DECAY RESISTANCE AND CHANGES IN CHEMICAL COMPOSITION OF TWO FAST-GROWING TREE SPECIES *NEOLAMARKCIA CADAMBA* AND *OCHROMA PYRAMIDALE*

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In the present study, the decay resistance and the changes in the amounts of chemical components of wood as a consequence of decay by *Fomitopsis palustris* and *Trametes versicolor* were investigated for two tropical fast-growing tree species – *Neolamarckia cadamba* and *Ochroma pyramidale*. Decay tests were conducted according to Japanese Industrial Standards K1571: 2010. The amounts of the extractives, holocellulose and lignin were determined for wood specimens after 30, 60 and 90 days of incubation. *Neolamarckia cadamba* wood underwent higher mass loss when decayed by *F. palustris*, compared to *T. versicolor*, while *O. pyramidale* showed the opposite results. All of the main chemical components of the wood started to degrade on the 30th day of incubation, indicating that *N. cadamba* and *O. pyramidale* wood is vulnerable to attacks by both types of fungi. In addition, during the decay period, the patterns of degradation that the chemical components of wood exhibited differed from one species to another.

Keywords: decay resistance, fast-growing tree species, mass loss, extractives, holocellulose, lignin

INTRODUCTION

In recent years, local communities throughout the world have been paying close attention to fast-growing tree species, which promise profitable economic value due to their ability to produce wood in a shorter period of time, approximately two to three times faster than slow-growing tree species.[1] To increase the economic value of wood from these fast-growing tree species, basic wood properties should be clarified.

It is well known that wood properties are affected by chemical composition. During the service life of wooden end-use products, the chemical components of wood are often degraded by environmental factors, leading to fungal attack.[2,3] In addition, it has been cautioned that a fast-growing tree species produces a less durable wood, when compared with that of a slow-growing tree species. A realistic approach to wood degradation caused by fungal attack is important from a global perspective, especially when promoting extensive utilization of wood from fast-growing tropical tree species. Therefore, the present study is important for wood industries seeking to gain understanding of the natural durability of wood from fast-growing tree species against fungi and of the alteration of wood chemical components by fungal degradation.

Among the tropical fast-growing tree species, jabon (*Neolamarckia cadamba* (Roxb.) Bosser, a synonym of *Anthocephalus cadamba* (Rob.) Miq.) has been extensively planted in community forests and in commercial plantations in South and South East Asian countries.[4] Another fast-growing tree species, also extensively planted in Asia Pacific and South America, is balsa (*Ochroma pyramidale* (Cav.) Urban., a synonym of *O. lagopus* Swartz).[5] These two fast-growing tree species are widely planted in industrial plantations and community forests in Indonesia, and have become the main commercial species for

several wood industries. The basic wood properties of these species have been reported in our previous study.[6,7] According to the findings, the mean values of basic density, compressive strength parallel to grain, MOE and MOR for *N. cadamba* were 300 kg m^{-3}, 15.5 MPa, 5.94 GPa, and 67.9 MPa, respectively.[6] Furthermore, the mean values of basic density, compressive strength parallel to grain, MOE and MOR for *O. pyramidale* were established as 140 kg m^{-3}, 10.4 MPa, 4.65 GPa, and 23.4 MPa, respectively.[7] However, the available information about wood susceptibility to fungal decay and alteration of its chemical composition as a consequence of wood decay is still limited for these species.

The objective of the present study was to investigate the durability of *N. cadamba* and *O. pyramidale* wood against fungal decay and their suitability for establishing plantations of these fast-growing tree species for obtaining wood resources sustainably. Decay resistance of *N. cadamba* and *O. pyramidale* wood was evaluated using brown-rot (*Fomitopsis palustris*) and white-rot (*Trametes versicolor*) fungi. Furthermore, changes in the amounts of chemical components as a result of wood decay by these two fungi were also determined.

EXPERIMENTAL

Materials

Three *Neolamarckia cadamba* trees and nine *Ochroma pyramidale* trees were used for the experiments. The trees of both species were collected from Probolinggo, East Java, Indonesia. Table 1 shows data on the location of the sampling sites, as well as stem diameter and age of the trees used in the present study.

Logs were obtained from the trees from 0.2 to 1.2 m above the ground. Then, radially sawn boards (3 cm in thickness) were obtained from these logs. After drying, the boards were planed to 2 cm in thickness. For the decay test, the specimens of 2×2×1 cm (tangential × radial × longitudinal), without any defects, were prepared from the radially sawn boards. In total, there were 324 and 972 specimens for *N. cadamba* and *O. pyramidale*, respectively.

Decay test

The decay test was conducted according to Japanese Industrial Standards (JIS) K1571: 2010.[8,9] The specimens were dried at 60 ± 2 °C for 48 h and then weighed to determine initial weight. After measuring the initial weight, the specimens were sterilized with propylene oxide gas in a desiccator for 4 days. A brown-rot fungus (*Fomitopsis palustris*, FFPRI 0507) and a white-rot fungus (*Trametes versilolor*, FFPRI 1030), both provided by the Forestry and Forest Products Research Institute, Tsukuba, Japan, were used for the decay test. The fungi were pre-cultured on potato-dextrose-agar (PDA; Difco, Becton, Dickinson and Company, USA) medium in Petri dishes (9 cm in diameter) at 26 ± 1 °C for 14 days. As a growth medium for the decay test, 100 mL of the medium (4.0% glucose, 0.3% peptone, 1.5% malt extract, and 2.0% agar) was poured into polypropylene bottles (9.5 cm in diameter, 850 mL in volume). The bottles with the medium were then sterilized in an autoclave (HV-110, Hirayama, Japan) at 121 °C and 0.12 MPa for 20 min, then cooled. Then, the mycelial discs of each fungus were punched out from the pre-cultured PDA using a cork borer (7 mm in diameter) and inoculated into the center of the agar medium surface in the polypropylene bottles. The fungi were incubated at 26 ± 2 °C and 70% relative humidity (RH). After the mycelium grew enough for the test, three sterilized wood specimens were placed onto the surface of the medium in the bottles and then incubated in a dark room at 26 ± 2 °C with 70% RH. After 30, 60, and 90 days of incubation, the mycelia covering the wood blocks were removed carefully using a small tweezer. The decayed wood blocks were air-dried for 24 h and then dried in an oven at 60 ± 2 °C for 48 hours.

Table 1
Information on sample trees used in the present study

Information		Species	
		Neolamarckia cadamba	*Ochroma pyramidale*
Type of forests		Community forest	Industrial plantation
Sampling site	South latitude	7°53'	7°58'
	East longitude	113°28'	113°29'
	Altitude	ca. 830 m	ca. 1050 m
Number of trees		3	9
Mean stem diameter		14.8 cm	31.5 cm
Age of trees		4-year-old	7-year-old

Note: Stem diameter was determined at 1.3 m above the ground

The percentage of mass loss was calculated by the following formula:

Mass loss (%) = $(M_0 - M_1) / M_0$ x 100% (1)

where M_0 is initial wood mass before the decay test and M_1 is final wood mass after the decay test.

Chemical composition of wood

The content of extractives (ethanol-toluene and 1% NaOH extractives) and holocellulose were determined by the methods described by Japan Wood Research Society.[10] The amount of lignin was determined by the acetyl bromide method, according to Iiyama and Wallis.[11] Specimens were ground with a rotary speed mill (P-14, Fritsch, Germany) and sieved to obtain wood meal (size of about 0.18 to 0.42 mm). All measurements were carried out in triplicate. In addition, the chemical component contents of wood after decay were expressed as percentages of the original sound wood basis.

Statistical analysis

For the statistical analysis, R software (ver. 4.02)[12] was used. The Tukey HSD test was applied to detect significant differences of mass loss and chemical components of wood among different decay periods for each wood species and each fungus. Correlation coefficients between the measured properties were also determined for each fungus.

RESULTS AND DISCUSSION

Mass loss upon fungal decay

The mass loss data for the two wood species are shown in Table 2 during the wood decay caused by the fungi. Wood specimens of *N. cadamba* were completely covered with the mycelia of *F. palustris* and *T. versicolor* after 15 days of incubation. In *F. palustris*, the mass loss significantly increased with an increase in incubation time. Finally, the mass loss of *N. cadamba* wood was 45.0 ± 6.1% after 90 days of incubation. In *T. versicolor*, no significant differences of mass loss were found between the 30 and 60 day periods of incubation (Table 2). Finally, *N. cadamba* wood showed a mass loss of 35.2 ± 6.0% after 90 days of incubation of *T. versicolor*.

Table 2
Mass loss of *Neolamarckia cadamba* and *Ochroma pyramidale* wood decayed by *Fomitopsis palustris* and *Trametes versicolor*

Fungus	Degradation period (days)	*Neolamarckia cadamba*			*Ochroma pyramidale*		
		n	Mean	SD	*n*	Mean	SD
Fomitopsis palustris	30	54	5.1[a]	4.4	162	0.0[a]	0.1
	60	54	19.9[b]	8.6	162	3.4[a]	5.2
	90	54	45.0[c]	6.1	162	10.6[b]	7.6
Trametes versicolor	30	54	7.3[a]	2.3	162	1.9[a]	3.1
	60	54	14.4[a]	6.1	162	11.5[b]	6.7
	90	54	35.2[b]	6.0	162	39.1[c]	9.7

Note: *n*, number of specimens; SD, standard deviation. The same letter indicates no significant difference for each degradation period and each fungus by Tukey's HSD test at 5% level

Table 2 also shows the mass loss data of *O. pyramidale* decayed by *F. palustris* and *T. versicolor*. After 30 days of incubation, the wood mass did not decrease, indicating that the mycelia of both fungi might penetrate deeply into wood, but did not degrade the wood components. After 60 days of incubation, the mass loss of *O. pyramidale* significantly increased after decay by *T. versicolor* (Table 2). Finally, after 90 days of incubation, the mass loss of *O. pyramidale* wood decayed by *F. palustris* and *T. versicolor* was 10.6 ± 7.6 and 39.1 ± 9.7%, respectively. Yamamoto and Hong[13] reported the mass losses of 24 tropical hardwood species from Peninsular Malaysia, decayed by three white-rot fungi (*T. versicolor*, *Ganoderma lucidum* and *Pycnoporus coccineus*) and a brown-rot fungus (*F. palustris*), during 12 weeks. They established that greater mass loss in most of the timber species was observed in the wood blocks decayed by *F. palustris*. In the present study, *O. pyramidale* wood was more severely decayed by *T. versicolor*, compared to *F. palustris*. The results obtained for *O. pyramidale* were in contrast to those for *N. cadamba*: *F. palustris* caused more severe degradation in *N. cadamba* wood. The results for *N. cadamba* were similar to those reported by Yamamoto and Hong.[13] Based on the findings, it is considered that the decay resistance of the wood from tropical fast-growing trees differs among species, suggesting that decay resistance should be evaluated for each individual species.

Bhat and Florence[14] reported that the mean value of mass loss was approximately 21.4 ± 7.8% in the outer and inner heartwood of 5-year-old teak (*Tectona grandis*) decayed by *T. versicolor* for 8 weeks. Compared to young teak wood,[14] the wood of both fast-growing tree species used in the present study showed an almost similar performance, with up to 60 days of incubation by *T. versicolor*. Even in the wood from fast-growing tree species, therefore, some resistance exists, especially in the initial stage of decay.

Abnormal shrinkage and cubically shaped checking were observed in the *N. cadamba* and *O. pyramidale* wood specimens decayed by *F. palustris* after drying. These phenomena may be related to the degradation of holocellulose from the wood cell walls during decay. This is also true for *Eucalyptus grandis* wood, decayed by a brown-rot fungus (*Wolfiporia cocos*).[15] Ferraz *et al*.[15] reported that *W. cocos* preferred to degrade glucan and xylan (carbohydrates), without intensive degradation of lignin.

Chemical components

Table 3 shows the changes in the amounts of chemical components in *N. cadamba* wood decayed by *F. palustris* and *T. versicolor.* In the *N. cadamba* wood decayed by *F. palustris*, the amount of 1% NaOH extractives increased. Particularly, after 60 days of incubation, the 1% NaOH extractives content in the wood was significantly higher and was twice that of sound wood. The amount of ethanol-toluene extractives in the wood decayed by *F. palustris* showed almost the same or relatively higher values, compared to those of sound wood. In addition, the amount of holocellulose was also significantly lower with the increase in incubation time. On the other hand, no significant difference was observed in the lignin content before and during wood degradation by *F. palustris*. In *T. versicolor*, the amount of ethanol-toluene extractives was significantly decreased after 30 days of incubation, and both the amounts of 1% NaOH and lignin were significantly lower after 90 days of incubation. In addition, the amount of holocellulose also decreased, even in the initial stage of degradation. The ratio of the amounts of lignin to holocellulose was 0.32 for the sound wood (Table 3), while it gradually rose with the increase in incubation time for the wood decayed by *F. palustris*. On the other hand, this ratio was almost the same up to 90 days of incubation of *T. versicolor*.

Table 4 shows the changes in the amounts of chemical components of *O. pyramidale* wood decayed by *F. palustris* and *T. versicolor*. The amount of 1% NaOH extractives tended to increase in the wood decayed by *F. palustris*. The amount of ethanol-toluene extractives in the wood decayed by *F. palustris* showed an almost five times higher value than that of the sound wood. The values remained almost constant up to 90 days of incubation. Lignin and holocellulose slightly decreased after 60 days of incubation, indicating that *F. palustris* intensively degraded holocellulose at the same time after 60 days of incubation. The amounts of 1% NaOH extractives significantly increased after 30 days of incubation and remained almost constant during the 90 days of incubation with *T. versicolor*. The amounts of ethanol-toluene extractives also increased after 30 days of decay by *T. versicolor*, and they remained almost constant until the end of the degradation period. The increasing patterns in the amounts of ethanol-toluene extractives for the wood degraded by the white-rot fungus used in the present study were in accordance with those observed in a previous study on *Tectona grandis* wood decayed by several white-rot fungi.[16] Out of six white-rot fungi tested, four fungi led to increased values of ethanol-benzene extractives of *T. grandis* after decay for 20 days.[16] In addition, the lignin and holocellulose of *O. pyramidale* slightly decreased after 30 days. The ratio of lignin to holocellulose was 0.29 for *Ochroma pyramidale* sound wood (Table 4), and it was almost the same up to 90 days of incubation with *F. palustris* (0.29 - 0.30) and *T. versicolor* (0.26 - 0.28).

Table 3
Changes in amounts of chemical components of *Neolamarckia cadamba* wood upon degradation by *Fomitopsis palustris* and *Trametes versicolor*

Fungus	Degradation period (days)	Chemical components (%)								L/H ratio
		1% NaOH extractives		Ethanol-toluene extractives		Lignin		Holocellulose		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	0	23.7[a]	2.4	4.4[a]	1.0	25.4[a]	2.5	79.7[a]	2.8	0.32
Fomitopsis palustris	30	32.5[ab]	6.5	6.5[b]	1.4	24.4[a]	2.1	68.1[b]	2.7	0.36
	60	45.8[cd]	6.9	4.5[ab]	1.8	24.5[a]	5.6	52.4[c]	7.7	0.47
	90	39.0[bc]	4.9	4.9[ab]	0.6	23.4[a]	4.2	34.0[d]	8.4	0.69
Trametes versicolor	30	21.8[a]	1.6	2.8[b]	1.0	25.8[a]	1.5	65.1[b]	5.3	0.40
	60	20.9[a]	2.7	2.3[b]	0.5	23.1[a]	3.4	56.0[b]	9.7	0.41
	90	15.8[b]	2.4	2.9[b]	0.9	16.9[b]	1.8	45.9[c]	4.6	0.37

Note: SD, standard deviation. The same letter indicates no significant difference between rows in the column by Tukey's HSD test at 5% level for each fungal treatment. Chemical component contents (%) after decay are expressed as percentages of the original sound wood basis. Ratio L/H, ratio of lignin to holocellulose. Number of replications = 3

Table 4
Changes in amounts of chemical components of *Ochroma pyramidale* wood upon degradation by *Fomitopsis palustris* and *Trametes versicolor*

Fungus	Degradation period (days)	Chemical components (%)								L/H ratio
		1% NaOH extractives		Ethanol-toluene extractives		Lignin		Holocellulose		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	0	19.1[a]	1.1	1.6[a]	0.4	23.0[a]	1.8	79.3[a]	1.0	0.29
Fomitopsis palustris	30	24.7[b]	3.0	6.0[b]	2.9	23.0[a]	1.8	77.3[a]	3.0	0.30
	60	22.3[ab]	3.4	5.2[b]	2.4	22.3[ab]	6.0	75.5[a]	4.9	0.30
	90	25.1[b]	6.0	5.9[b]	2.8	18.9[b]	3.2	65.2[b]	6.8	0.29
Trametes versicolor	30	23.1[ab]	5.2	3.4[b]	1.4	20.9[ab]	5.9	75.7[ab]	4.5	0.28
	60	25.9[b]	2.9	3.0[b]	0.7	17.3[b]	2.5	66.9[bc]	7.0	0.26
	90	21.5[ab]	5.5	3.5[b]	0.6	12.6[c]	3.8	47.3[c]	13.0	0.27

Note: SD, standard deviation. The same letter indicates no significant difference between rows in the column by Tukey's HSD test at 5% level for each fungal treatment. Chemical component contents (%) after decay are expressed as percentages of the original sound wood basis. Ratio L/H, ratio of lignin to holocellulose. Number of replications = 3

In *N. cadamba*, *F. palustris* mainly degraded holocellulose, without extensive degradation of lignin. In addition, both holocellulose and lignin were simultaneously degraded by *T. versicolor*, although the degradation speed of lignin by *T. versicolor* was slower than that of holocellulose. For *O. pyramidale*, *F. palustris* intensively degraded holocellulose and lignin at the same time after 60 days of incubation. On the other hand, *T. versicolor* gradually degraded holocellulose and lignin during the incubation period. The results indicate that the rapid degradation of chemical components in *O. pyramidale* wood is caused by *T. versicolor*, compared to that by *F. palustris*. Based on the results obtained in the present study, it is considered that the degradation pattern of wood components differed between the tree species, although the fungi used were the same. In addition, the results described above also indicate that the wood of the fast-growing tree species *N. cadamba* and *O. pyramidale* was vulnerable to the attack of both types of fungi. Therefore, when *N. cadamba* and *O. pyramidale* wood is considered for use by the wood industries, the wood condition should be taken into account prior to processing, as there is a possibility of fungal attack that would affect the wood properties.

General relationship between mass loss and chemical composition of wood

Figures 1 and 2 show the relationships between mass loss and chemical composition of wood decayed by *F. palustris* and *T. versicolor*. For the analysis, the data for the two tree species were combined.

In *F. palustris*, mass loss negatively correlated with the amounts of holocellulose (r = –0.984) and positively correlated with the ratio of the amounts of lignin to holocellulose (r = 0.961). A significant positive correlation was found between mass loss and the amounts of 1% NaOH extractives (r = 0.732), indicating that substances that could be solved in alkaline solution were increased with progressing wood decay. Under the action of the brown-rot fungus, cellulose and hemicelluloses are broken down in the wood substrate, while lignin remains preserved in a slightly modified form.[17]

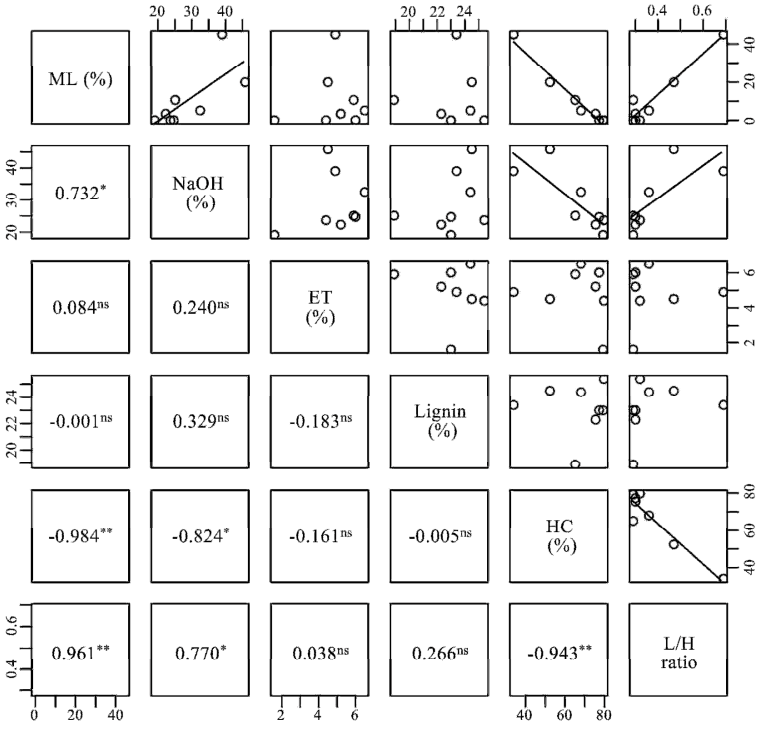

Figure 1: Relationships between mass loss and amounts of chemical components in *Neolamackia cadamba* and *Ochroma pryamodale* wood decayed by *Fomitopsis palustris* (Note: ML, mass loss; NaOH, 1% NaOH extractives; ET, ethanol-toluene extractives; HC, holocellulose; L/H ratio, lignin/holocellulose ratio; *significance at 5% level; **significance at 1% level; ns, no significance. Values on lower diagonal indicate correlation coefficients)

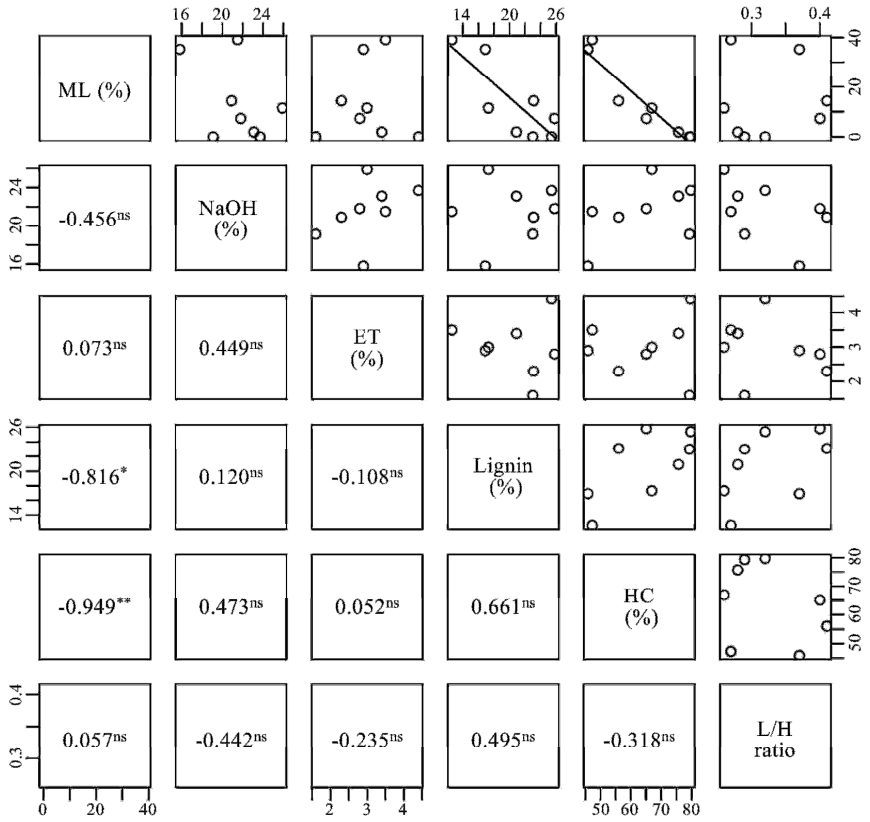

Figure 2: Relationships between mass loss and amounts of chemical components in *Neolamackia cadamba* and *Ochroma pryamodale* wood decayed by *Trametes versicolor* (Note: ML, mass loss; NaOH, 1% NaOH extractives; ET, ethanol-toluene extractives; HC, holocellulose; L/H ratio, lignin/holocellulose ratio; *significance at 5% level; **significance at 1% level; ns, no significance. Values on lower diagonal indicate correlation coefficients)

Kawase[18] also reported that the increments of alkali soluble matter in decayed wood consisted mainly of degraded cellulose and lignin. Our results obtained in the present study for the brown-rot fungus *F. palustris* are similar to those reported by previous researchers.[17,18] In addition, a significant negative correlation was found between the amounts of holocellulose and the amounts of 1% NaOH extractives (r = 0.824). Hillis[19] reported that a small amount of alkali was required to dissolve water-soluble carbohydrates and their derivatives, as well as polymerized polyphenols. Therefore, the tendency observed in the present study might be related to an increased number of small fragments produced from cellulose and hemicelluloses.[20,21]

The white-rot fungus can simultaneously degrade hemicelluloses and lignin.[15,22,23] Ferraz *et al*.[15] reported that *T. versicolor* degraded both carbohydrates and lignin in *E. grandis* wood, even at the beginning of the biodegradation period. In addition, Daniel[23] also reported that white-rot fungi can produce a number of endoglucanases, exoglucanases (a synonym of cellobiohydrolases), and β-glucosidases for breaking down cellulose. For example, *T. versicolor* is known to produce cellobiose dehydrogenase (CDH) for oxidizing products produced through the hydrolytic activities of cellulases and other hydrolytic enzymes.[23] In the present study, as shown in Figure 2, significant negative correlations were found between mass loss by *T. versicolor* and the amounts of lignin (r = –0.816) or holocellulose (r = –0.949).

CONCLUSION

Wood mass loss upon degradation by *F. palustris* and *T. versicolor* was investigated for two fast-growing tree species: *N. cadamba* and *O. pyramidale*. Furthermore, the changes in wood chemical components were also determined. *N. cadamba* wood showed higher mass loss when decayed by *F. palustris*, as compared to *T. versicolor*. Holocellulose started to degrade after

30 days of incubation in the wood decayed by both *F. palustris* and *T. versicolor*. The ratio of lignin to holocellulose rose with an increase in the incubation time of the wood blocks of both species decayed by *F. palustris* and *T. versicolor*. On the other hand, *O. pyramidale* wood showed higher mass loss when decayed by *T. versicolor*, compared to that decayed by *F. palustris*. Holocellulose and lignin were degraded simultaneously by *T. versicolor* during the first 30 days of incubation. However, *F. palustris* degraded holocellulose after 60 days of incubation. Thus, the degradation period and pattern differs from species to species.

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