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Evaluation of the Natural Durability of Twelve Korean Major Domestic Wood Species

Jae-Hee JUNG[1] ・ Sun Lul KWON[1] ・ Sae-Min YOON[1] ・ Jinae SHIN[1] ・ Hyun-Mi LEE[1] ・ Won-Joung HWANG[1] ・ Yong-Seok CHOI[1,†]

ABSTRACT

This study evaluated the natural durability of 12 major Korean domestic wood species (four softwoods and eight hardwoods) against wood-decay fungi (*Fomitopsis palustris*, *Trametes versicolor*) and subterranean termites (*Reticulitermes speratus*). The natural decay resistance and natural termite resistance were evaluated in accordance with KS F 2213 and AWPA E1, respectively. The results confirmed significant differences in durability among tree species. In a decay resistance test, Mossy locust exhibited the highest durability with weight losses of 2.1% and 4.7%, which classified it as “Highly resistant”. By contrast, Korean red pine and East Asian white birch exhibited the lowest durability, with weight losses of 57.7% and 45.4%, respectively, which classified them as “Slightly resistant or Nonresistant”. In the termite resistance test, Japanese cedar, Tulip tree, and Sawleaf zelkova exhibited low weight loss (3.6%, 1.8%, and 1.7%, respectively) and high termite mortality rates (100%, 99.2%, and 90.3%, respectively) and were classified as “Highly resistant”. By contrast, Korean red pine, Japanese larch, and East Asian white birch showed the highest weight loss (45.4%, 46.9%, and 40.3%, respectively) and lowest termite mortality (28.3%, 22.7%, and 13.9%, respectively) and were classified as “Slightly resistant or Nonresistant”. The results of this study expand the durability database of Korean domestic wood species and provides fundamental reference data for their efficient and sustainable utilization.

Keywords: Korean domestic wood species, natural durability, decay resistance, termite resistance

1. INTRODUCTION

Wood is an environment-friendly material that has been widely used in various industries because of its ease of processing and structural stability. However, wood is susceptible to biological degradation, significantly affecting its durability. The durability of wood varies greatly based on species and environmental factors such as growth region and climate conditions (Brischke *et al*., 2024; Oregon State University, 2023). Therefore, a fundamental understanding of wood species is essential to utilize them effectively.

The most significant biological factors affecting wood durability include wood-decay fungi and subterranean termites (ISO, 2007). Wood-decay fungi degrade the chemical components of wood, with brown-rot fungi degrading holocellulose and white-rot fungi decomposing major components, including lignin, thereby resulting in substantial deterioration in durability (Blanchette, 1991; Eaton and Hale, 1993). Subterranean termites, which are

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[1] Forest Products and Industry Department, National Institute of Forest Science, Seoul 02455, Korea
[†] Corresponding author: Yong-Seok CHOI (e-mail: choikfri@korea.kr, https://orcid.org/0009-0002-5827-9086)

important insects in soil ecosystems, can damage wooden structures and other cellulose-based materials in urban environments (Cowie and Wood, 1989; Ghaly and Edwards, 2011; Jouquet *et al*., 2011; Rust and Su, 2012; Wood, 1991).

Studies on the durability of local wood species have been conducted in the United States and Europe. In the United States, the Wood Handbook (Forest Products Laboratory, 2010) provides comprehensive data on the durability of numerous domestic wood species. Similarly, in Europe, EN 350 (CEN, 2016) classifies and provides reference data on the natural durability of wood species against biological factors that include wood-decay fungi and termites. These databases serve as important references to select and apply wood in construction and industrial settings.

In South Korea, studies have been conducted to evaluate the natural durability of domestic and imported wood species used in heritage sites and as building materials (Im and Han, 2024; Kim and Chung, 2022; Kim and Kim, 2024). Yoon *et al*. (2023) examined the durability of five major domestic species using standardized field tests (AWPA E7-15) and found that the heartwood of Japanese larch (*Larix kaempferi*) and Sawtooth oak (*Quercus acutissima*) exhibited superior durability compared to that of Korean red pine (*Pinus densiflora*), Northern red oak (*Quercus rubra*), and Oriental cork oak (*Quercus variabilis*). Lee *et al*. (2015) evaluated five domestic softwoods using EN 350-1 and found that Japanese larch (*Larix leptolepis*) had a slightly higher natural durability than those of Japanese red pine (*P. densiflora*), Pitch pine (*Pinus rigida*), Japanese cedar (*Cryptomeria japonica*), and Scots pine (*Pinus sylvestris*). However, all species lost ~30% of their weight when exposed to the brown-rot fungus *Poria placenta*. Further, Lee *et al*. (2017) examined the durability of Yellow- hearted pine (*P. densiflora* for. *erecta* Uyeki) against wood-decay fungi (*Fomitopsis palustris* and *Trametes versicolor*) and found that the heartwood of yellow-hearted pine exhibited superior durability, with a weight loss less than 5%. Oh *et al*. (2023) reported that three imported tropical hardwood species exhibited superior resistance to decay fungi and termites compared to that of preservative-treated wood. However, these studies were limited to specific species, highlighting the need for a more systematic database on the durability of domestic wood species.

Given this context, the National Institute of Forest Science (NIFoS) conducted extensive research to establish a comprehensive database of wood durability, including the anatomical, physical, mechanical, and chemical characteristics of domestic Korean wood species. Chong and Park (2008) compiled comprehensive data on the physical, mechanical, and durability properties of Korean wood species, thereby laying the foundation for ongoing research and data updates. As part of this effort, Park *et al*. (2024a, 2024b) evaluated the anatomical, physical, mechanical, and chemical properties of major domestic Korean wood species. In addition, numerous studies have provided complementary data on the anatomical, physical, and mechanical properties of domestic wood species, contributing to the establishment of a comprehensible database on Korean wood characteristics (Jeon *et al*., 2018a, 2018b; Kim and Kim, 2019, 2020; Kim *et al*., 2018, 2020; Seo *et al*., 2018).

This study aimed to evaluate the durability of 12 domestic Korean wood species (four softwoods and eight hardwoods) against wood-decay fungi and subterranean termites to expand the existing database and provide fundamental data for the efficient use and sustainable management of Korean wood resources.

2. MATERIALS and METHODS

2.1. Wood materials

Twelve domestic Korean wood species, consisting of four softwoods and eight hardwoods, were prepared to test their natural durability. The prepared softwood species included Korean red pine (*P. densiflora*), Korean pine (*Pinus koraiensis*), Japanese larch (*L. kaempferi*), and Japanese cedar (*C. japonica*). The hardwood species included the Tulip tree (*Liriodendron tulipifera*), Mossy locust (*Robinia pseudoacacia*), Sawtooth oak (*Q. acutissima*), Mongolian oak (*Quercus mongolica*), Sawleaf zelkova (*Zelkova serrata*), Oriental cork oak (*Q. variabilis*), East Asian ash (*Fraxinus rhynchophylla*), and East Asian white birch (*Betula pendula*). Wood specimens were collected from diverse geographic regions within Korea, with detailed information regarding their origin and age presented in Table 1.

2.2. Natural decay resistance test

Wood decay resistance was conducted based on KS F 2213 (Laboratory test method of natural decay resistance of wood; Korean Standards Association, 2018). The test method was based on the *Evaluation Manual of Domestic Wood Properties* (NIFoS, 2024). A brown-rot fungus *F. palustris* was employed for softwood species, whereas the white-rot fungus *T. versicolor* was employed for hardwood species. In addition, specimens of Korean red pine (*P. densiflora*) sapwood and Loose-flower hornbeam (*Carpinus laxiflora*) sapwood were prepared to determine the endpoint of fungal decay, and the test was terminated when the weight loss reached 50%. Weight loss caused by fungal degradation was determined after preparing nine specimens [25 mm (radial direction) × 25 mm (tangential direction) × 9 mm (longitudinal direction)] and their oven-dried weights at 60 ± 2℃ before and after the decay test. The results were evaluated in accordance with the grades for the decay resistance test of KS F 2213.

2.3. Natural termite resistance test

The termite resistance test was performed according to AWPA E 1-17 (AWPA, 2017). Detailed experimental procedures were performed in accordance with the guidelines outlined in the *Evaluation Manual of Domestic*

Table 1. Information on domestic softwood and hardwood species used in the test

Wood species			Site	Age (years)
Softwood	Japanese cedar	*Cryptomeria japonica*	Seogwipo-si, Jeju-do	37
	Japanese larch	*Larix kaempferi*	Jecheon-si, Chungcheongbuk-do	41
	Korean pine	*Pinus koraiensis*	Jinan-gun, Jeollabuk-do	37
	Korean red pine	*Pinus densiflora*	Pyeongchang-gun, Gangwon-do	42
Hardwood	East Asian ash	*Fraxinus rhynchophylla*	Yeongwol-gun, Gangwon-do	35
	East Asian white birch	*Betula platyphylla*	Hongcheon-gun, Gangwon-do	50
	Mongolian oak	*Quercus mongolica*	Yeongwol-gun, Gangwon-do	36
	Mossy locust	*Robinia pseudoacacia*	Chungju-si, Chungcheongbuk-do	32
	Oriental cork oak	*Quercus variabillis*	Haman-gun, Gyeongsangnam-do	41
	Sawleaf zelkova	*Zelkova serrata*	Yeongwol-gun, Gangwon-do	64
	Sawtooth oak	*Quercus acutissima*	Yeoju-si, Gyeonggi-do	28
	Tulip tree	*Liriodendron tulipifera*	Gangjin-gun, Jeollanam-do	28

Wood Properties (NIFoS, 2024). Subterranean termites (*Reticulitermes speratus*) were collected from an experimental forest at the Forest Technology and Management Research Center in Pocheon, Gyeonggi-do, South Korea. Six wood specimens, each measuring 50.8 mm (radial direction) × 25.4 mm (tangential direction) × 6.4 mm (longitudinal direction), were prepared and cut into 25.4 mm (radial direction) × 25.4 mm (tangential direction) × 6.4 mm (longitudinal direction) sections. The specimens were separated into two groups: one for the moisture content (MC) measurement, and the other for the termite resistance test. In addition, Korean red pine (*P. densiflora*) sapwood was used as a control group for the termite resistance test. The MC was determined by measuring the air-dried weight of the specimens after reaching a constant weight in the dry state (20 ± 2℃, RH 65 ± 3%), followed by the oven-dried weight after drying at 103 ± 2℃ for 24 h. The test was conducted over a four-week period, during which the number of live termites was recorded before and after exposure to determine the mortality rate. The weight loss of the specimens was assessed by measuring their oven-dried weight at 103 ± 2℃ before and after the test. Finally, a visual rating of the cross-sectional damage was assessed according to the AWPA standards.

2.4. Data analysis

All statistical analyses were conducted using the R software version 4.3.2 (R Core Team, 2024). Multiple comparisons were conducted for comparing fungal decay resistance (weight loss) and termite resistance (weight loss and termite mortality rate) among the wood species. Differences between mean values were determined using an analysis of variance (ANOVA) and Duncan's multiple range test. The statistical significance level was set at $p < 0.05$. The results are presented as mean ± SD, the values followed by different letters indicate statistically significant differences ($p < 0.05$).

3. RESULTS and DISCUSSION

3.1. Fungal decay resistance of wood

The natural decay resistance of 12 domestic wood species was evaluated using wood-decay fungi (*F. palustris* and *T. versicolor*). Table 2 presents the results of the study. The average weight loss of softwoods was as follows: Korean red pine (57.7%), Korean pine (39.3%), Japanese cedar (35.8%), and Japanese larch (19.5%). The average weight loss of hardwoods was as follows: East Asian white birch (45.4%), East Asian ash (37.5%), Tulip tree (36.0%), Mongolian oak (33.8%), Oriental cork oak (26.9%), Sawtooth oak (23.1%), Sawleaf zelkova (17.4%), and Mossy locust (4.7%).

According to the classification grade of KS F 2213, the highest durability grade, "Highly resistant", was assigned to Mossy locust. The "Resistant" grade included Japanese larch, Sawtooth oak, and Sawleaf zelkova. The "Moderately resistant" grade included Korean pine, Japanese cedar, Tulip tree, Mongolian oak, Oriental cork oak, and East Asian ash. The lowest durability rating, "Slightly resistant or Nonresistant", was assigned to Korean red pine among the softwoods, and East Asian white birch among the hardwoods.

Previous studies have reported decay resistances for Mossy locust and Japanese larch similar to those found in this study (Jang *et al.*, 2013; Nezu *et al.*, 2022; Scheffer and Morrell, 1949). However, Chung (1987) reported higher decay resistances against *T. versicolor* for East Asian white birch and Korean pine (mass losses of 16.05% and 11.49%, respectively) than those found in this study. Previous studies have indicated that anatomical and chemical characteristics such as the heartwood ring width, extractive content and composition, and wood density can significantly influence natural durability (Humar *et al.*, 2008; Latorraca *et al.*, 2011; Martín and López, 2023).

These results highlight the variability of natural decay

Table 2. Weight loss rate and resistance classification after the decay resistance test

Wood species			Average weight loss (%)[1)]	Class of resistance[2)]
Softwood	Japanese cedar	*Cryptomeria japonica*	35.8 ± 8.3[b]	Moderately resistant
	Japanese larch	*Larix kaempferi*	19.5 ± 5.1[c]	Resistant
	Korean pine	*Pinus koraiensis*	39.3 ± 11.3[a]	Moderately resistant
	Korean red pine	*Pinus densiflora*	57.7 ± 2.3[b]	Slightly resistant or Nonresistant
Hardwood	East Asian ash	*Fraxinus rhynchophylla*	38.6 ± 9.7[b]	Moderately resistant
	East Asian white birch	*Betula platyphylla*	45.5 ± 4.7[a]	Slightly resistant or Nonresistant
	Mongolian oak	*Quercus mongolica*	33.8 ± 6.5[b]	Moderately resistant
	Mossy locust	*Robinia pseudoacacia*	4.7 ± 1.2[e]	Highly resistant
	Oriental cork oak	*Quercus variabillis*	26.9 ± 3.6[c]	Moderately resistant
	Sawleaf zelkova	*Zelkova serrata*	17.4 ± 5.4[d]	Resistant
	Sawtooth oak	*Quercus acutissima*	23.1 ± 5.0[c]	Resistant
	Tulip tree	*Liriodendron tulipifera*	36.0 ± 5.7[b]	Moderately resistant

[1)] Value followed by different letters ([a–e]) indicate significant differences according to Duncan's multiple range test ($p < 0.05$).
[2)] Classification of decay resistance designated by KS F 2213: Highly resistant, ≤ 10% weight loss; Resistant, ≤ 24% weight loss; Moderately resistant, ≤ 44% weight loss; Slightly resistant or Nonresistant, > 44% weight loss.

resistance both between species and within the same species. Therefore, future studies should aim to identify the key factors influencing decay resistance through comprehensive analyses of the anatomical, chemical, and physical properties of domestic wood species.

3.2. Termites resistance of wood

The results of the natural termite resistance test (weight loss, visual rating, and termite mortality rate) for the 12 domestic wood species are presented in Table 3. After termite exposure, the softwood weight loss was as follows: Japanese cedar (3.6%), Korean pine (22.1%), Korean red pine (45.4%), and Japanese larch (46.9%). The weight loss of hardwoods was as follows: Sawleaf zelkova (1.7%), Tulip tree (1.8%), Oriental cork oak (4.4%), Mongolian oak (4.5%), Mossy locust (5.2%), Sawtooth oak (12.0%), East Asian ash (26.1%), and East Asian white birch (40.3%).

The visual rating of the cross-sectional damage was assessed based on AWPA standards. The softwood and hardwood ratings were Japanese cedar (9.0), Korean pine (6.9), Korean red pine (4.5), Japanese larch (0.0). Sawleaf zelkova (9.5), Tulip tree (9.4), Mongolian oak (8.8), Oriental cork oak (8.5), Mossy locust (8.4), Sawtooth oak (7.9), East Asian ash (6.1), and East Asian white birch (4.9).

Based on the classification of termite resistance, among softwoods, Korean red pine and Japanese larch were categorized as "Slightly resistant or Nonresistant", Korean pine as "Moderately resistant", and Japanese cedar as "Highly resistant". Among hardwoods, East Asian white birch was classified as "Slightly resistant or Nonresistant", Sawtooth oak and East Asian ash as "Moderately resistant", Mossy locust, Mongolian oak, and Oriental cork oak as "Resistant", and Tulip tree and

Table 3. Weight loss, termite mortality, visual rate, and resistance classification after the termite resistance test

Wood species			Average weight loss (%)[1)]	Mortality (%)[1)]	Visual rate[2)]	Class of resistance[3)]
Softwood	Japanese cedar	*Cryptomeria japonica*	3.6 ± 1.2[c]	100 ± 0.0[a]	9.0	Moderately resistant
	Japanese larch	*Larix kaempferi*	46.9 ± 6.9[a]	22.7 ± 7.0[c]	0.0	Nonresistant
	Korean pine	*Pinus koraiensis*	22.1 ± 5.5[b]	36.6 ± 8.1[b]	6.9	Moderately resistant
	Korean red pine	*Pinus densiflora*	45.4 ± 5.7[a]	28.3 ± 5.5[bc]	4.5	Nonresistant
Hardwood	East Asian ash	*Fraxinus rhynchophylla*	26.1 ± 0.7[b]	19.0 ± 4.9[c]	6.1	Moderately resistant
	East Asian white birch	*Betula platyphylla*	40.3 ± 1.6[a]	13.9 ± 3.2[c]	4.9	Nonresistant
	Mongolian oak	*Quercus mongolica*	4.5 ± 0.5[d]	98.3 ± 2.7[a]	8.8	Resistant
	Mossy locust	*Robinia pseudoacacia*	5.2 ± 1.0[d]	97.4 ± 1.6[a]	8.4	Resistant
	Oriental cork oak	*Quercus variabillis*	4.4 ± 0.4[d]	81.5 ± 17.8[ab]	8.5	Resistant
	Sawleaf zelkova	*Zelkova serrata*	1.7 ± 0.3[e]	90.3 ± 8.9[a]	9.5	Highly resistant
	Sawtooth oak	*Quercus acutissima*	12.0 ± 2.3[c]	72.7 ± 27.7[b]	7.9	Moderately resistant
	Tulip tree	*Liriodendron tulipifera*	1.8 ± 0.3[e]	99.2 ± 0.9[a]	9.4	Highly resistant

[1)] Value followed by different letters ([a–e]) indicate significant differences according to Duncan's multiple range test ($p < 0.05$).
[2)] Visual rating was designated by AWPA E 1-17: sound, 10; trace (surface nibbles permitted), 9.5; light attack (up to 3% of the cross-sectional area affected), 9; 3%–10% affected, 8; 10%–30% affected, 7; 30%–50% affected, 6; 50%–75% affected, 4; failure, 0.
[3)] Classification of termite resistance based on visual rating: Highly resistant, ≥ 9; Resistant, ≥ 8; Moderately resistant, ≥ 6; Nonresistant, < 6.

Sawleaf zelkova as "Highly resistant". The visual rating was assessed by comparing the cross-sectional damage and the results were similar to the weight loss results.

The termite mortality rate was assessed after four weeks of exposure. The mortality rates for softwoods were as follows: Japanese cedar (100%), Korean pine (36.6%), Korean red pine (28.3%), and Japanese larch (22.7%). The mortality rates for hardwoods were as follows: Tulip tree (99.2%), Mongolian oak (98.3%), Mossy locust (97.4%), Sawleaf zelkova (90.3%), Oriental cork oak (81.5%), Sawtooth oak (72.7%), East Asian ash (19.0%), and East Asian white birch (13.9%). The termite mortality results were similar to the weight loss and visual rating results. Most termites died in the higher-grade specimens, whereas most termites survived in the lower-grade specimens.

Previous studies have indicated that higher wood density limits termite feeding, which enhances the resistance of the wood and leads to increased termite mortality (Arango *et al*., 2006; Esenther, 1977). Additionally, wood extracts that contain toxic compounds, such as such as noxious compounds, may also contribute to termite resistance (Park *et al*., 2023; Rust and Reierson, 1977). However, there is limited information linking the characteristics of wood to its resistance against termites. Therefore, further studies are needed to evaluate the relationships between the characteristics of wood and termite resistance.

4. CONCLUSIONS

This study evaluated the natural durability of 12 major domestic Korean wood species. The durability of each species was assessed against wood-decay fungi and subterranean termites.

The decay resistance tests classified Mossy locust as "Highly resistant". Japanese larch, Sawtooth oak, and Sawleaf zelkova were classified as "Resistant", while Korean pine, Japanese cedar, Tulip tree, Mongolian oak, Oriental cork oak, and East Asian ash were classified as "Moderately resistant". The Korean red pine and East Asian white birch showed the lowest durability and were categorized as either "Slightly resistant or Nonresistant".

A termite resistance test was performed using weight loss, visual rating, and termite mortality rate, which exhibited similar tendencies. The Japanese cedar, Tulip tree, and Sawleaf zelkova exhibited the highest resistance and were classified as "Highly resistant". Mossy locust, Mongolian oak, and Oriental cork oak were categorized as "Resistant", while Korean pine, Sawtooth oak, and East Asian ash were classified as "Moderately resistant". The lowest resistance was observed in Korean red pine, Japanese larch, and East Asian white birch, which were categorized as "Slightly resistant or Nonresistant".

Establishing a durability database for domestic wood species is important for their efficient use and industrial application. Even within the same species, durability can vary depending on origin and growth conditions. Therefore, it is necessary to continuously expand this database and conduct comparative analyses of the anatomical, physical, and chemical characteristics of wood species. This database will help identify the key factors influencing species-specific natural durability. Furthermore, it will support efforts to understand the specific durability of wood and develop standardized guidelines for wood use.

Future research will include studies on the characteristics of additional domestic wood species and comparative analyses of their durability against wood-decay fungi and termites.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

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