



Maderas. Ciencia y tecnología

ISSN: 0717-3644

ISSN: 0718-221X

Universidad del Bío-Bío

Oh, Jeong-Joo; Choi, Yong-Seok; Kim, Min-Ji; Kim, Gyu-Hyeok
Natural durability of some hardwoods imported into Korea for deck boards
against decay fungi and subterranean termite in accelerated laboratory tests
Maderas. Ciencia y tecnología, vol. 25, 37, 2023
Universidad del Bío-Bío

DOI: <https://doi.org/10.4067/s0718-221x2023000100437>

Available in: <https://www.redalyc.org/articulo.oa?id=48575202040>

- How to cite
- Complete issue
- More information about this article
- Journal's webpage in redalyc.org

redalyc.org

Scientific Information System Redalyc

Network of Scientific Journals from Latin America and the Caribbean, Spain and Portugal

Project academic non-profit, developed under the open access initiative

NATURAL DURABILITY OF SOME HARDWOODS IMPORTED INTO KOREA FOR DECK BOARDS AGAINST DECAY FUNGI AND SUBTERRANEAN TERMITE IN ACCELERATED LABORATORY TESTS

Jeong-Joo Oh^{1,2}

<https://orcid.org/0000-0002-6836-7875>

Yong-Seok Choi³

Min-Ji Kim³

<https://orcid.org/0000-0002-0762-5703>

Gyu-Hyeok Kim^{1,}*

<https://orcid.org/0000-0002-2681-6652>

ABSTRACT

This study evaluated the natural durability of seven imported hardwoods Bangkirai (*Shorea laevis*), Burckella (*Burckella.*), Ipe (*Handroanthus.*), Jarrah (*Eucalyptus marginata.*), Kempas (*Koompassia malaccensi*), Malas (*Homalium foetidum*) and Merbau (*Instia*) used for deck boards against decay fungi (*Fomitopsis palustris*, *Gloeophyllum trabeum*, *Trametes versicolor*, and *Irpex lacteus*) and the subterranean termite (*Reticulitermes speratus kyushuensis*) in accelerated laboratory tests. Ipe, Jarrah, and Merbau were very durable to fungal attack, with performance comparable to ACQ-treated wood. Bangkirai, Burckella, Kempas, and Malas were classified as durable or moderately durable, depending on the fungal species tested. All wood species except for Merbau were highly resistant to termite attack. Termite resistance was similar to ACQ-treated wood. Merbau showed somewhat less than all other species but still significant termite resistance. These results indicated that selected naturally durable hardwood species could inhibit fungal and termite attacks as effectively as ACQ treatment. The natural durability of wood species tested in this study is most likely due to the biocidal extractive content of the wood.

Keywords: Decay fungi, hardwoods, natural durability, subterranean termite, wood extractives.

INTRODUCTION

The use of chromated copper arsenate (CCA) has been banned in Korea since October 2007 due to public concern over the potential hazards of CCA. Copper amine-based preservatives, such as alkaline copper quat (ACQ), have been formulated as alternatives. Still, these preservatives have some drawbacks compared to CCA, mainly including the toxicity of leached copper from treated wood to aquatic organisms. As a result, markets for naturally durable wood are expanding to solve the inadequacies of copper amine-based preservatives. Naturally durable wood has been called an environmentally friendly or chemical-free alternative to preservative-treated wood (Evans 2003).

¹Korea University. Division of Environmental Science & Ecological Engineering. Seoul, Korea.

²Korea University. Institute of Life Science and Natural Resources. Seoul, Korea.

³National Institute of Forest Science. Department of Forest Products and Industry. Seoul, Korea.

*Corresponding author: lovewood@korea.ac.kr

Received: 26.12.2021 Accepted: 10.06.2023

The natural durability of the heartwood of some wood species against fungal and termites attack is thought to be due to the presence of various extractives in the wood (Hillis 1987, Scheffrahn 1991). This is especially true in tropical hardwood species because there is no frost all year round to keep pest populations down (Beal *et al.* 1974). Several studies carried out to investigate the natural durability of hardwoods tested in this study to fungal attacks (Clark 1969, Osborne 1970, Amemiya and Matsuoka 1979, Yamamoto and Hong 1989, Yamamoto and Momohara 2002, Miller *et al.* 2003, Morrell 2011). For some wood species, studies have also been on the types of extractives responsible for their natural durability (Hillis and Carle 1962, Romagnoli *et al.* 2013). Grace *et al.* (1998), Suzuki (2004), Grace and Tome (2005), Arango *et al.* (2006), and Morrell (2011) found that hardwoods tested in this study have strong resistance to termite feeding. Many researchers have reported the correlation between extractive content and termite resistance in naturally termite-resistant wood species (Little *et al.* 2010, Kadir and Hale 2012, Kirker *et al.* 2013, Mankowski *et al.* 2016, Hassan *et al.* 2017, Hassan *et al.* 2018, Hassan *et al.* 2019, Kadir and Hassan 2020).

Currently, tropical and non-tropical wood species with excellent natural durability are imported into Korea from around the world and substituted for some pressure-treated wood in the domestic market. The general public doubts whether these species are resistant to decay fungi and termites, and if any, differences in resistance among species, and whether they have a resistance equal to or greater than that of preservative-treated wood. Therefore, research is needed to resolve these doubts of the general public. This study was carried out to evaluate the natural durability of some hardwood species imported into Korea for deck boards against decay fungi and subterranean termites and to compare their durability with that of ACQ-treated wood.

MATERIALS AND METHODS

Radially sawed deck boards measuring 21 mm - 24 mm × 90 mm by various lengths (1800 mm -2400 mm) of seven imported hardwoods, Bangkirai (*Shorea laevis* Ridley), Burckella (*Burckella* sp.), Ipe (*Handroanthus* sp.), Jarrah (*Eucalyptus marginata* Donn ex Sm.), Kempas (*Koompassia malaccensis* Maing. ex Benth.), Malas (*Homalium foetidum* (Roxb.) Benth.), and Merbau (*Instia* sp.), were obtained from local hardware stores. Boards were selected from different bundles to minimize the probability of choosing more than one sample from a single tree. Bangkirai, Kempas, and Merbau were imported from Indonesia, Burckella and Malas from Papua New Guinea, Ipe from Brazil, and Jarrah from Australia. Wood stick measuring 20 mm × 20 mm in cross-section were prepared from the board's innermost portion judged by growth-ring curvature. One stick was prepared from each of three boards from each wood species. Each stick was further cut into nineteen 10 mm long test samples, free of defects, to provide end-matched samples.

One test sample from each board were ground to pass a 20-mesh screen, and the resulting sawdust was assessed for ethanol-toluene soluble extractives according to methods described in ASTM D 1105-96 (2010). The remaining 18 test samples were oven-dried at 60 °C and weighed, then steam-sterilized in the autoclave at 121 °C for 15 minutes. Sixteen test samples (4 samples from each board × 4 fungal strains) were subjected to laboratory soil block decay tests using procedures described in JIS K 1571 (2004). Two brown-rot fungi, *Fomitopsis palustris* (Berk. et Curt.) Gilbn. & Ryv. and *Gloeophyllum trabeum* (Pers. ex Fr.) Murr, and two white-rot fungi, *Trametes versicolor* (L. ex Fr.) Pilat and *Irpex lacteus* Fries, were used in this study as test fungi. Six samples, two samples from each board, were exposed to the subterranean termite (*Reticulitermes speratus kyushuensis* Morimoto) collected from active wild colonies on the Seoul campus of Korea University (Seoul, Korea). The colony was maintained in a dark room at 28 °C and 80 % - 85 % relative humidity (RH) until use. The no-choice termite bioassay was conducted according to a method previously described in the literature (Kim *et al.* 2010). Test containers were 9-cm diameter x 5,5-cm-tall plastic jars containing 10 g coarse vermiculite and 17 ml distilled water. One wood sample was placed on the surface of the damp vermiculite, and 200 termite workers were introduced to each jar. The containers were kept at 28 °C and 80 % - 85 % RH in a dark room for 4 weeks. At the end of the test, the wood samples were cleaned, dried at 60 °C, and reweighed to determine mass loss.

To compare decay and termite resistance of the test wood species used with that of preservative-treated wood, eighteen wood samples, measuring 20 mm × 20 mm in cross-section by 10 mm in length, cut from radiata pine sapwood were treated with 3 % alkaline copper quat (ACQ) type 2 (66,7 % CuO and 33,3 % dodecyldimethylammonium chloride) solution by vacuum impregnation. All treated samples were stored under wet conditions at 60 °C for three days for complete fixation of preservative components and then subjected to decay and termite tests along with untreated radiata pine sapwood samples.

The fungal mass loss data were subjected to an analysis of variance, and then the resulting means were compared using Duncan’s multiple range test ($\alpha=0,05$). The potential relationship between % extractive content and % fungal mass loss was assessed by plotting the data and determining the correlation coefficient. All statistical analyses were performed using the statistical package SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Natural durability against decay fungi

The average percentage of mass losses (ML %) for each wood species after 12 weeks exposure to various fungi is shown in Table 1. The ML % varied depending on the wood and fungal species, ranging from 0,7 % (merbau samples exposed to *G. trabeum*) to 29,4 % (Burckella samples exposed to *F. palustris*). All fungi caused high ML % on the reference radiata pine sapwood controls, confirming that the decay tests conducted in this study were valid. For reference, the Japanese Industrial Standard JIS K 1571 (2004) states that a laboratory decay test may be considered valid where *F. palustris* and *T. versicolor* produce ML % of more than 30 % and 15 % in untreated controls, respectively.

Natural durability to wood decay fungi was classified according to EN 350-1 1994. The decay index (x) was calculated for the species tested using radiata pine sapwood as the reference species. Wood species were classified as very durable ($x \leq 0,15$), durable ($0,15 < x \leq 0,30$), moderately durable ($0,30 < x \leq 0,60$), slightly durable ($0,60 < x \leq 0,90$), or not durable ($x > 0,90$). The durability class of the wood species against each decay fungus tested is presented in Table 2. Ipe, Jarrah, and Merbau were classified as very durable, except for Jarrah which was classified as durable against *F. palustris*. Jarrah’s unusually weak resistance to *F. palustris* may be explained as reported by Hastrup *et al.* (2005), where *F. palustris*, a well-known copper-tolerant fungus, is far more aggressive than other fungi tested. *F. palustris* may also be better at metabolizing wood in the presence of Jarrah’s extractives than other fungi. Bangkirai, Burckella, and Kempas were rated moderately durable to durable depending on test fungi in this study. Malas was shown to be moderately durable after exposure to all fungi tested.

Table 1: Percentage mass loss for seven imported hardwoods after 12 weeks of exposure to decay fungi in soil-block tests.

Wood species	Fungal species				<i>Reticulitermes speratus</i>
	<i>F. palustris</i>	<i>G. trabeum</i>	<i>T. versicolor</i>	<i>I. lacteus</i>	
Bangkirai	14,0 (6,2) cd	7,9 (1,6) c	12,5 (4,1) c	10,4 (2,3) b	1,6 (0,1) cd
Burckella	29,4 (6,6) b	7,4 (1,6) c	19,5 (6,1) b	10,2 (3,1) b	1,4 (0,3) cd
Ipe	1,9 (0,5) e	2,0 (0,5) d	3,4 (0,4) d	3,0 (0,8) cd	0,9 (0,1) d
Jarrah	13,6 (7,0) cd	3,8 (0,9) d	5,7 (1,9) d	3,1 (1,0) cd	2,0 (0,4) c
Kempas	19,8 (7,2) c	5,9 (0,7) cd	15,0 (4,8) bc	7,0 (1,9) bc	1,5 (0,3) cd
Malas	28,1 (5,3) b	12,7 (5,5) b	19,8 (1,3) b	11,6 (2,3) b	1,7 (0,4) cd
Merbau	1,8 (1,1) e	1,2 (0,5) d	3,0 (1,1) d	0,7 (0,8) d	4,6 (1,1) b
Untreated radiata pine	50,9 (4,4) a	31,1 (7,2) a	41,8 (9,7) a	37,3 (8,6) a	23,1 (3,1) a
ACQ-treated radiata pine (for above ground uses)	11,2 (4,2) d	0,5 (0,4) d	1,5 (0,5) d	0,8 (0,4) d	1,9 (0,5) c

Each value represents the mean of 12 samples. Values in parentheses are the standard deviation. Numbers followed by the same letter in each column are not significantly different ($\alpha=0,05$) according to the Duncan’s multiple range test.

The increased ML % after exposure to *F. palustris* indicated that this fungus was more aggressive compared to other fungi tested. Overall, ML % was in the order of *F. palustris* > *T. versicolor* > *I. lacteus* ≥ *G. trabeum*. For Ipe and Merbau, which have a durability class of very durable, there was no significant difference in ML % among the decay fungi tested. For the remaining wood species, the ML % caused by *F. palustris* was the highest. As pointed out earlier, *F. palustris* was the most aggressive wood decay fungus tested, and this finding agrees with other research (Yamamoto and Hong 1994, Miller *et al.* 2003, Bhat *et al.* 2005). The ML % caused by *T. versicolor* and *I. lacteus* was higher than that by *G. trabeum* even though the ML % of *I. lacteus* and *G. trabeum* was similar in Malas and Merbau.

Table 2: Durability classes of seven imported hardwoods used for deck board according to EN 350-1.

Wood species	Fungal species			
	<i>F. palustris</i>	<i>G. trabeum</i>	<i>T. versicolor</i>	<i>I. lacteus</i>
Bangkirai	2	2	2	3
Burckella	3	2	3	3
Ipe	1	1	1	1
Jarrah	2	1	1	1
Kempas	3	2	3	2
Malas	3	3	3	3
Merbau	1	1	1	1

1 = very durable, 2 = durable, 3 = moderately durable, 4 = slightly durable, and 5 = not durable

Our results for Ipe, Jarrah, and Merbau agree with earlier laboratory and field tests. Yamamoto and Momohara (2002) reported that Ipe and Jarrah were highly durable in both accelerated decay tests using *F. palustris* and *T. versicolor* as well as in fungal cellar tests. Miller *et al.* (2003) and Morrell (2011) showed that Ipe was exceptionally resistant to fungal attack in laboratory soil-block tests and non-soil contact exposure, respectively. Clark (1969) found that Jarrah was highly resistant to fungal attack in soil-block and field stake tests. Merbau was exceptionally resistant to fungal attack in non-soil contact (Morrell 2011) and categorized as durable by Yamamoto and Hong (1989). Jarrah and Merbau are classified as very durable (class 1) and very durable to durable (class 1-2) in the EN 350-2 1994, respectively. Our results related to other species are or are not in agreement with the results in the literature. Amemiya and Matsuoka (1979) reported Bangkirai was very durable. Osborne (1970) reported that Burckella was durable and Malas was moderately durable. Yamamoto and Hong (1989) grouped Kempas as a moderately durable species. For reference, Bangkirai and Kempas are classified as durable (class 2) in the EN 350-2 1994. The difference with our results might be due to different geographic origins where the wood samples were collected and the specific conditions of the test, such as fungal species and exposure period.

Several factors such as the amount and chemistry of extractives, wood density, growth characteristics, and hemicellulose and lignin content, have been used to explain the natural durability of wood species (Zabel and Morrell 1992, Eaton and Hale 1993). It appears that the primary factor affecting durability is the type and amount of extractive compounds found in the heartwood (Hillis 1971). The durability of heartwood is greatly affected by differences in preservative qualities of the wood extractives (Zabel and Morrell 1992, Eaton and Hale 1993). The relationship between the total extractive content summarized in Table 3 and ML % shows that the greater the total extractive content of the species, the smaller the ML % , i.e., greater durability regardless of test fungi. The correlation coefficient (R^2) of this relationship ranges from 0,42 for *T. versicolor* to 0,57 for *F. palustris*. If Jarrah, which has a low extractive content compared to excellent decay resistance, is excluded, the correlation between extractive content and ML % is significantly improved for the remaining six species. The relationship between extract content and ML % was excellent in the order of *I. lacteus* ($R^2 = 0,94$), *G. trabeum* ($R^2 = 0,84$), *T. versicolor* ($R^2 = 0,82$), and *F. palustris* ($R^2 = 0,74$), as shown in Figure 1. Despite low extractive content, Jarrah is thought to have excellent decay resistance because the extractives responsible for the durability of Jarrah might not be extracted with the ethanol-toluene solvent. Ipe heartwood contains high levels of lapachol that was shown to be a fungi toxicant (Romagnoli *et al.* 2013). The durability of Jarrah heartwood is likely attributed to methanol-soluble catechin and gallic acid (Hillis and Carle 1962). From the research results that the ML% of unextracted and methanol-extracted merbau samples by *T. versicolor* was 3,8 % and 42,5% respectively (Yamamoto and Hong 1989), it can be inferred that methanol extractives of merbau impart natural durability to wood. Robinetin, the main polyphenol of the heartwood of merbau extracted using methanol solvent, is believed to be responsible for its natural durability (Hillis and Yazaki 1973). Even though density has been shown to correlate with decay resistance in previous studies (Takahashi and Kishima 1973, Wong *et al.* 1983), no significant correlation between density and ML % was found in this study, possibly due to narrow range (0,72 g/cm³ to 1,01 g/cm³) of the density of seven test species.

Table 3: Ethanol-toluene soluble extractive content of seven imported hardwoods.

Wood species	Extractive content (%)
Bangkirai	2,74 (1,03)
Burckella	3,42 (1,76)
Ipe	9,02 (1,18)
Jarrah	0,67 (0,71)
Kempas	3,86 (0,39)
Malas	0,90 (1,15)
Merbau	13,09 (1,03)

Values represent means of 3 samples while figures in parentheses represent one standard deviation.

As shown in Table 1, the ML % of Ipe, Jarrah, and Merbau was equal to or lower than that of ACQ-treated radiata pine sapwood for above-ground uses, regardless of fungi tested. Our results indicate that selected naturally durable hardwood species can inhibit decay damage as effectively as preservative treatment with ACQ and could be used in place of pressure-treated wood. The poor resistance of ACQ-treated wood to the brown-rot fungus *F. palustris* can be explained by its well-known copper tolerance (Hastrup *et al.* 2005, Köse and Kartal 2010).

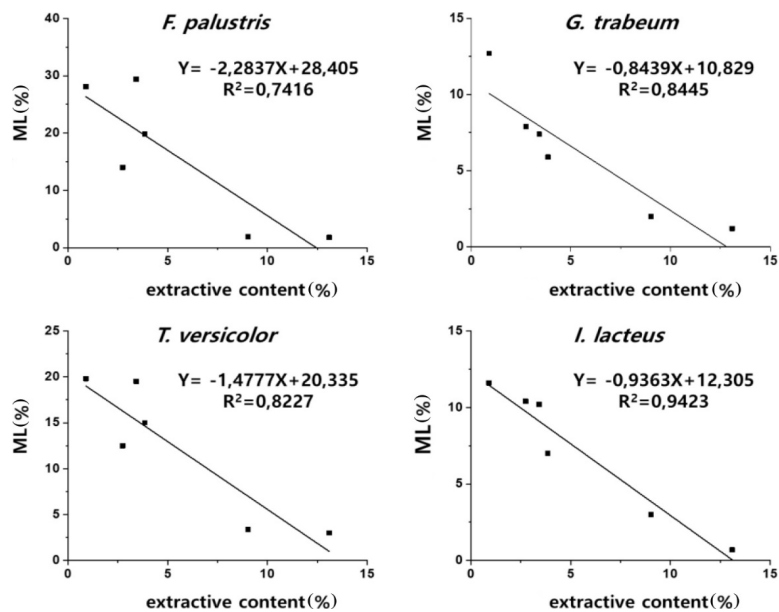


Figure 1: Relationship between total extractive contents and mass loss of six hardwood species exposed to four decay fungi.

Natural durability against subterranean termites

The ML % for each wood species after the 4-week test period is given in Table 1. The resistance test showed that untreated radiata pine sapwood blocks incurred the highest ML % (23,1 %). All wood species tested were highly resistant to termite attack (ML less than 5,0 %), with performance comparable to ACQ-treated radiata pine sapwood except for merbau.

Our results agree with previous studies examining termite resistance of selected naturally durable wood species. Grace and Tome (2005) reported that Indonesian Bangkirai was extremely resistant to *Coptotermes formosanus* Shiraki (ML % of 1,25 %), with performance comparable to CCA-treated wood. Arango *et al.* (2006) found that Ipe was highly resistant to *Reticulitermes flavipes* Kollar attack with a ML % of 3,0 %. Other studies (Morrell 2011, Suzuki 2004) have also demonstrated the high resistance of Ipe to attack by *C. formosanus*. Suzuki (2004) reported that the heartwood of Jarrah was highly resistant to *C. formosanus* attack (ML % -0,6 %~1,0 %). Kempas was shown to be quite resistant to attack by *C. formosanus* (ML % of 2,84 %) (Grace *et al.* 1998). Malas from Papua New Guinea showed very high resistance to *C. formosanus* attack (ML in the range of 1,4 %~2,1 %) in studies by Suzuki (2004). Grace and Tome (2005) reported that the Indonesian merbau lost 7,01 % of their mass after attack by *C. formosanus*. The slight differences in ML %

with our results may possibly be attributed to the difference in geographic origin of the wood samples and the specific conditions of the our test including termite species tested.

The two reasons why termite resistance of wood differ from wood species might be the amount and type of extractives and wood density. The effect of extractives on termite resistance is evident based on the literature (Hassan *et al.* 2017, Hassan *et al.* 2018, Hassan *et al.* 2019, Kadir and Hassan 2020, Kirker *et al.* 2013, Kadir and Hale 2012, Little *et al.* 2010, Mankowski *et al.* 2016). In our study, with the exception of merbau, the correlation between extractive content and ML % of six wood species was excellent, with an R^2 of 0,92. Merbau's low termite resistance compared to the other species tested despite its high extract content may be that the ethanol-toluene extract of merbau affects decay resistance, as mentioned earlier, but not termite resistance. The effect of wood density on termite resistance is still unclear; in general, termite resistance of wood seems to be positively affected by wood density (Kadir and Hale 2012, McConnell *et al.* 2010, Arango *et al.* 2006, Bultman *et al.* 1979). The correlation between density and termite resistance was poor in our study, possibly due to the narrow range of densities of test wood species.

CONCLUSIONS

Ipe (*Handroanthus* sp.), Jarrah (*Eucalyptus marginata* Donn ex Sm.), and Mmerbau (*Instia* sp.) woods were classified as very durable to decay caused by all the fungi tested except that Jarrah wood was classified as durable to *F. palustris*. Bangkirai (*Shorea laevis* Ridley), Burckella (*Burckella* sp.), Kempas (*Koompassia malaccensis* Maing. ex Benth.), and Malas (*Homalium foetidum* (Roxb.) Benth.) were durable or moderately durable, depending on which fungal species they were exposed to. The ML % of Ipe, Jarrah, and Merbau was equal to or lower than the ML % of ACQ-treated radiata pine sapwood for above-ground uses, regardless of fungi tested. All hardwood species tested were highly resistant to termite attack, and termite resistance was comparable to ACQ-treated radiata pine with the exception of merbau. These results indicate that selected naturally durable hardwood species inhibit decay and termite damage as effectively as ACQ treatment and can be an adequate substitute for pressure-treated wood. Field evaluation is needed to accurately assess the natural durability of wood since toxic extractives might be leached and different fungal and termite species are present under field conditions.

AUTHORSHIP CONTRIBUTIONS

J-J. O.: Investigation, Formal analysis, and Writing – original draft. Y-S. C.: Investigation, Methodology, and Writing – original draft. M-J. K.: Investigation. G-H. K.: Conceptualization, Funding acquisition, and Writing – review & editing.

REFERENCES

- Arango, R.A.; Green III, F.; Hintz, K.; Lebow, P.K.; Miller, R.B. 2006. Natural durability of tropical and native wood against termite damage by *Reticulitermes flavipes* (Kollar). *International Biodeterioration & Biodegradation* 57(3): 146-150. <https://doi.org/10.1016/j.ibiod.2006.01.007>
- Amemiya, S.; Matsuoka, S. 1979. Durability of tropical woods. *Japan Agricultural Research Quarterly* 13(4): 256-262. https://www.jircas.go.jp/sites/default/files/publication/jarq/13-4-256-262_0.pdf
- Beal, R.H.; Carter, R.L.; Southwell, C.R. 1974. Survival and feeding of subterranean termites on tropical woods. *Forest Products Journal* 24(8): 44-48.
- Bhat, K.M.; Thulasidas, P.K.; Maria Florence, E.J.; Jayaraman, K. 2005. Wood durability of home-garden teak against brown-rot and white-rot fungi. *Trees* 19: 654-660. <https://doi.org/10.1007/s00468-005-0429-0>
- Bultman, J.D; Beal, R.H.; Ampong, F.F.K. 1979. Natural resistance of some tropical African woods to *Coptotermes formosanus* Shiraki. *Forest Products Journal* 29(6): 46-50.
- Clark, J.W. 1969. Natural decay resistance of fifteen exotic woods imported for exterior use. Research Paper FPL-RP-103. USDA Forest Service, Forest Products Laboratory: Madison, WI., USA. 5p. https://www.fpl.fs.usda.gov/products/publications/specific_pub.php?posting_id=18214
- Eaton, R.A.; Hale, M.D. 1993. *Wood: Decay, pests, and protection*. Chapman and Hall: London, UK.

- EN. 1994.** Durability of wood and wood-based products - Natural durability of solid wood. Part 1. Guide to the principles of testing and classification of natural durability of wood. EN 350-1. Brussels, Belgium.
- EN. 1994.** Durability of wood and wood-based products - Natural durability of solid wood. Part 2. Guide to natural durability and treatability of selected wood species of importance in Europe. EN 350-2. Brussels, Belgium.
- Evans, P. 2003.** Emerging technologies in wood protection. *Forest Products Journal* 53(1): 14-22.
- Grace, J.K.; Tome, C.H.N. 2005.** Resistance of Indonesian woods Bangkirai (*Shorea laevis*) and Merbau (*Intsia palembanica*) to Formosan subterranean termite attack. *Sociobiology* 45(2): 503-509. <https://www.ctahr.hawaii.edu/gracek/pdfs/212.pdf>
- Grace, J.K.; Wong, A.H.H.; Tome, C.H.M. 1998.** Termite resistance of Malaysian and exotic woods with plantation potential: Laboratory evaluation. International Research Group on Wood Protection. Maas-tricht, The Low Countries. Doc. No. IRG/WP 98-10280. <http://manoa.hawaii.edu/ctahr/termite/aboutcontact/grace/pdfs/130.pdf>
- Hassan, B.; Mankowski, M.E.; Kirker, G.T.; Ahmed, S. 2017.** Effects of heartwood extractives on symbiotic protozoan communities and mortality in two termite species. *International Biodeterioration & Biodegradation* 123: 27-36. <https://doi.org/10.1016/j.ibiod.2017.05.023>
- Hassan, B.; Ahmed, S.; Kirker, G.T.; Mankowski, M.E.; Misbah-ul-Haq, M. 2018.** Antioxidant effects of four heartwood extractives on midgut enzyme activity in *Heterotermes indicola* (Blattodea: Rhinotermitidae). *Environmental Entomology* 47(3): 741-748. <https://doi.org/10.1093/ee/nvy029>
- Hassan, B.; Ahmed, S.; Mehmood, N.; Mankowski, M.E.; Misbah-ul-Haq, M. 2019.** Toxicity potential of heartwood extractives from two mulberry species against *Heterotermes indicola*. *Maderas. Ciencia y Tecnología* 21(2): 153-162. <http://dx.doi.org/10.4067/S0718-221X2019005000203>
- Hastrup, A.C.S.; Green III, F.; Clausen, C.A.; Jensen B. 2005.** Tolerance of *Serpula lacrymans* to copper-based wood preservatives. *International Biodeterioration & Biodegradation* 56(3): 173-177. <https://doi.org/10.1016/j.ibiod.2005.06.008>
- Hillis, W.E.; Carle A. 1962.** The origin of the wood and bark polyphenols of *Eucalyptus* species. *Biochemical Journal* 82(3): 435-439. <https://doi.org/10.1042/bj0820435>
- Hillis, W.E. 1971.** Distribution, properties and formation of some wood extractives. *Wood Science and Technology* 5(4):272-289. <https://doi.org/10.1007/bf00365060>
- Hillis, W.E.; Yazaki, Y. 1973.** Polyphenols of *Intsia* heartwoods. *Phytochemistry* 12(10): 2491-2495. [https://doi.org/10.1016/0031-9422\(73\)80461-3](https://doi.org/10.1016/0031-9422(73)80461-3)
- Hillis, W.E. 1987.** *Heartwood and tree exudates*. Springer-Verlag. Berlin, Germany. <https://doi.org/10.1007/978-3-642-72534-0>
- JIS. 2004.** Test methods for determining the effectiveness of wood preservatives and their performance requirements. JIS K 1571. Japanese Standards Association: Tokyo, Japan.
- Kadir, R.; Hassan, B. 2020.** Toxicity and repellent effects of wood extractives of five Malaysian wood species on Asian subterranean termite *Coptotermes gestroi* Wasmann. *European Journal of Wood and Wood Products* 78: 1249-1262. <https://doi.org/10.1007/s00107-020-01592-z>
- Kadir, R.; Hale, M.D. 2012.** Comparative termite resistance of 12 Malaysian timber species in laboratory tests. *Holzforschung* 66: 127-130. <https://doi.org/10.1515/HF.2011.116>
- Kim, G.H.; Hhang, W.J.; Yoshimura, T; Imamura, Y. 2010.** Laboratory evaluation of the termiticidal efficacy of copper HDO. *Journal of Wood Science* 56: 166-168. <https://doi.org/10.1007/s10086-009-1072-y>
- Kirker, G.T.; Blodgett, A.B.; Arango, R.A.; Lebow, P.K.; Clausen, C.A. 2013.** The role of extractives in naturally durable wood species. *International Biodeterioration & Biodegradation* 82: 53-58. <https://doi.org/10.1016/j.ibiod.2013.03.007>

- Köse, C.; Kartal, S. N. 2010.** Tolerance of brown-rot and dry-rot fungi to CCA and ACQ wood preservatives. *Turkish Journal of Agriculture and Forestry* 34(3): 181-190. <https://doi.org/10.3906/tar-0902-43>
- Little, N.S.; Schultz, T.P.; Nicholas, D.D. 2010.** Termite-resistant heartwood. Effect of antioxidants on termite feeding deterrence and mortality. *Holzforschung* 64: 395-398. <https://www.degruyter.com/document/doi/10.1515/hf.2010.053/html>
- Mankowski, M.E.; Boyd, B.; Hassan, B.; Kirker, G.T. 2016.** GC-MS characterizations of termiticidal heartwood extractives from wood species utilized in Pakistan. International Research Group on Wood Protection. Lisbon, Portugal. Doc. No. IRG/WP 16-10857. <https://www.fs.usda.gov/research/treesearch/52594>
- McConnell, T.E.; Little, N.S.; Shi, S.Q.; Schultz, T.P. 2010.** Technical note: the susceptibility of chemically treated southern hardwoods to subterranean termite attack. *Wood and Fiber Science* 42(2): 252-254. <https://wfs.swst.org/index.php/wfs/article/view/1321>
- Miller, R.B.; Wiedenhoft, A.C.; Williams, R.S.; Stockman, W.; Green III, F. 2003.** Characteristics of ten tropical hardwoods from certified forests in Bolivia. Part II Natural durability of decay fungi. *Wood and Fiber Science* 35(3): 429-433. <https://wfs.swst.org/index.php/wfs/article/view/821>
- Morrell, J.J. 2011.** Resistance of selected wood-based materials to fungal and termite attack in non-soil contact exposures. *Forest Products Journal* 61(8): 685-687. <https://core.ac.uk/download/pdf/9126432.pdf>
- Osborne, L.D. 1970.** Decay resistance of south-west pacific rain-forest timbers. Division of Forest Products Technological Paper No. 56. Commonwealth Scientific and Industrial Research Organization: Australia.
- Romagnoli, M.; Segoloni, E.; Luna, M.; Margaritelli, A.; Gatti, M.; Santamaria, U.; Vinciguerra, V. 2013.** Wood colour in Lapacho (*Tabebuia serratifolia*): chemical composition and industrial implications. *Wood Science and Technology* 47(4): 701-716. <https://doi.org/10.1007/s00226-013-0534-y>
- Scheffrahn, R.H. 1991.** Allelochemical resistance of wood to termites. *Sociobiology* 19(1): 257-281. <https://www.cabdirect.org/cabdirect/abstract/19921163893>
- Suzuki, K. 2004.** Termite resistance classification of some tropical and temperate species based on the laboratory choice test results against formosan termite, *Coptotermes formosanus*. International Research Group on Wood Protection. Ljubljana, Slovenia. Doc. No. IRG/WP 04-20291.
- Takahashi, M.; Kishima, T. 1973.** Decay resistance of sixty-five Southeast Asian timber specimens in accelerated laboratory tests. *Japanese Journal of Southeast Asian Studies* 10(4): 525-541. https://doi.org/10.20495/tak.10.4_525
- Wong, A.H.H.; Wilkes, J.; Heather, W.A. 1983.** Influence of wood density and extractive content on the decay of the heartwood of *Eucalyptus delegatensis* R.T. Baker. *Journal of Wood Science* 9(6): 261-263. https://www.researchgate.net/profile/Andrew-Wong-36/publication/288846729_Influence_of_wood_density_and_extractives_content_on_the_decay_resistance_of_the_heartwood_of_Eucalyptus_delegatensis_RT_Baker/links/56a4e87708ae232fb20784d1/Influence-of-wood-density-and-extractives-content-on-the-decay-resistance-of-the-heartwood-of-Eucalyptus-delegatensis-RT-Baker.pdf
- Yamamoto, K.; Momohara, I. 2002.** Estimation of service life of durable timber species by accelerated decay test and fungal cellular test. International Research Group on Wood Protection. Cardiff, Wales, UK. Doc. No. IRG/WP 02-20249.
- Yamamoto, K.; Hong, L.T. 1994.** A laboratory method for predicting the durability of tropical hardwoods. *Japan Agricultural Research Quarterly* 28(4): 268-275. https://www.jircas.go.jp/sites/default/files/publication/jarq/28-4-268-275_0.pdf
- Yamamoto, K.; Hong, L.T. 1989.** Location of extractives and decay resistance in some Malaysian hardwood species. *Journal of Tropical Forest Science* 2(1): 61-70. <https://www.jstor.org/stable/43594566>
- Zabel, R.A.; Morrell, J.J. 1992.** *Wood microbiology. Decay and its prevention*. Academic Press: San Diego, USA.