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Changes in surface properties of tropical wood species exposed to the Indonesian climate in relation to mold colonies

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Abstract Changes in mold populations and genera on the exposed surfaces of tropical hardwoods – albizia (*Paraserianthes falcata*), kapur (*Dryobalanop lanceolata*), mahoni (*Switenia macrophylla*), nangka (*Artocarpus heterophyllus*), puspa (*Schima wallchii*) – were investigated. The wood specimens were exposed to the Indonesian climate for 32 weeks. Properties including mass loss, wettability, mold growth (colony-forming units), and mold genera were evaluated. The change in properties after exposure was significantly affected by the wood species, but there was no clear relation between mass loss and the initial chemical components or between wettability and wood density. The number of mold populations was different by exposure period and wood species, but there was no significant effect of climate conditions, such as rainfall and ultraviolet radiation. Of the genera identified, *Aureobasidium, Cladosporium*, and *Penicillium* were dominant molds on the exposed wood surfaces.

Key words Tropical hardwood · Natural weathering · Wettability · Mold · Wood component

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Introduction

The need for wood as a material for housing and other exterior applications has been expanding yearly and worldwide owing to the amenity characteristics and the environmental friendliness of the materials. Indonesia has considerable tropical hardwood resources (approximately 4000 tree species) that are potentially useful as timber. Although about 400 species are currently considered valuable economically as timber, only 290 species are distributed commercially.[1] It is inevitable that the lesser-used species should be utilized for housing and exterior constructions.

To date, the main wood species for exterior use have been kapur and mahoni, which exhibit comparatively strong physical properties and dimensional stability in the tropical climate of Indonesia.[1] Albizia has been mostly used for interior finishes and furniture because it has a fairly soft texture and is relatively perishable.[1,2] However, this species is needed for new applications because it is one of the fast-growing trees, 38–56 m^3/ha/year,[3] and must be thinned to obtain timber of good quality. Nangka and puspa are ordinarily used to construct houses and furniture.[2,3] The use of these two species should be expanded to outdoors use owing to their abundance as waste in agriculture and because they provide shade for roads.

The exterior application of these lesser-used species could be better promoted if technical data on their properties of resistance against weathering were available. Although the main weathering agents are solar radiation, water, wind, and dust,[4] degradation by mold, fungi, and insects are also significant factors. Molds generally grow on exposed wood within a comparatively short period and occasionally cause the deterioration of surface characteristics. Mold growth is possibly affected by the chemical and physical properties of the wood and climatic conditions. It is also suggested that the degradation of wood components by photochemical reactions influences the growth rate of molds. In this study, we attempted to clarify the relations between wood properties and weathering conditions and changes in the mold population on the wood surfaces ex-

posed to the high temperatures and high humidity of the Indonesian climate.

Materials and methods

Sample specimens

Samples from the five tropical hardwood species mentioned above were tested. Their local names, scientific names,[3] and physical properties are listed in Table 1. Wood specimens, 50 (L) × 50 (T) × 3 (R) mm, were sawn from heartwood that was more than 35 years old (kapur, mahoni, nangka, puspa) or 20 years old (albizia). They were harvested from the plantation forests at Serpong, Tangerang, Indonesia.

Exposure conditions

The specimens were exposed to outdoor conditions for 2 to 32 weeks from September 2000 to April 2001 at the R & D Centre for Applied Physics, LIPI, Serpong, Tangerang, Indonesia. This site is located at 6°54′ south latitude, 106°42′ east longitude, and at an elevation of 50 m. The specimens were placed on a rack at an inclination of 5° from the horizontal facing east at a height of 1 m above the ground. Three replications per exposure period were made for each species.

Determination of mass loss due to weathering

The mass loss (ML) of each specimen during weathering was calculated from the differences in the weight before and after exposure.

Determination of wettability

A drop of water (0.2 ml) was placed in the center of the sample and covered with a petri dish (25 mm diameter) to prevent evaporation. After 1 min the water remaining on the surface was swabbed using filter paper and the weight of the water absorbed by the wood was calculated by measuring the initial (W_1) and final (W_2) weight of the test samples. Wettability (Wa) was calculated according to the following equation:

$$Wa\,(\%) = \frac{W_2 - W_1}{0.2} \times 100$$

Measurement of color changes

The change in color of the surface of each specimen was determined with a colorimeter (Scan CR-3000 Minolta, Japan). The average color difference (ΔE^*) was calculated according to JIS Z 8729.[5]

Chemical analyses

Cold-water and hot-water extractions of wood meal samples were carried out according to ASTM-D 1110-84.[6] Ethanol-benzene extracts and Klason lignin determinations were conducted in accordance with methods described in a reference.[7] Ethanol-benzene extraction was continued more than 24 h until the eluate showed no coloration. Phenolic content was determined by an analytical method for the Stiasny value.[8] Three replications were conducted to obtain the mean value of each chemical analysis, except ethanol-benzene extracts.

Mold isolation and identification

The weathered surface of each sample was divided into quarters, one of which was then whittled with a blade. The shavings obtained were introduced into autoclaved water containing 0.025% Tween-80 and stirred for 15 min at room temperature. Then the spore suspension (0.5 ml) was aseptically diluted with distilled water (4.5 ml) in a test tube. The diluted suspension (100 μl) was inoculated onto potato dextrose agar (PDA) plates containing 100 ppm tetracycline hydrochloride to prevent bacterial contamination. This process was conducted in a day to avoid microbial growth on the suspension. The PDA plates were incubated at 26°C and 95% relative humidity (RH) for more than 2 days.

Mold populations were evaluated by counting the number of viable colonies after the incubation. The total number of colonies for each sample, expressed as colony-forming units (CFU) was calculated by multiplying colony numbers and a coefficient obtained from the dilution frequency.[9] Well-enlarged colonies of a different shape and color were picked up and inoculated independently into fresh PDA medium. A pure culture was obtained by successive inoculation of an individual colony in PDA medium. Mold genera were identified by such macroscopic and microscopic observations as: colony growing speed; color of the surface and undersurface of the mycelium extension on the medium; hyphal characteristics, such as the existence of

Table 1. Common and scientific names, densities, and original colors of tested heartwood samples

Common name	Scientific name	Family name	Mean density (g/cm^3)	Original color
Albizia	*Paraserianthes falcata* Becker	Leguminoceae	0.38	Light brown
Kapur	*Dryobalanop lanceolata* Burck	Dipterocarpaceae	0.77	Dark brown
Mahoni	*Switenia macrophylla* King	Meliaceae	0.65	Bright brown
Nangka	*Artocarpus heterophyllus* Lamk	Moraceae	0.69	Yellow
Puspa	*Schima wallichii* Korth	Theaceae	0.70	Pale brown

Table 2. Meteorological data of the test site (Serpong, Indonesia) during the exposure period

Measurement duration	Exposure period (weeks)	Temperature (°C)			Ave. RH (%)	Total rainfall (mm)	Rainfall/ week (mm)	Total UV radiation (kj/m^2)	UV radiation/ week (kj/m^2)
		Min.	Max.	Ave.					
September 1–14, 2000	2	26.6	28.0	27.3	85.0	4	2	8125	4063
September 15–28, 2000	4	26.0	27.4	26.7	87.3	104	52	7383	3692
September 29 to October 12, 2000	6	25.7	27.0	26.4	90.1	103	52	7740	3870
October 13–26, 2000	8	26.0	27.6	26.9	89.0	85	42	8390	4195
October 27 to December 21, 2000	16	25.9	27.2	26.6	90.8	360	45	35679	4460
December 22, 2000 to April 12, 2001	32	25.5	26.6	26.0	92.8	1151	72	67948	4247

Min., minimum; Max., maximum; Ave., average; RH, relative humidity; UV, ultraviolet

Table 3. Results of chemical analyses of five wood species tested

Wood species	Cold water extracts (%)	Hot water extracts (%)	EtOH-benzene extracts (%)	Klason lignin (%)	Phenolics contents (%)
Albizia	2.78 (0.05)	4.30 (0.15)	2.28	22.69 (1.82)	1.16 (0.05)
Kapur	3.66 (0.13)	4.62 (0.38)	2.30	29.79 (0.51)	1.77 (0.10)
Mahoni	3.77 (0.13)	8.06 (0.08)	5.73	25.73 (0.04)	7.16 (0.18)
Nangka	9.98 (0.26)	8.63 (0.28)	12.08	28.01 (0.11)	7.98 (0.35)
Puspa	1.80 (0.04)	4.38 (0.51)	1.98	24.28 (0.85)	0.25 (0.05)

Values in parentheses are standard deviations. Ethanol-benzene extracts have no replication

septum or clamp connection; shape of conidiophores and conidial shape; divide and color.[10–12]

Results and discussion

Climatic conditions at the test site were measured during the exposure period (Table 2). The rainy season in this area is generally from September to April, but no great change in average temperature or RH was observed during the exposure period. Early in the rainy season, September 1–14, there was less total rainfall. The rainfall per week was about the same from week 4 to 16 but had increased by week 32. Also, the dose of ultraviolet (UV) radiation per week at 16 and 32 weeks of exposure increased.

Table 3 shows the results for the chemical components of wood tested before exposure. There was a large yield of cold-water extracts from nangka compared with other wood species. For the hot-water extracts, mahoni and nangka contained about 8%, and others had about half of those. Usually, yields of hot-water extracts are larger than those of cold-water extracts. The yield of hot-water extracts of nangka was less than that of cold-water extracts, which was possibly caused by thermochemical changes in the extracts. The largest yield from the ethanol-benzene extracts was determined for nangka (12.08%). The Klason lignin contents ranged from 23% to 30% and the range was smaller than those of the other components. An extremely small value for phenolics was shown in puspa, whereas the largest was in nangka. Nangka has been used for building members that require durability in Indonesian houses because this species is empirically known to be a durable species against fungi and termites. The large quantities of all components of this species are possibly related to its properties. This point should be investigated in future studies.

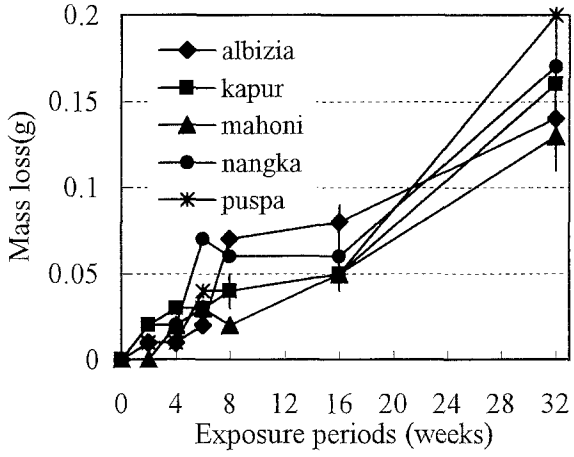

Fig. 1. Change in mass losses of five wood species exposed to natural weathering. *Vertical bars*, standard deviations

As shown in Fig. 1, there is no large difference among the mass losses (ML) of tested wood specimens based on exposure duration. Although the original masses of the samples ranged from 2.0 g (albizia) to 4.5 g (kapur), the range of ML was 0.13–0.20 g after a 32-week exposure. This means that the MLs were mainly due to photochemical or physical degradation (or both), not to drastic biodegradation such as decay. The reduction of mass is assumed to be due to the decomposition of wood components resulting from UV–

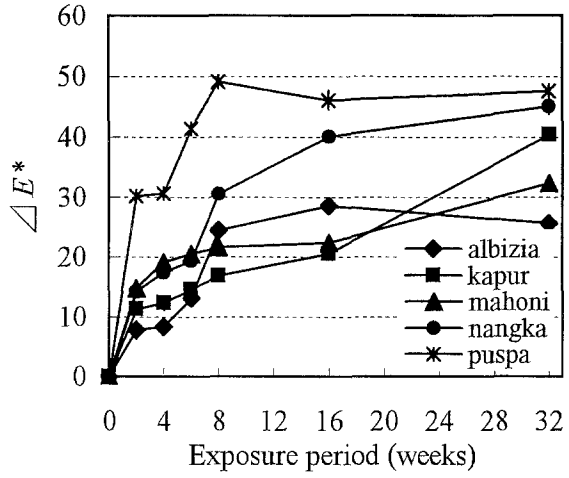

Fig. 2. Color changes of five wood species exposed to natural weathering.

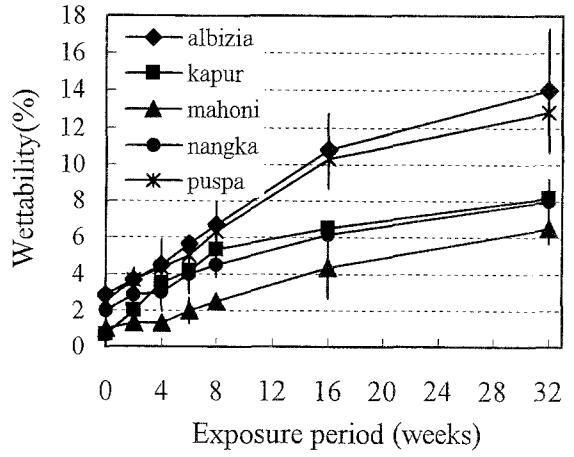

Fig. 3. Change in wettability of five wood species exposed to natural weathering. *Vertical bars*, standard deviations

induced photooxidation.[13] When radiata pine veneers were weathered in the Australian climate for 30 days, the decrease in Klason lignin was much larger than that of hemicellulose and cellulose.[14] Hence, wood species rich in lignin are thought to be more resistant to the weathering process. However, in this experiment, there was no significant relation among the MLs and the initial quantities of chemical components including lignin, which is a key light-absorbing component for any of the wood species tested.

The relation of the color differences (ΔE^*) of exposed woods and the periods of exposure are shown in Fig. 2. The ΔE^* of puspa showed the most drastic change up to 8 weeks of exposure, and it remained constant until week 32. The colors of the other species changed at about the same rate up to 8 weeks. At week 32, nangka had the same ΔE^* as puspa, followed by kapur, whereas the values for albizia and mahoni were comparatively constant after 8 weeks. Consequently, the surface of albizia changed from a light brown to dark gray, and mahoni and puspa changed from a bright brown and pale brown to dark brown, respectively. The surface of nangka changed from yellow to a dull black-brown. The changes of ΔE^* were mainly due to the weathering process without mold extension because there was no correlation between the changes of ΔE^* and mold CFUs. Although the weathering effect from UV radiation and water (e.g., artificial weathering process) alone generally colors the wood surface silver to white,[15] air-borne dust and mold extension partially affected the color changes during this exposure.

The relation between the wettability (*Wa*) of the wood samples and exposure periods is shown in Fig. 3: *Wa* increased with exposure time. The *Wa* values for albizia and puspa were more than 6%, and those for the other species were about 4%–6% after 8 weeks of exposure. After week 32, the *Wa* values were divided to two groups: albizia and puspa had about 13%–14%; kapur, nangka, and mahoni 6%–8%. It is assumed that the difference between the two groups depends on the quantities of chemical components

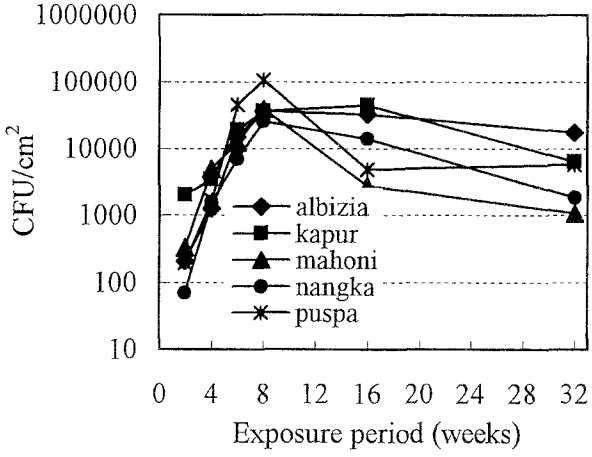

Fig. 4. Change in the total population of molds isolated from specimens exposed to natural weathering for 32 weeks

because the latter groups have somewhat large values for each component.

The numbers of CFUs of molds isolated from the wood specimens during the 32-week exposure are shown in Fig. 4. Preliminary experiments before exposure showed that all specimens were free from both yeast and mold. Comparatively few CFUs were detected immediately after 2 weeks of exposure. Especially, only 70 CFU/cm^2 was detected from nangka. These values increased markedly, however, after 4–6 weeks and were high after 8 weeks of exposure. At 8 weeks the number of CFUs peaked for puspa at more than 10^5/cm^2, and for the other wood species it ranged from 2.5×10^4 to 4×10^4/cm^2. The mold population of most wood species began to decrease after 16 weeks of exposure and continued until week 32, except for puspa. Lower values were recorded for mahoni and nangka, whereas the largest number of CFUs was 1.7×10^4/cm^2 for albizia. There was no significant relation between the number of CFUs and the

Table 4. Mold genera or families isolated from wood exposed for 32 weeks

Genus or family of isolate	No. isolated, by wood species					
	Albizia	Kapur	Mahoni	Nangka	Puspa	Total
Aspergillus	–	1	–	–	2	3
Aureobasidium	6	9	10	7	5	37
Acremonium	–	–	–	1	1	2
Brachysporiella	1	–	–	–	–	1
Cladosporium	4	1	2	6	3	16
Culvularia	1	–	–	1	–	2
Fusarium	1	–	1	1	1	4
Monilia	1	–	–	1	–	2
Geotrichum	–	–	–	1	–	1
Nigrospora	1	–	–	–	–	1
Neurospora	1	–	1	–	–	2
Paecilomyces	–	–	1	–	–	1
Penicillium	3	7	1	1	2	14
Pithomyces	–	–	1	–	–	1
Actinomycetes	–	–	–	1	–	1
Basidiomycetes	–	–	–	–	3	3
Unidentified	1	2	3	1	2	9
Total	20	20	20	21	19	100

chemical components of the wood samples. No information was obtained on the effect of wood density.

When we isolated colonies developed on PDA plates, colonies with the same shape, color, and extension degree were picked up as the same isolates. Altogether, 100 isolates were collected from all 32-week-exposed samples. Nine of the isolates could not be identified owing to only mycelial extension without sporophores. During the period of study, 14 genera were identified as imperfect fungi and ascomycetes, 1 genus as actinomycetes, and 3 genera as basidiomycetes. There was no significant difference in isolate number among the wood species: approximately 20 isolates for each (Table 4). *Aureobasidium* and *Cladosporium* were dominant among the samples of albizia, mahoni, nangka, and puspa, whereas *Aureobasidium* and *Penicillium* were dominant on the kapur samples. *Fusarium* was less dominant but was found on four wood species, whereas *Aspergillus* infected only kapur and puspa. *Paecilomyces* was identified only on mahoni. Although it is generally difficult to distinguish this genus from *Penicillium*, the isolate was easy identified as *Paecilomyces* from the extremely divergent spore chains. The puspa samples infested with basidiomycetes did not decay visually. The effects of coexisting actinomycetes and basidiomycetes were not investigated during this investigation. Because the mold genera were associated with the conditions of exposure and isolation, such as the medium, temperature, and humidity, this paper should be considered a case study of the tropical region. However, the dominant genera, *Aureobasidium*, is also found in European countries,[15–17] the United States,[18] and Japan.[19] This means that, in terms of the mold genera that settle on wood surfaces, there is no major difference between areas and climates when they are exposed to outdoor conditions.

Based on this experiment, it is clear that the wettability of the kapur and mahoni applied for exterior use was distinctly less than that of albizia and puspa after outdoor exposure. An increase in wettability is generally expected to create a condition in which wood decays easily. Mold growth also promotes decay from the viewpoint of maintaining water and nutritional conditions. Some decay damage to roof and exterior wall members composed of albizia are often observed in Indonesia. To extend the demand for the two latter wood species for exterior members, these woods must be protected from weathering by treating them, for example, by painting or finishing. Nangka showed a resistant potential against mold parasites at the initial stage of exposure and maintained low wettability even after 32 weeks of exposure. This suggests that a large amount of extractives contributes to the arrest of mold growth and to suppression of weathering.

Conclusions

There was no clear relation among wood properties, including chemical components, weathering conditions, and changes in the mold population on the wood surfaces exposed to outdoor condition, contrary to our expectation. However, an experiment to clarify the effect of weathering-induced deterioration on decay resistance of each wood species is in progress, as it is often observed that decay damage to the exterior wood of Indonesian houses is possibly accelerated by weathering.

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References

1. Soerianegara I, Lemmens RHMJ (1994) Plant resources of south-east Asia 5.1. Timber trees: major commercial timbers. Prosea, Jakarta, Indonesia
2. R&D Institute of Forestry (1987) Tumbuhan berguna Indonesia. II. Yayasan Sarana Wana Jaya, Jakarta, Indonesia. [Translated from Heyne K (ed.) De nuttige planten van Indonesie.]
3. Anonymous (1976) Vademecum Kehutanan Indonesia [Indonesian Forestry Handbook]. Departemen Pertanian, Directorat Jenderal Kehutanan, Jakarta, Indonesia
4. Dunningham EA, Plackett DV, Singh AP (1992) Weathering of chemically modified wood, natural weathering of acetylated radiata pine: preliminary results. Holz Roh Werk 50:429–432
5. JIS Z 8729(1994) Colour specification-CIE LAB and CIE LUV colour spaces
6. ASTM standards D 1110-84 (1981) (reapproved 1995) Standard test methods for water solubility of wood
7. Japan Wood Research Society (1985) Mokuzai-kagaku-jikken-sho [Hand book of wood science experimental], chemicals edition (in Japanese) Naigai-sangyou-chousakai, Tokyo, pp 145–161
8. Wissing A (1955) The utilisation of bark. II. Investigation of the stiasny reaction for the precipitation of polyphenols in pine bark extractives. Svensk Papperstidn 31:745–750
9. Horisawa S, Tamai Y, Sakuma Y, Doi S, Terazawa M (2000) Effect of moisture content of wood matrix on scale biodegradation system for organic of solid waste. J Wood Sci 46:317–321
10. Barnett HL, Hunter BB (1998) Illustrated genera of Imperfect fungi, 4th ed. American Phytopathological Society, Minnesota, USA
11. Ellis MB (1993) Dematiaceous, hyphomycetes: the Commonwealth Mycological Institute, Kew, Surrey, England
12. Fassatiova O (1986) Moulds and filamentous fungi in technical microbiology. Prog Ind Microbiol 22:233
13. Kalnis A (1984) Photochemical degradation of acetylated, methylated phenyl-hydrazine-modified, and ACC-treated wood. J Appl Polym Sci 29:105–115
14. Evans PD, Michell AJ, Schmalzl KJ (1992) Studies on the degradation and protection of wood surfaces. Wood Sci Technol 26:151–163
15. Sell J (1968) Investigations on the infestation of untreated and surface treated wood by blue stain fungi. Holz Roh Werk 26:215–222
16. Kuhne H, Leukens U, Sell J, Walchli O (1970) Investigations on weathered wood surfaces. Part I. Scanning electron microscope observation on mold fungi causing grey stain. Holz Roh Werk 28:223–229
17. Butin H (1991) Mykologishe untersuchungen an vergrauten Holzoberflachen im Gebirge. Holz Roh Werk 49:235–238
18. Schmidt EL, French DW (1976) *Aureobasidium pullulans* on wood shingles. For Prod J 26(7):34–37
19. Doi S, Horisawa S (2001) Fungi isolated from the surface of sugi (*Cryptomeria japonica*) heartwood lumbers exposed at six test site of Japanese islands. In: Imamura Y (ed.) High-performance utilization of wood for outdoor uses: report of the Grant-in-Aid for scientific research supported by the Ministry of Education, Science and Culture of Japan, pp 45–54