Rot Resistance of Tropical Wood Species Affected by Water Leaching

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Initial water leaching affects were studied relative to the rot resistance of 21 tropical wood species to the brown-rot fungus *Coniophora puteana* and the white-rot fungus *Trametes versicolor*. The rot resistance of tropical woods, determined by their weight loss (Δm) at 6-weeks fungal attack, was differently influenced by the initial water leaching, as follows: in the 1st group of eight durable species (dark red meranti, macassar ebony, cerejeira, merbau, santos rosewood, zebrano, wengé, and karri) there occurred a very significant decrease of their high rot resistance (with statistical confidence in the range 99 to 99.9% for different species); in the 2nd group of 10 durable species (ipé, yellow balau, doussié, bubinga, ovengol, padouk, iroko, blue gum, maçaranduba, and makoré) there did not occur a decrease of their high rot resistance; and in the 3rd group of three less durable species (okoumé, tineo, sapelli) a weaker rot resistance did not change due to leaching. The durable tropical woods (18 species from the 1st and 2nd groups) were more resistant to the brown-rot fungus ($\Delta m_{\text{C.p.-average}}$ = 0.72%) than the white-rot fungus ($\Delta m_{\text{T.v.-average}}$ = 1.07%). However, this phenomenon was no longer apparent after water leaching ($\Delta m_{\text{C.p.-Leached-average}}$ = 2.61%; $\Delta m_{\text{T.v.-Leached-average}}$ = 2.32%).

Keywords: Tropical woods; Water leaching; Rot resistance; Coniophora puteana; Trametes versicolor

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INTRODUCTION

The natural durability of individual wood species in moisture and temperature conditions suitable for biodegradation processes is closely related to their molecular structure, in particular, to the type, amount, and distribution of their biocidal extracts present in cell walls and lumens (Wong *et al.* 2005; Taylor *et al.* 2006; Kirker *et al.* 2013; Nascimento *et al.* 2013; Amusant *et al.* 2014; Sablík *et al.* 2016; Lopes *et al.* 2018). Extracts in heartwood zones of the majority of tropical wood species range from 10% to 20%, while in European species such values would be in the range 4% to 10%. According to the EN 350 (2016) standard, several tropical wood species belong to the category of very durable species (*e.g.*, cumaru, doussié, ipé, jarrah, and maçaranduba) or durable species (*e.g.*, bubinga, karri, lotofa, ovengol, and mahogany). Their natural durability is not only influenced by an individual wood species, but also by the location of the tree's heartwood zone, its age, and growth conditions (Amusant *et al.* 2014; Sundararaj *et al.* 2015). For example, the outer heartwood obtained from older trees is usually more resistant to rotting than the outer heartwood from younger trees (Scheffer and Cowling 1966). This is due to the gradual formation of larger quantities of biocidal extracts in the heartwood (Magel *et al*. 1994).

Regarding the practical application of different wood species, the following principle is valid: a required durability of wooden products (*i.e.*, natural and technologically increased) should be assigned based on the conditions of their use (EN 460 1994; Baar and Gryc 2012; EN 335 2013; Moya and Berrocal 2015; Pánek and Reinprecht 2016). For example, in exterior applications, the following woods should preferably be used: wood species with non-leachable or low-leachable biocidal extracts, wood that is chemically preserved with fixable and water-stable biocides, or thermally/chemically-modified wood that has a water-stable and biologically resistant structure.

Organic and inorganic wood extracts are mainly localized in the epithelial cells (bituminous channels) and parenchyma cells, but also in the lumens and cell walls of vessels, fibres, and tracheids. Extracts present in wood can be leached out by various solvents: polar (*e.g.*, water), medium polar (*e.g.*, ethanol, acetone), and nonpolar (*e.g.*, hexane, toluene). Heartwood zones of durable wood species contain extracts of various chemical structures, *e.g.*, monoterpenes, diterpenes, terpenoids, fats, waxes, and polyphenols such as stilbenes, tannins, flavonoids, flobafenes, rubrenolide, and rubrynolide (Rodrigues *et al.* 2010; Valette *et al.* 2017). After the initial leaching or evaporation of biocidal extracts, the original biological resistance of very durable, durable, and medium durable wood species decreases.

Several tropical wood species have a strong biological resistance to decaying fungi (Wong *et al.* 2005) and insects (Yalcin *et al.* 2018). However, this resistance is not always permanent, due to leaching or evaporation of biocidal extracts. This indirectly means that high rot resistance of durable tropical wood species can be reduced in a permanently moist environment due to water leaching of their biocidal extracts.

The aim of this work was to investigate the impact of initial water leaching of selected tropical wood species on their resistance to the brown-rot fungus *Coniophora puteana* and the white-rot fungus *Trametes versicolor*. The results from this study will have great importance in the practical use of tropical wood species in adverse environments.

EXPERIMENTAL

Materials

Tropical and reference woods

In this experiment, 21 tropical wood species (Table 1) and 2 reference European wood species, beech (*Fagus sylvatica* L.) and Scots pine (*Pinus sylvestris* L.), were used. Tropical woods used in the experiment, with names by Association Technique Internationale des Bois Tropicaux (ATIBT) in France, were obtained from the trading company JAF Holz, Ltd. (Špačince, Slovakia), in the form of naturally dried and conditioned boards with a moisture content of 13 ± 2.5%. The classes of durability, according to EN 350 (2016), of the tropical wood species used are between 1 "very durable" and 5 "nondurable" (Table 1).

Micro-specimens with dimensions of 25 mm × 25 mm × 3 mm (longitudinal × radial × tangential) were prepared from the heartwood zone of the tropical wood species and the sapwood zone of the reference wood species. The micro-specimens had no biological damage, knots, or other inhomogeneities. The experiment was performed with 16 micro-specimens from each tropical wood species and with 84 micro-specimens from each reference wood species.

Table 1. Tropical Woods Used in the Experiment

Species Common Name	Species Scientific Name	Density[4] (kg/m^3)	Class of Durability as per EN 350 (2016)	
			Field Test	Laboratory Test
Ipé	*Handroanthus serratifolius* (Vahl) S. O. Grose[3]	968 (26)	1	
Okoumé	*Aucoumea klaineana* Pierre	566 (27)	4	4 to 5
Tineo	*Weinmannia trichosperma* Cav.	646 (31)		
Dark red meranti	*Shorea curtisii* Dyer ex. King	592 (10)	2 to 4	2
Yellow balau[1]	*Shorea laevis* Ridl.	925 (55)	2	
Macassar ebony	*Diospyros celebica* Bakh.	1013 (82)		
Doussié	*Afzelia bipindensis* Harms	889 (18)	1	
Cerejeira	*Amburana cearensis* A. C. Sm.	651 (10)	3	
Bubinga	*Guibourtia demeusei* J. Léonard	830 (13)	2	
Ovengol	*Guibourtia ehie* J. Léonard	755 (27)	2	
Merbau	*Intsia bijuga* O. Ktze.	837 (50)	1 to 2	1
Santos rosewood	*Machaerium scleroxylon* Tul.	904 (6)		
Zebrano	*Microberlinia brazzavillensis* Chev.	718 (23)		
Wengé	*Millettia laurentii* De Wild.	823 (37)	2	1
Padouk	*Pterocarpus soyauxii* Taub.	647 (37)	1	
Sapelli	*Entandrophragma cylindricum* Sprague	631 (38)	3	3 to 4
Iroko	*Milicia excelsa* C. C. Berg	551 (16)	1 to 2	
Karri	*Eucalyptus diversicolor* F. Muell.	804 (30)	2	
Blue gum	*Eucalyptus globulus* Labill.	760 (59)	1 to 2	1
Maçaranduba[2]	*Manilkara bidentata* A. Chev.	916 (19)	1	
Makoré	*Tieghemella heckelii* Pierre	570 (25)	1	

[1] Other commonly used name is Bangkirai; [2] its other commonly used name is Massaranduba; [3] registered in The IUCN Red List of Threatened Species™ (IUCN 2017); [4] Mean values of densities are from 16 micro-specimens, at which standard deviations are in parentheses (Vidholdová and Reinprecht 2019)

Methods

Water Leaching

Eight micro-specimens from each tropical wood species, and 42 micro-specimens from each reference wood species (with an input moisture content of 12% ± 2%), were leached in distilled water over 14 d, using 9 leaching cycles at a 1:5 hydro module ratio, according to conditions described in the EN 84 (1997) standard.

Fungal attack

Micro-specimens of the individual tropical and reference wood species (both native and initially water-leached) were subjected to attack by the brown-rot fungus *Coniophora puteana* (Schumacher ex Fries) Karsten, strain BAM Ebw. 15 (Bundesanstalt für Materialforschung und -prüfung, Berlin, Germany) or to attack by the white-rot fungus *Trametes versicolor* (Linnaeus ex Fries) Pilat, strain BAM 116 (Bundesanstalt für Materialforschung und -prüfung, Berlin, Germany).

Before the fungal attacks, the native and water-leached micro-specimens were conditioned to achieve a moisture content of 12% ± 1%, weighed with an accuracy of 0.001 g (m_i), and sterilized with a 30 W germicidal lamp (Chirana Medical, a.s., Stará Turá, Slovakia) at a temperature of 22 ± 2 °C for 20 min on each side.

The fungal attacks of micro-specimens were performed in glass Petri dishes with a diameter of 100 mm. Two replicates of the same tropical wood species, and one replicate of the reference wood species, were placed into one dish on plastic mats under which a fungal mycelium had already been grown on a sterilized and a solidified layer of 4.5 wt% malt agar medium (HiMedia, Ltd., Mumbai, India) with a thickness from 3 mm to 4 mm. Malt agar medium was sterilized in autoclave (Autoclave PS 121V, Chirana, Brno, Czech Republic) at a temperature of 118 °C for 15 minutes. The incubation of micro-specimens in fungal mycelia lasted 6 weeks at a temperature of 24 ± 2 °C, and a relative humidity of 90% ± 5% according the rapid screening test (Van Acker *et al.* 2003).

After the fungal attacks, the micro-specimens were carefully cleaned of surface fungal mycelia, slowly conditioned in the laboratory to their moisture content of 12% ± 1%, and weighed again with an accuracy of 0.001 g (m_f). The weight loss (Δm) of micro-specimens was calculated as a percentage from their weights (determined in grams) in the conditioned state before (m_i) and after (m_f) fungal attack according to the standard EN 113 (1996), using Eq. 1:

$$\Delta m = [(m_i - m_f) / m_i] \times 100 \quad (1)$$

Statistical analyses

The effect of initial water leaching of the tropical wood species on changes in their rot resistance, which was determined using values of Δm, was analyzed by Duncan tests applying Statistica v. 12 software (StatSoft CR, s.r.o., Prague, Czech Republic).

RESULTS AND DISCUSSION

The rot resistance of 21 tropical wood species to the decaying fungi *C. puteana* and *T. versicolor* was dependent on a few factors, as documented in Table 2. These were as follows: (1) the wood species, (2) application of the initial water leaching, and (3) the fungal species. Visualization of the fungal mycelia growth on the top surfaces of two selected tropical wood species in their native and water-leached state is shown in Fig. 1.

Table 2. Weight Losses of Native and Initially Water-leached Tropical and Reference Woods after 6 Weeks' Action of the Brown-rot Fungus *C. puteana* or the White-rot Fungus *T. versicolor*

Wood Species	Weight Loss Δm (%) Caused by Decay Fungus									
	Coniophora puteana					*Trametes versicolor*				
	Native Wood		Water-leached Wood		Duncan Test	Native Wood		Water-leached Wood		Duncan Test
	x	SD	x	SD		x	SD	x	SD	
Ipé	0.20	(0.03)	0.61	(0.29)	c	1.39	(1.21)	0.32	(0.26)	–
Okoumé	6.48	(2.98)	5.39	(1.83)	–	6.39	(1.05)	8.23	(1.78)	d
Tineo	5.38	(3.71)	6.00	(2.87)	d	5.35	(1.77)	2.90	(0.36)	–
Dark red meranti	0.22	(0.09)	8.51	(1.70)	a	0.60	(0.27)	1.59	(0.30)	b
Yellow balau	0.40	(0.08)	0.69	(0.46)	d	0.83	(0.23)	0.30	(0.10)	–
Macassar ebony	0.52	(0.30)	4.68	(0.45)	a	2.00	(0.64)	6.84	(1.82)	a
Doussié	1.63	(1.51)	0.53	(0.30)	–	0.73	(0.25)	0.23	(0.11)	–
Cerejeira	0.30	(0.15)	1.05	(0.30)	b	0.80	(0.18)	2.21	(0.94)	b
Bubinga	0.96	(0.13)	0.75	(0.19)	–	1.17	(0.23)	0.66	(0.08)	–
Ovengol	0.61	(1.02)	1.30	(0.04)	d	1.34	(0.15)	1.60	(0.33)	d
Merbau	0.48	(0.32)	5.36	(1.07)	a	0.99	(1.02)	5.33	(1.08)	a
Santos rosewood	1.28	(0.31)	4.67	(0.61)	a	1.70	(0.20)	4.46	(0.23)	a
Zebrano	1.65	(0.62)	4.81	(0.72)	a	0.62	(0.30)	2.33	(0.66)	b
Wengé	0.67	(0.35)	5.84	(1.27)	a	0.99	(0.31)	6.40	(0.91)	a
Padouk	0.95	(1.69)	0.66	(0.25)	–	0.76	(0.07)	0.32	(0.12)	–
Sapelli	3.12	(1.15)	4.72	(2.36)	d	2.55	(0.92)	1.79	(0.17)	–
Iroko	0.20	(0.97)	0.47	(0.52)	d	0.41	(0.16)	1.69	(0.50)	b
Karri	0.69	(0.47)	2.50	(0.36)	a	1.18	(0.21)	2.38	(0.21)	a
Blue gum	0.38	(0.21)	2.30	(0.92)	b	1.82	(0.60)	2.17	(0.43)	d
Maçaranduba	0.08	(0.05)	0.23	(0.05)	b	0.52	(0.40)	0.22	(0.03)	–
Makoré	1.78	(1.84)	1.96	(0.85)	d	1.37	(0.08)	2.70	(1.12)	c
Beech						10.64	(3.65)	11.45	(3.21)	d
Pine	17.01	(3.71)	16.78	(3.25)	–					

x - mean weight loss values were from 4 replicates of tested tropical wood species and from 42 replicates of reference European wood species; SD - standard deviations are in parentheses; a, b, c, d - indexes of the Duncan test characterizing the significance level of water leaching on the decreased rot resistances (*i.e.*, increased weight loss) of tropical and reference woods (a = very significant decrease of rot resistance > 99.9%, b = significant decrease > 99%, c = less significant decrease > 95%, d = insignificant decrease < 95%, and -- = even an increase of rot resistance)

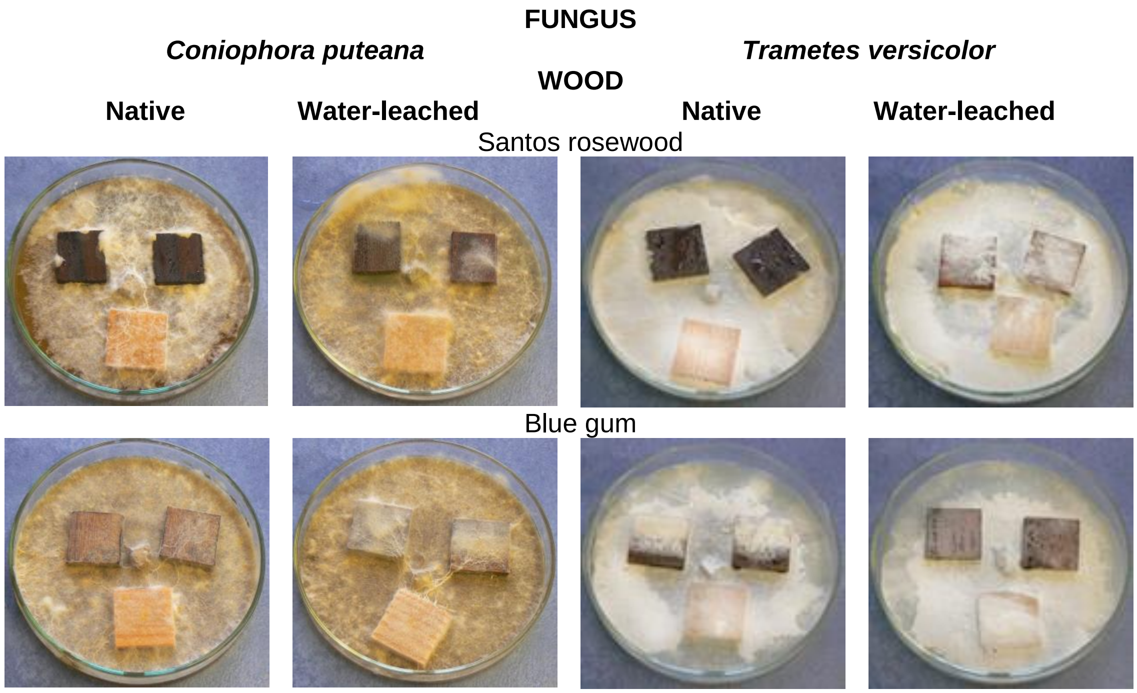

Fig. 1. Examples of the fungal mycelia growth on the top surfaces of the native and water-leached tropical woods after 6 weeks of incubation. In the Petri dish are 2 micro-specimens of the tested tropical wood species and at the bottom is 1 micro-specimen of reference Scots pine sapwood (for *C. puteana*) or beech sapwood (for *T. versicolor*).

Rot Resistance of Native Tropical Woods

The rot resistance of 18 durable tropical wood species (ipé, dark red meranti, yellow balau, macassar ebony, doussié, cerejeira, bubinga, ovengol, merbau, santos rosewood, zebrano, wengé, padouk, iroko, karri, blue gum, maçaranduba, and makoré) was excellent in their native state, because their weight losses only ranged from 0.08% to 2% (Table 2). These durable wood species exhibited a stronger resistance to the brown-rot fungus *C. puteana* ($\Delta m_{\text{C.p.- average}}$ = 0.72%) compared to the white-rot fungus *T. versicolor* ($\Delta m_{\text{T.v.-average}}$ = 1.07%). A relatively more intensive attack of durable tropical wood species by *T. versicolor* is in the literature attributed to peroxidase and laccase enzymes produced by this fungus. These enzymes are able to catalyze degradation processes not only in lignin, but also in polyphenols, flavonoids, quinones, and some other biocidal extracts (Eriksson *et al.* 1990).

The rot resistance of 3 less durable tropical wood species (okoumé, tineo, and sapelli) was weaker. A slightly lower rot resistance compared to durable species was shown by sapelli (Δm approximately 3%). However, okoumé and tineo had an apparently lower rot resistance (Δm approximately 6%) (Table 2). In summary, these 3 wood species had a comparative resistance to *C. puteana* ($\Delta m_{\text{C.p.-average}}$ = 4.99%) and *T. versicolor* ($\Delta m_{\text{T.v.-average}}$ = 4.76%) (Table 2). Nevertheless, their resistance to decay processes was approximately from two-times to three-times higher in comparison with the sapwood zones of the reference beech and Scots pine species (Table 2).

Rot Resistance of Water-leached Tropical Woods

The initial water leaching of 21 tropical woods had different effects on their rot resistance (Table 2).

After water leaching, an apparently lower rot resistance to both decaying fungi *C. puteana* and *T. versicolor* were observed in the 1st group of the following eight durable tropical wood species: dark red meranti, macassar ebony, cerejeira, merbau, santos rosewood, zebrano, wengé, and karri. This group includes durable species with a potentially decreased rot resistance in permanent wet exterior conditions. A reduced rot resistance of these tropical species after water leaching, where their weigh losses caused by fungal attacks increased more than 2% (*C. puteana:* $\Delta m_{\text{C.p.-average}}$ = 0.73%; $\Delta m_{\text{C.p.-Leached-average}}$ = 4.68%; *T. versicolor:* $\Delta m_{\text{T.v.-average}}$ = 1.11%; $\Delta m_{\text{T.v.-Leached-average}}$ = 3.94%), was confirmed by the Duncan tests at a 99.9% or 99% level of significance (Table 2). The experimental results were in accordance with the works of Wanschura *et al.* (2014) and other researchers (Table 3). They found that some biocidal extracts presented in these tropical wood species are water soluble, so the initial water leaching process decreased their original decay resistance.

Conversely, a relatively unchanged rot resistance after water leaching was observed for the 2nd group of the following 10 durable tropical wood species: ipé, yellow balau, doussié, bubinga, ovengol, padouk, iroko, blue gum, maçaranduba, and maroré. This 2nd group included durable wood species with a potentially stable resistance under wet exterior conditions. Tropical wood species of this group usually had a comparable decay resistance before and after water leaching (*C. puteana*: $\Delta m_{\text{C.p.-average}}$ = 0.719%; $\Delta m_{\text{C.p.-Leached-average}}$ = 0.95%; *T. versicolor*: $\Delta m_{\text{T.v.-average}}$ = 1.034%; $\Delta m_{\text{T.v.-Leached-average}}$ = 1.021%), as confirmed by the Duncan tests (Table 2). Due to the initial water leaching, only blue gum and makoré woods had a lower resistance to decaying fungi with $\Delta m > 2\%$ (Table 2). In summary, no (or only smaller) decreases in the rot resistance of water-leached tropical woods of the 2nd group could be explained by hypothesis 1 that some extracts of durable tropical wood species have a high fungicidal efficiency and simultaneously have strong stability against water leaching.

Rot resistance of the 3rd group of 3 less durable tropical wood species (okoumé, tineo, and sapelli) was not greatly decreased due to the initial water leaching processes (Table 2). This result was explained by hypothesis 2 that water insoluble and soluble extracts of less durable tropical wood species do not have a more apparent fungicidal efficiency (Tables 2 and 3).

The authors wanted to confirm hypotheses 1 and 2 in prepared experiments that analyzed the chemical substances in water and organic-solvent extracts from selected tropical wood species and their efficiency against decaying fungi.

Rot Resistance of Investigated Tropical Woods by Other Researchers

Several of the tropical wood species researched in this work have a known chemical structure (including information about the type and amount of extracts), anatomical structure, and physical-mechanical properties (Porter 2006; Wagenführ 2007). In the following section, the rot resistance of some tropical wood species researched in this work is discussed, both in their native and water-leached states.

Table 3. Water Soluble Extracts Presented in Some of the Researched Tropical Woods

Wood Species	Extracts	
	Water Soluble	References
Ipé	5.1% in water 12.63% in hot water	Wanschura *et al.* (2014) Jankowska *et al.* (2018)
Dark red meranti	1.0% to 2.1% in hot water	Yamamoto and Hong (1989)
Yellow balau	5.2% in water 1.9% to 7.4% in hot water	Wanschura *et al.* (2014) Yamamoto and Hong (1989)
Doussié	4.16% in cold water 2.85% in cold water, 2.40% in hot water 7.99% in hot water 10.30% in hot water 5.99% in hot water	Kilic and Niemz (2012) Arslan *et al.* (2018) Fan *et al.* (2012) Jankowska *et al.* (2018) Kilic and Niemz (2012) Arslan *et al.* (2018)
Cerejeira	10.8% in cold water 17.4% in hot water	da Silva Oliveira *et al*. (2005) da Silva Oliveira *et al*. (2005)
Bubinga	6.86% in hot water	Mahút *et al*. (1995)
Ovengol	5.93% in hot water	Jankowska *et al.* (2018)
Merbau	2.88% in cold water 6.1% in water 8.84% in hot water 12.5% to 16.5% in hot water 17.29% in hot water	Kilic and Niemz (2012) Wanschura *et al.* (2014) Kilic and Niemz (2012) Yamamoto and Hong (1989) Jankowska *et al.* (2018)
Zebrano	2.42% in cold water 3.41% in hot water	Kilic and Niemz (2012) Kilic and Niemz (2012)
Wengé	3.11% in cold water 4.33% in hot water 5.89% in hot water	Kilic and Niemz (2012) Jankowska *et al.* (2018) Kilic and Niemz (2012)
Padouk	5.73% in hot water 5.84% in hot water	Jankowska *et al.* (2018) Fan *et al.* (2012)
Sapelli	2.59% in cold water 1.19% in hot water 5.90% in hot water 6.07% in hot water	Arslan *et al.* (2018) Arslan *et al.* (2018) Fan *et al.* (2012) Jankowska *et al.* (2018)
Iroko	4.45% in cold water 3.93% in hot water 6.47% in hot water 8.64% in hot water	Arslan *et al.* (2018) Arslan *et al.* (2018) Jankowska *et al.* (2018) Fan *et al.* (2012)
Maçaranduba	1.4% in hot water	Wanschura *et al.* (2014)

Ipé wood has been found to belong to the very durable species group. For example, Lee *et al.* (2013) found that ipé has a high resistance to the white-rot fungus *T. versicolor* (Δm = 0.41% after 12 weeks) as well as to several other brown-rot fungi (*Gloeophyllum trabeum*: Δm = 1.59% after 12 weeks; *Fomitopsis palustris*: Δm = 2.69% after 12 weeks). Additionally, Andres *et al.* (2015) determined a high resistance of ipé to the brown-rot fungus *Serpula lacrymans* (Δm = 3.67% after 16 weeks). Heartwood of ipé contains a remarkable portion of the biocidal extract naphthoquinone "lapachol" (Romagnoli *et al.* 2013), providing it with a high resistance to damaging fungi and termites (Arango *et al.* 2006; Nascimento *et al.* 2013; Futuro *et al.* 2018).

Dark red meranti (*Shorea* spp.) wood grows in different regions of the world. It has many species; therefore, it is often characterized as durable, medium durable, or less durable (Table 1), with a durability ranging from 2 to 4 according to EN 350 (2016). Some researchers have established that this wood species has a low decay resistance to *T. versicolor* (Takahashi and Kishima (1973): Δ*m* = 21.6%, and Da Silva Oliveira *et al.* (2005): Δ*m* = 14.5%). Conversely, dark red meranti researched in this work had a high resistance to *T. versicolor* (Table 2: Δ*m* = 0.60%). Roszaini *et al.* (2016), in accordance with the present experiment (Table 2), also found a high decay resistance of dark red meranti to *T. versicolor* (Δ*m* = 1.65%). Based on these different results, the dark red meranti was again confirmed as highly variable in its durability, which depends on the tree growth conditions and other factors.

Yellow balau and merbau wood species were both highly resistant to *T. versicolor* (Table 2: Δ*m* = 0.83% and 0.99%, respectively), basically in agreement with the experiments of Yamamoto and Hong (1989) (Δ*m* = 1.2% and 3.8%, respectively). A comparable high resistance of these two tropical species to *T. versicolor* is also documented by Takahashi and Kishima (1973), determining similar weight losses for balau originating from Indonesia (Δ*m* = 2.60%) or Singapore (Δ*m* = 1.88%) and for merbau (Δ*m* = 2.47%). According to Lee *et al.* (2013), merbau can have a lower resistance to white-rot fungi (*e.g.*, *T. versicolor*: Δ*m* = 5.87% after 12 weeks) compared to brown-rot fungi (*e.g.*, *G. trabeum*: Δ*m* = 1.19%). However, the present experiment with *T. versicolor* and *C. puteana* (Table 2: Δ*m* < 1.0%) did not correspond with their findings. Yamamoto and Hong (1989) found that under the action of *T. versicolor*, the rot resistance of balau remained unchanged in response to its initial hot-water leaching (Δ*m* remained low, 1.2%). However, rot resistance evidently worsened for water-leached merbau (Δ*m* increased from 3.8% to 22.7%). These findings were in accordance with the present experiment (Table 2). Merbau wood contains extracts of a phenolic nature (Hofmann *et al.* 2011; Kilic and Niemz 2012), which are relatively easily washed out with water (Yamamoto and Hong 1989). Therefore, in line with previous mycological tests with merbau wood, and with knowledge related to the chemical structure of its extracts, the authors of this article determined that water leaching significantly deteriorated its decay resistance to *T. versicolor* (Table 2: Δ*m* increased from 0.99% to 5.33%) and *C. puteana* (Table 2: Δ*m* increased from 0.48% to 5.36%).

According to Da Silva Oliveira *et al.* (2005), cerejeira is a tropical species that is highly resistant to *G. trabeum* (Δ*m* approximately 2%), both with and without previous leaching in water. Conversely, this study indicated that its initial water leaching caused a partial but significant drop in its decay resistance to *C. puteana* and *T. versicolor* (Table 2: Δ*m* increased from 0.3% to 1.05% and from 0.8% to 2.21%, respectively).

Bubinga and wengé, in their native state, have a high rot resistance to *C. puteana* and *T. versicolor* (Table 2). Van Acker *et al.* (2003) also reported a high decay resistance of wengé to *C. puteana*, determining its small weight loss (0.2%) by the mini-mycological test on micro-specimens, or only a slightly higher weight loss (0.4%) by the standardized EN 113 (1996) mycological test. However, wengé (as opposed to bubinga) probably contained some water-leachable extracts, as its rot resistance significantly decreased after the initial water leaching (Table 2).

Padouk and iroko belonged to the very durable species group, with durability classes of 1 and 1 to 2 according to EN 350 (2016). Reinprecht *et al.* (2012) found that after 16 weeks of decay attack on 0.6-mm-thick veneers made from padouk and iroko, both of these durable wood species exhibited a strong resistance to the brown-rot fungi *Serpula lacrymans* (Δ*m* = 2.54% and 1.35%, respectively) and *C. puteana* (Δ*m* = 0.88% and 3.51%, respectively). The high durability of padouk, according to Déon and Schwartz (1988) and Surowiec *et al.* (2004), can be attributed to pterocarane, deoxysanthalene, sandaline, and other santal analog extracts. These biocidal extracts of padouk wood were probably waterproof, because its rot resistance had not deteriorated after water leaching (Table 2: $\Delta m < 1\%$).

Generally, the weight loss parameter, which is often used for assessing the rot resistance of wood, is greatly affected by the wood species and its chemical structure, mainly by the presence of biocidal extracts. According to Valette *et al.* (2017), the antifungal efficacy of various extractive compounds present in wood species and other plants is based on the following multiple mechanisms: (1) capture of Fe^{2+} and other metal ions or free radicals, (2) binding of degrading enzymes produced by the fungi, (3) direct attack and destruction of the cell wall and plasma membrane of the fungi, (4) failure of ion homeostasis in the fungi, and (5) chaotropic activity, for example, connected with inhibition of microbial growth and metabolism of more compounds in extracts such as alcohols and phenols.

However, rot processes in the molecular structure of wood species are also influenced by exposure conditions (such as temperature, moisture, and pH value) and their duration. Simultaneously, from evaluation of results achieved through mycological tests performed in a laboratory, high importance should also be assigned to some other factors. First, the dimensions of the wood had a significant effect. For example, thin veneers were usually attacked more easily and quicker by decaying fungi. Second, the actual amount of specific biocidal extracts in wood should be considered. For example, tropical woods were usually attacked faster by white-rot fungi than by brown-rot fungi, because lignin peroxidase, laccases, and other oxidation enzymes produced by white-rot fungi were able to degrade, except for lignin, also phenolic, and some other types of biocidal extracts (Barz and Weltring 1985; Eriksson *et al.* 1990; Couto and Herrera 2006; Fackler *et al.* 2007). Third, the exposition of wood before durability tests is important. For example, some tropical wood species initially exposed to weathering processes often lost water-leachable biocidal extracts, and their original decay resistance was decreased. This was more evident with thinner specimens.

CONCLUSIONS

1. The 18 durable tropical wood species in their native state (ipé, dark red meranti, yellow balau, macassar ebony, doussié, cerejeira, bubinga, ovengol, merbau, santos rosewood, zebrano, wengé, padouk, iroko, karri, blue gum, maçaranduba, and makoré) were by means of 6-weeks mycological tests determined as highly rot resistant, with weight losses ≤ 2%. Three tropical woods (okoumé, tineo, and sapelli) were characterized as being less rot resistant, with weight losses from 3% to 6%.
2. The initial water leaching significantly decreased the high rot resistance of 8 durable tropical species: dark red meranti, macassar ebony, cerejeira, merbau, santos rosewood, zebrano, wengé, and karri. This was probably due to the leaching of their biocidal extracts.
3. The initial water leaching had no apparent negative impact on the high rot resistance of 10 durable tropical wood species: ipé, yellow balau, doussié, bubinga, ovengol, padouk, iroko, blue gum, maçaranduba, and makoré. These tropical woods could be applied in more demanding expositions without fungicidal treatment.

4. The initial water leaching did not affect a poorer rot resistance of 3 less durable tropical wood species: okoumé, tineo, and sapelli.
5. Without water leaching, several tropical wood species had a partly higher resistance to the brown-rot fungus *C. puteana* compared to the white-rot fungus *T. versicolor*. This was in accordance with the knowledge that white-rot fungi are able also to deteriorate the phenolic or other biocidal extracts

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