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

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## ABSTRACT

This study evaluated the natural durability of seven imported hardwoods (bangkirai, burckella, ipe, jarrah, kempas, malas, and merbau) 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, imported 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).

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, 2018, 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 (ASTM 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 (JIS 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 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 (JIS 2010).

Natural durability to wood decay fungi was classified according to EN 350-1 (EN 1994a). 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.[1]

| Wood species | Fungal species | | | | *Reticulitermes speratus* |
|---|---|---|---|---|---|
| | *F. palustris* | *G. trabeum* | *T. versicolor* | *I. lacteus* | |
| Bangkirai | 14,0 (6,2) cd[2] | 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 |

[1]Each value represents the mean of 12 samples. Values in parentheses are the standard deviation.
[2] Numbers followed by the same letter in each column are not significantly different (α=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 | | | |
|---|---|---|---|---|
| | *F. palustris* | *G. trabeum* | *T. versicolor* | *I. lacteus* |
| 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, respectively (EN 1994b). 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 (EN 1994b). 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/cm$^3$ to 1,01 g/cm$^3$) of the density of seven test species.

**Table 3:** Ethanol-toluene soluble extractive content of seven imported hardwoods.[1]

| 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) |

[1]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).

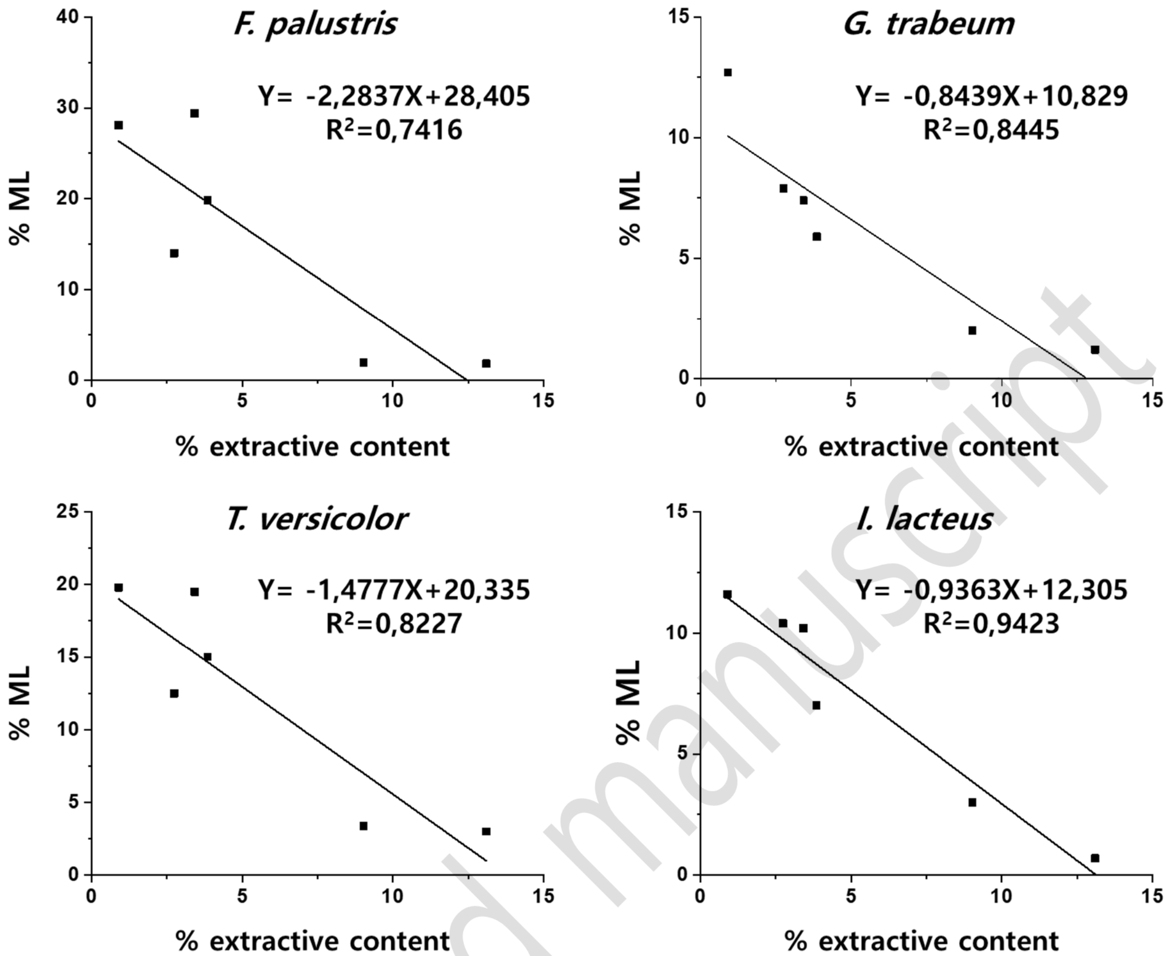


**Figure 1:** Relationship between total extractive contents and mass loss of six hardwood species exposed to four decay fungi.

## 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, 2018, 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 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, jarrah, and merbau 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, burckella, kempas, and malas 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.

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