sylvatica*) samples (12 replicates per fungal strain) were used as virulence controls (pine sapwood for CP and beech for the 3 fungal strains). According to the median ML calculated per species, wood samples were sorted by durability class (table II).

Resistance to termites by screening tests

The Guianese wood species were exposed to subterranean termites (*Reticulitermes flavipes, ex. santonensis*) in non-choice and choice screening tests. Termites were collected from Oleron Island, France (Lat. 45°49'5.9''N; Long. −1°13'47.8''W). The colony was reared in a climatic chamber regulated at 27 ± 2 °C and RH > 75%.

Pinus sylvestris sapwood and *V. surinamensis* samples, with dimensions of 25 × 15 × 5 mm (L × R × T), were also tested against termites as temperate and tropical virulence controls for choice and non-choice tests.

As for the fungal decay tests, both tested and control samples were weighted and their moisture contents measured in order to determine their theoretical anhydrous mass (m_3) before exposure to termites.

Non-choice tests

The non-choice tests were carried out according to the main criteria of the EN 117 (2013), with some adjustments concerning the sample size and the exposure period to the termites. Five replicates (1 sample per tree) and three control samples were tested separately for each species (figure 2). Each specimen was placed on a plastic mesh at the centre of a 9 cm-diameter Petri dish, containing 35 g of Fontainebleau wet sand (4 volumes of sand/1 volume of deionized water). Considering the dimension of the samples to be tested and according to the method used in previous studies (Afzal et al. 2017; Mohareb et al. 2017; Salman et al. 2017; Elaieb et al. 2020), 50 termite workers, one nymph, and one soldier were then introduced into each test device. These test devices were placed for 4 weeks in a dark climatic chamber conditioned at 27 ± 2 °C and RH > 75%. Once a week, water was added and termite behaviour was checked.

At the end of the exposure, the samples were removed, sand was cleaned, and the rate of surviving termites was calculated. Sample degradations were given a visual rating according to the criteria of EN 117 (2013) (the criteria being adjusted to the sample size). Then, the samples were dried at 103 ± 2 °C to obtain their anhydrous mass after termite exposure (m4), and their mass losses (ML%) were calculated similarly to Equation 3.

Table II.
Durability rating scale according to EN 113-2 (2020).

Durability class	Description	Median mass loss (%)
1	Very durable	< 5
2	Durable	> 5 to < 10
3	Moderately durable	> 10 to < 15
4	Slightly durable	> 15 to < 30
5	Not durable	> 30

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Multi-choice tests

For the choice tests, 1 sample per species was placed on a plastic mesh around the centre of a 14 cm-diameter Petri dish, containing 150 g of Fontainebleau wet sand (4 volumes of sand/1 volume of deionized water). The 8 Guyanese woods were exposed together to 250 termite workers, 5 nymphs, and 5 soldiers, with and without *V. surinamensis* samples used as controls and placed at the centre of the Petri dish (figure 2). Both modalities were carried out to assess the impact of the presence of a non-durable wood in the multi-choice test devices.

Three replicates of each tested modality were carried out. In addition, two devices containing 8 samples of *P. sylvestris* sapwood or 8 samples of *V. surinamensis* were performed as controls. All the test devices were placed for 4 weeks in a dark climatic chamber conditioned at 27 ± 2 °C and RH > 75%. Termite survival rate, visual rating of wood samples, and mass loss were evaluated just as the non-choice tests.

Table III.
Median mass loss of *Pinus sylvestris* and *Fagus sylvatica* control samples according to the three tested fungus, and decay resistance validation test conditions relative to EN 113-2 (2020).

	Median Mass Loss (ML) and Standard Deviation In % (m/m)	Minimal (median) mass loss values of control samples, required in EN 113-2 (2020) In % (m/m)
Brown rot on Scots Pine		
Coniophora puteana (CP)	32.0 ± 7.5	30
Brown rot on Beech		
Coniophora puteana (CP)	31.5 ± 6.1	30
White rot on Beech		
Trametes versicolor (TV)	26.2 ± 7.8	20
Optional fungi **Tropical White rots on Beech**		
Pycnoporus sanguineus (PS)	38.4 ± 3.9	No requirement

Results and discussion

Decay resistance

The average values of mass loss on *P. sylvestris* and *F. sylvatica* wood control samples (table III) are respectively above the thresholds required (EN 113-2 2020) hence validating the decay test.

All the results of the decay resistance test are presented in figure 3. For all tested species, a common pattern can be observed: tropical rot (PS) is the most virulent, leading to median mass losses ranging from 4.6% for *P. bangii* to 44% for *V. surinamensis*. In addition, temperate rots virulence appears lower for white rot (TV) than brown rot (CP) considering control species, but this pattern does not apply to all species tested.

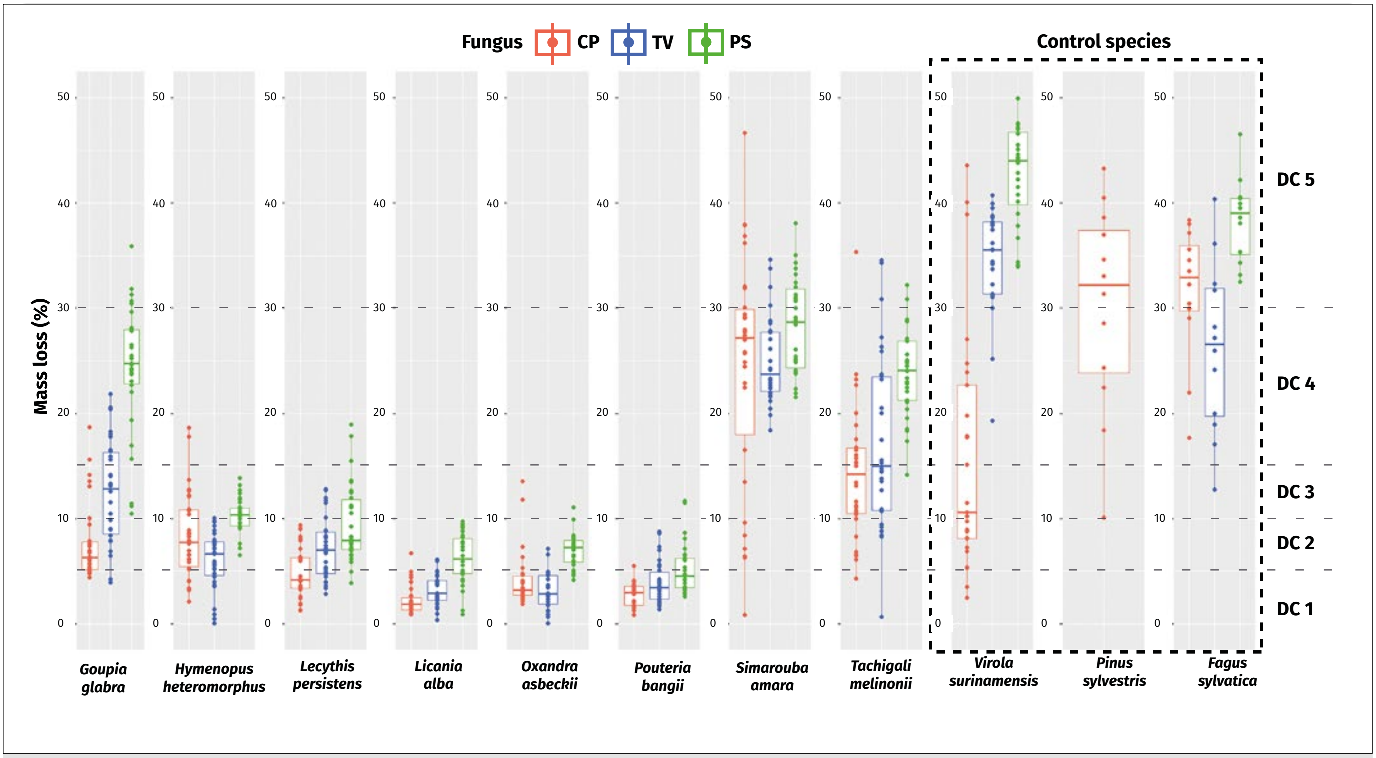

Figure 3.
Mass loss (%) and associated durability class (1 to 5) for all studied species after 8 weeks of exposure to *Coniophora puteana* (CP), *Trametes versicolor* (TV) (temperate rots) and *Pycnoporus sanguineus* (PS) (tropical rot). DC: Durability class.

Goupia glabra, *L. alba*, and *O. asbeckii* median mass losses with tropical rot are about double those of temperate rots. In this sense, it is therefore important to consider the biological risks of the concerned geographical area, by selecting the most discriminant fungal strain that may be encountered in the area where the wood will be used (EN 460 2023). *Lecythis persistens, L. alba, O. asbeckii,* and *P. bangii* present the lowest degradation for all tested rots (table IV).

According to their higher mass loss (ML), recorded with *P. sanguineus*, *P. bangii* (ML = 4.6%) is classified as highly durable (class 1), whereas *L. alba* (ML = 6.2%), *O. asbeckii* (ML = 7.3%), and *L. persistens* (ML = 8.0%) are classified as durable (class 2), meaning they can be used as indoor and outdoor building or joinery materials under tropical climate (within the limits of classes 3 or 4 under certain conditions), without any protection systems. Contrary to *L. alba* and *O. asbeckii*, which have been very little studied, the results obtained for *L. persistens* were expected since the durability of this species has already been studied (Gérard et al. 2017). However, it should be pointed out that this species belongs to a complex gender, gathering many species (with identification difficulties based on simple botanical criteria) having different durability classes [*L. persistens* is class 3 or 4 (Gérard et al. 2017) whereas *L. pisonis* is class 1 or 2 (Comvalius 2001)].

Goupia glabra and *H. heteromorphus* resulted in moderate degradations. Previous studies conducted in Guiana and Suriname also reported *G. glabra* as moderately durable (Van Acker et al. 2000; Chudnoff 1984). Concerning *H. heteromorphus,* no data concerning the wood's natural durability has been found in the scientific literature.

Finally, *S. amara* and *T. melinonii* appeared to be the most degraded species among the rots tested. *Simarouba amara*, as mentioned in the Tropical Atlas Timbers (Gérard et al. 2017), results in susceptible wood species. The Guyanese species tested as a local control, *V. surinamensis,* was classified as susceptible and the most attacked species by the tropical rot (median ML = 44.0%). This result confirms it could be, in that sense, a good marker of rot degradation intensity in a tropical context. However, for temperate rots, and specifically considering only CP results, it appears that *S. amara* (median ML = 28.5%) could be more suitable as a control species than *V. surinamensis* in laboratory conditions (median ML = 18.6%, less than the minimal value of 30% required by the standard) for further decay tests. In other words, particular attention needs to be paid to the choice of the couple (control wood sample; Fungi type) to carry out decay resistance testing on tropical wood species.

The median values of fungal mass losses (ML%) and associated durability classes of the 8-wood species tested after 8 weeks exposure to CP, TV, and PS are detailed in table IV.

Table IV.
Median fungal mass loss (ML%) and associated durability class* (DC, determined from median values according to EN 350 (2016) of the 8-wood species tested), after 8 weeks of exposure to *Coniophora puteana* (CP), *Trametes versicolor* (TV) and *Pycnoporus sanguineus* (PS). *Pinus sylvestris* sapwood, *Fagus sylvatica*, and *Virola surinamensis* have been tested as virulence control samples.

Wood species	Density (20 °C, RH = 65%)	Median value of fugal mass loss (ML) and durability class (DC)* for each tested fungus according to EN 350 (2016)					
		Coniophora puteana (CP)		*Trametes versicolor* (TV)		*Pycnoporus sanguineus* (PS)	
		ML (%)	DC	ML (%)	DC	ML (%)	DC
Goupia glabra	0.888	6.3	2	12.8	3	24.8	4
Hymenopus heteromorphus	1.05	7.7	2	6.6	2	10.4	3
Lecythis persistens	0.869	4.2	1	7.0	2	8.0	2
Licania alba	1.079	1.9	1	2.9	1	6.2	2
Oxandra asbeckii	1.071	3.2	1	2.8	1	7.3	2
Pouteria bangii	1.083	3.0	1	3.4	1	4.6	1
Simarouba amara	0.375	28.5	4	24.1	4	28.7	4
Tachigali melinonii	0.751	14.2	3	15.0	3	24.1	4
Virola surinamensis	0.499	17.7	4	35.5	5	44.0	5
Fagus sylvatica	0.717	32.9	5	26.6	4	39.0	5
Pinus sylvestris sapwood	0.687	33.1	5	n.c		n.c	

* Class 5: Not durable; Class 4: Slightly durable; Class 3: Moderately durable; Class 2: Durable; Class 1: Highly durable.
RH: Relative Humidity

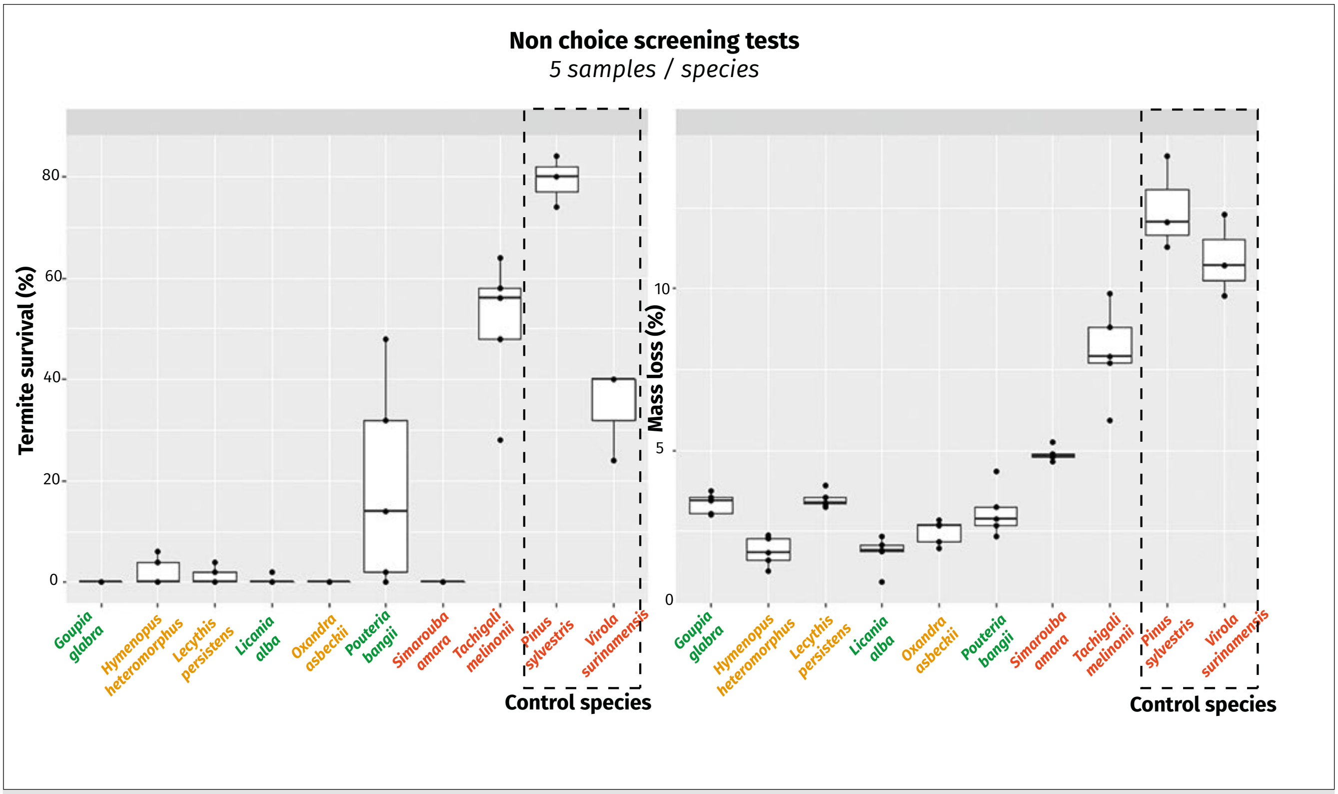

Figure 4.
Termite survival rates (%) and mass loss (%) of the 8 tested species after 4 weeks exposure to *Reticulitermes flavipes* using non-choice tests. *Virola surinamensis* and *Pinus sylvestris* sapwood have been tested as virulence control samples. All the wood species were classified as durable (in green), moderately durable (in orange) or not durable (in red) to termites, according to the visual rating as specified in the EN 350 (2016).

Table V.
Visual rating and corresponding termite durability class determined according to the EN 117 (2013) and EN 350 (2016), of the tested species, after 4 weeks of exposure to *Reticulitermes flavipes* termite using non-choice tests. *Virola surinamensis* and *Pinus sylvestris* sapwood were tested as virulence control samples. Class D: durable, Class M: moderately durable, and Class S: not durable.

Species	Visual rating*	Comments	Durability class EN 350 (2016)
Goupia glabra	1 [5]	more than 90% of the tested specimens are rated 0 or 1	D
Hymenopus heteromorphus	2 [2] - 1 [3]	more than 10% of the tested specimens are rated 2	M
Lecythis persistens	2 [3]- 1 [2]	more than 10% of the tested specimens are rated 2	M
Licania alba	1 [5]	more than 90% of the tested specimens are rated 0 or 1	D
Oxandra asbeckii	2 [2] - 1 [3]	more than 10% of the tested specimens are rated 2	M
Pouteria bangii	1 [5]	more than 90% of the tested specimens are rated 0 or 1	D
Simarouba amara	3 [3] - 2 [2]	more than 50% of the tested specimens are rated 3 or 4	S
Tachigali melinonii	4 [4] - 3 [1]	more than 50% of the tested specimens are rated 3 or 4	S
Virola surinamensis	4 [5]	more than 50% of the tested specimens are rated 3 or 4	S
***Pinus sylvestris* sapwood**	4 [5]	more than 50% of the tested specimens are rated 3 or 4	S

*[X]: number of samples with the respective visual rating.
0: no attack; 1: attempted attack; 2: slight attack; 3: average attack; 4: strong attack.

Resistance towards termites

Non-choice tests

The results from termite resistance non-choice tests carried out on the selected small-diameter round wood species are illustrated in figure 4. The visual rating and corresponding termite durability class according to the standards (EN 117 2013; EN 350 2016) are presented in table V.

The *P. sylvestris* sapwood and *V. surinamensis* control samples were severely degraded (mass loss up to 12.47 ± 1.45% and 10.93 ± 1.26%, respectively, with a termite survival rate of 79.33 ± 5.03% and 34.67 ± 9.24%, respectively). Both sets of control samples have a visual rating of 4 (susceptible to termites). The results from *P. sylvestris* sapwood samples confirmed the high virulence of termites and the validity of the termite resistance tests according to the standards. Interestingly, *V. surinamensis* is also susceptible to termites, but presents a lower termite survival rate than those obtained with *P. sylvestris* sapwood. In this sense, a more appropriate wood species could be used for control samples during termite resistance tests to limit termite mortality and thus better meet the requirements of the standards. It could also be envisaged to raise termites in the laboratory by giving them *V. surinamensis* as their main source of feed, enabling them to adapt their symbiotic system to this wood.

Goupia glabra, L. alba and *P. bangii* appeared to be durable against *R. flavipes*, according to their visual rating of 1 (100% of the five samples tested per species). The mass losses recorded for these three species (< 3.36%) are similar. These results are concordant with previous studies. Comvalius (2001) has determined a similar classification of these three wood species. However, a difference can be observed regarding the termite survival rate (TSR): *P. bangii* seems to be only repellent (TSR = 19.20 ± 20.52%) when *G. glabra* and *L. alba,* appears to be a little more toxic towards termites (TSR = 0.00% and 0.40 ± 0.89%, respectively).

Weekly monitoring of the test devices, giving termite behaviour information, confirms these results.

For *L. alba* samples (figure 5), we observed that all the termites were gathering on top of the wood sample, staying motionless for the whole duration of the test until they all died. According to Haifig et al (2015), “aggregation behaviour is a pattern found among most termites, characterised by high recruitment when a valuable resource is found”; but in the present case, termites were very inactive, hence suggesting that this behaviour was abnormal and unrelated to feeding. Furthermore, most of the individuals were found dead at the end of the experiment. Thus, their aggregation behaviour and death are very probably related to chemical wood compounds that acted as repellents. In addition, most of the wood species from the Chrysobalanaceae family, such as *L. alba* (Wiemann 2010), are known to be very rich in silica, which has high abrasive properties for cutting tools but also for termite mandibles, silica then acts as a digestibility reducer for the enzymatic digestion process of termite (Dhawan et al. 2007).

Pretty similar observations were obtained for *G. glabra*. At the beginning of the test, all termites were attracted by the sample, gathering around it. Finally, they all died during the first week after eating (average ML = 3.5%), proving the toxicity of this species. The anti-termite effect of these wood species could be due to the presence of some toxic or repellent extractive compounds. These properties could be used for the development of natural insecticides for the treatment of non-durable wood species (Rodrigues et al. 2011).

For *P. bangii* and *O. asbeckii*, the two species were less degraded than *G. glabra* (figure 4) and the termites died slightly latter. *Pouteria bangii* and *L. alba,* which here gave interesting resistance to termite attacks, were also the most resistant to rot degradation. Past studies showed that chemical compounds that have been widely isolated from the extractives of *Pouteria* and *Licania* genus included phenolic acid, other phenolics non-flavonoid, flavonoids, and terpenoids derivatives (Fitriansyah et al. 2021; Silva et al. 2012). According to this chemical composition, their extractives might thus be quite effective against both degradation agents (fungi and termites), making them good candidates for log building applications without any treatment.

Hymenopus heteromorphus, *L. persistens* and *O. asbeckii* were classified as moderately durable against *R. flavipes*. They presented a low termite survival rate (< 2.00%), a mass loss under 3.50% (for *L. persistens)* and more than 10% of the tested samples for each wood species presented a visual rating of 2. The *Lecythis* genus gathers several species with sometimes very different properties than those of *L. pisonis* (i.e., *L. idatimon* or *L. persistens* which have low natural durability) (Gérard et al. 2017). Great care must therefore be taken when identifying species within this genus, whose botanical identification is complex.

Finally, *S. amara* and *T. melinonii* showed the highest mass losses among the 8 tested species. Even if their mass losses (*S. amara*: 4.89 ± 0.22%, *T. melinonii*: 8.03 ± 1.46%) were lower than those of both control samples, they were also classified as non-durable towards termite attacks due to their visual ratings (more than 50% of tested samples

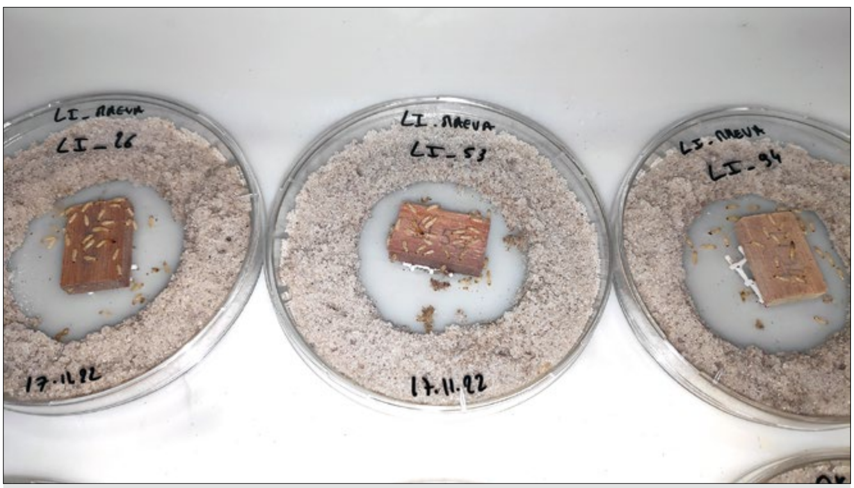

Figure 5.
Licania alba samples in termite resistance using non-choice tests. All the termites were gathering on top of the wood sample, staying motionless, for the whole duration of the test until they all died. Photo M. Leroy.

for each species rated 3 or 4). These findings are consistent with previous studies underlining the sensitivity against termites of *S. amara* and *T. melinonii* (Gérard et al. 2017). Besides, Barbosa et al. (2007) used *S. amara* as a "non-durable" control species and impregnation medium to test the resistance conferred by tropical wood extractives. However, in the same study, the tested samples were exposed to a full colony of *Nasutitermes* sp. for 8 weeks, which probably increased virulence towards the *S. amara* samples used. Still, besides the high level of degradation recorded, it is also worth noting that all termites died after being in contact with *S. amara* (TSR = 0%). It is known that the *Simaroubaceae* family contains quassinoids, secondary metabolites responsible for a wide spectrum of biological activities, including insecticides, antiparasitic, and herbicides (Alves et al. 2014). Finally, regarding *T. melinonii*, the combination of a high degree of degradation and a low impact on termite survival (average TSR = 50.8%, average visual rating = 3 and 4, and average ML = 8,03%), allows us to consider this species as a possible control species with *V. surinamensis* for termite tests.

These results need to be taken with caution. Indeed, the sampling does not really correspond to the one prescribed by the European standards, especially with regard to sample size, orientation, and replicates, resulting from the limitations caused by the specific geometry of the small-diameter sampled round woods. In addition, for these species characterised by non-differentiated wood, even if samples were cut in the middle of the radial profile of each tree, their extractives content and composition remain unknown.

Additional chemical analyses should be done to check that point. However, differences were observed between species, indicating that these results provide a good overview of the natural durability of the selected species if used as roundwood.

Multi-choice tests

The results from termite resistance multi-choice tests carried out on the 8 selected Guyanese small-diameter round wood species are reported in table VI.

The control devices demonstrated a good attractivity (majority of strong attacks recorded through visual rating) and a low termite resistance (*V. surinamensis*: TSR = 14.0%; ML = 8.49 ± 5.56%; *P. sylvestris* sapwood: TSR = 87.6%; ML = 8.1%), validating their use as a control method. For all multi-choice test devices (with and without *V. surinamensis* samples), termite survival was lower than 1.20%. The regular monitoring of test devices carried out during the whole test duration allowed to show that, for both modalities (with and without *V. surinamensis*), the termites were firstly attracted by the *G. glabra* sample.

Figure 6 illustrates the distribution of the mass consumed by the termites according to the wood species and for all test modalities. After one week, termites preferred *L. persistens*, *S. amara*, and *T. melinonii* samples in the absence of the *V. surinamensis* sample. Concerning the test including the *V. surinamensis* sample (figure 6), this one is clearly preferred and attacked by termites compared to the

Table VI.
Average termite's survival rates (%), mass loss (%), and visual rating of the 8 selected Guyanese wood species, after 4 weeks of exposure to *Reticulitermes flavipes* termite species using multi-choice tests (with and without *Virola surinamensis* samples). *Virola surinamensis* and *Pinus sylvestris* sapwood were tested as virulence control samples.

Species	Mass loss (%)	SD (%)	Survival rate (%)	SD (%)	Visual rating*
Termite resistance - Choice test with *Virola surinamensis*					
Goupia glabra	4.46	0.63	0.40	0.69	1 [3]
Hymenopus heteromorphus	1.28	0.46			1 [3]
Lecythis persistens	4.29	0.42			1 [3]
Licania alba	1.71	0.22			1 [3]
Oxandra asbeckii	2.20	0.72			1 [3]
Pouteria bangii	1.91	0.55			1 [3]
Simarouba amara	2.73	0.42			2 [1] - 1 [2]
Tachigali melinonii	2.77	1.13			2 [2] - 1 [1]
Virola surinamensis	27.39	5.26			4 [3]
Termite resistance - Choice test without *Virola surinamensis*					
Species	**Mass loss (%)**	**SD (%)**	**Survival rate (%)**	**SD (%)**	**Visual rating**
Goupia glabra	6.38	0.62	0.00	0.00	1 [3]
Hymenopus heteromorphus	1.81	0.83			1 [3]
Lecythis persistens	5.56	0.78			1 [3]
Licania alba	1.43	0.43			1 [3]
Oxandra asbeckii	2.00	1.05			1 [3]
Pouteria bangii	2.00	0.45			2 [1] - 1 [2]
Simarouba amara	6.61	1.56			4 [1] - 3 [1] -2 [1]
Tachigali melinonii	4.40	0.68			3 [1] - 2 [2]
Control devices					
Species	**Mass loss (%)**	**SD (%)**	**Survival rate (%)**	**SD (%)**	**Visual rating**
Virola surinamensis	8.49	5.56	14.00	0.00	4 [3] - 3 [1]- 2 [2] - 1 [2]
***Pinus sylvestris* sapwood**	8.10	7.02	87.60	0.00	4 [3] - 3 [3]- 3 [2]

*[X]: number of samples with the respective visual rating.
0: no attack; 1: attempted; 2: slight attack; 3: average attack; 4: strong attack; SD: Standard deviation.

other wood species, even if the *S. amara* and *T. melinonii* samples were also substantially degraded. According to the visual ratings presented in table VI, the most susceptible species to termites in multi-choice tests are *S. amara* and *T. melinonii,* which agrees with the termite durability class determined through the non-choice tests.

Concerning *P. sylvestris* sapwood and *V. surinamensis* control devices in tests (figure 6 in red), the average mass loss (%) after 4 weeks of exposure was 8.49% and 8.10%, respectively (table VI).

Finally, the multi-choice test devices without the *V. surinamensis* sample (in red) have a lower mass loss than multi-choice test devices with the *V. surinamensis* sample (in blue). This result confirms that *V. surinamensis* is an attractive or palatable species for termites and justifies its use as a control species.

The results from the average mass loss (table VI) and the distribution of the mass consumed among the different wood species (figure 6) are consistent with those from the non-choice tests, showing that the less susceptible wood species towards termites are *L. alba*, *H. heteromorphus*, and *P. Bangii*.

Durability classes of all wood species according to the different organisms

Table VII summarises the different durability classes of the 8 tested tropical round wood species concerning their resistance against Basidiomycete fungi (*T. versicolor* and *C. puteana*, *P. sanguineus* tropical strain) and subterranean termites (*R. flavipes*).

Interestingly, *L. alba* and *P. Bangii* demonstrated high natural durability, with the lowest susceptibility towards both fungal and termite attacks. *Goupia glabra* and *O. asbeckii* can be considered as intermediate cases since *G. glabra* is durable considering termite attacks but sensitive to tropical rot, and *O. asbeckii* is highly durable to durable for all rots but sensitive to termites. Something that can still be observed in wooden structures today in French Guiana, such as long-lived *carbets* (wooden shelters without walls, typical of Amerindian cultures), is that the posts sunk into the ground are made of very durable wood species such as *Vouacapoua* spp. or *Minquartia* spp., while the above-ground structure is made of wood species (Annonaceae and Lecythidaceae families) that were slightly less durable (Ogeron et al. 2018). Finally, *H. heteromorphus* and *L. persistens* are moderately durable, while *S. amara* and *T. melinonii* are susceptible to attacks for both tests but evidence toxicity against *R. flavipes* when it is tested in a non-choice test.

However, these results provide an interesting overview of the natural durability of the selected species if used in round wood. To complete these results, it would be interesting to determine and analyse the chemical composition of each tested wood, in order to better identify their defence mechanism and understand the variability of their durability according to the different wood-destroying organisms (Carter and Camargo 1983).

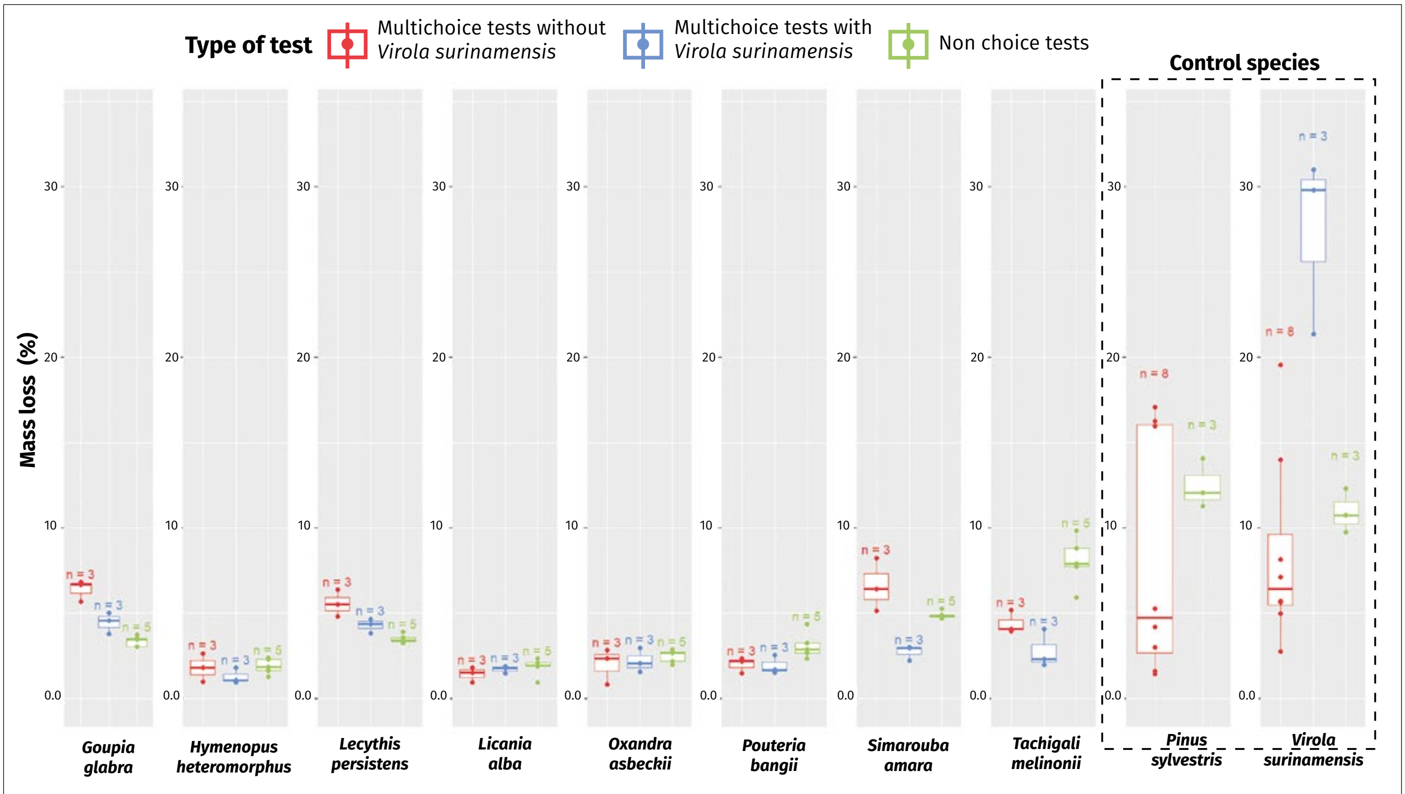

Figure 6.
Mass loss (%) per all studied species after exposure to termites in choice test without *Virola surinamensis* (red), choice test with *V. surinamensis* (blue), and non-choice test (green).

Conclusion

According to fungal and termite tests, only *Pouteria bangii* and *Licania alba* species have sufficient natural durability to be used as building material in ground contact under tropical climate without prior treatment.

Goupia glabra is an interesting species: even though it is poorly durable against fungi, it performed well against termites, showing appetent and termicidal properties.

Oxandra asbeckii and *Lecythis persistens* result as durable against fungi and moderately durable against termites, meaning they need at least a termicidal treatment before any use as building material. Concerning *L. genus*, a high variability in properties could be observed between the different species. In this sense, it is very important to accurately identify the wood species to reach the desired durability level for the final use of wood.

Even if *Simarouba amara* is classified as poorly durable and sensible against termites, a non-choice test indicated that it presents a certain termite toxicity. In this sense, *S. amara* can be used in indoor conditions. In agreement with this statement, it's common to find *S. amara* in the interior floors of old town houses in French Guiana.

Tachigali melinonii results as poorly durable and sensible against termites, *such as Virola surinamensis*, meaning they are not suitable as outdoor wooden material without prior treatment. Regarding treatment, their light microstructure could be one of the properties that would make them more suitable for impregnation, contrary to dense-wooded species such as *O. asbeckii* and *L. persistens*. If no treatment is applied, these light wood species could also be interesting for building light structures or temporary structures for emergency housing, for example.

Ongoing field durability experiments will complement these results, in order to compare the results obtained in controlled conditions at laboratory scale with the performances achievable under real-world conditions of use, where complex phenomena can occur, combining different fungal and termite attacks that can occur concomitantly in a natural environment. This complementary study will allow us to better evaluate and understand the natural durability of these 8 species in round wood in their natural condition. To complete these studies, it would also be interesting to analyse and quantify the chemical compounds present in each species to better understand the defence strategy developed by each species. Such chemical analyses could include a near-infrared spectroscopy survey, allowing further durability classification within each species. The silica content is also an interesting parameter (very variable even at intra-specific scale) that could be measured and linked with termite feeding behaviour.

Finally, the great diversity of Guyanese woods could be better valued, based on sustainable and local uses of a resource to minimise imports and chemical treatments, if more information about their decay resistance was available. In that sense, this study can contribute to the identification of new valorization pathways for the abundant and nonvaluated species tested here. More broadly, diversifying the species used in local constructions would help to limit the exploitation of conventional commercial species and the opening of ever-deeper forest tracks to access to these resources.

Table VII.
Summary of durability classes of the 8 tested round-wood species under laboratory condition using screening tests. *Virola surinamensis*, *Pinus sylvestris* sapwood and *Fagus sylvatica* have been tested as virulence control samples.

Wood species	Durability classes (EN 350, 2016)			
	Fungi* [EN 113-2 (2020)]			Termites** [EN 117(2013)]
	Coniophora puteana	*Trametes versicolor*	*Pycnoporus sanguineus*	*Reticulitermes flavipes*
Goupia glabra	2	3	4	D
Hymenopus heteromorphus	2	2	3	M
Lecythis persistens	1	2	2	M
Licania alba	1	1	2	D
Oxandra asbeckii	1	1	2	M
Pouteria bangii	1	1	1	D
Simarouba amara	4	4	4	S
Tachigali melinonii	3	3	4	S
Virola surinamensis	4	5	5	S
Fagus sylvatica	5	4	5	n.c.
***Pinus sylvestris* sapwood**	5	n.c.	n.c.	S

* Class 5: Not durable; Class 4: Slightly durable; Class 3: Moderately durable; Class 2: Durable; Class 1: Highly durable.
** D: Durable; M: Moderately durable; S: Susceptible.
n.c.: not communicated.

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Access to data

The detailed data obtained through this study and presented in this article are available in the "CIRAD Dataverse Portail" with the following reference:

Leroy, Maëva; Candelier, Kévin; Damay, Jérémie; Bossu, Julie; Lehnebach, Romain; Thévenon, Marie-France; Beauchêne, Jacques; Clair, Bruno, 2023, "Replication Data for: Natural durability of 9 tropical species suitable for round wood timber building: fungi and termites laboratory screening tests.", https://doi.org/10.18167/DVN1/V3KS6Z, CIRAD Dataverse.

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