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A Laboratory Method for Predicting the Durability of Tropical Hardwoods

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Abstract
The possibility of predicting the resistance of tropical hardwoods to fungal decay was studied. A multiple regression equation for predicting the natural durability of tropical timbers was proposed. The weight loss of 24 commercially popular Malaysian hardwoods was obtained by a modified ASTM D2017 soil block method using 3 white-rot fungi, *Coriolus versicolor, Ganoderma lucidum, Pycnoporus coccineus*, and a *brown-rot fungus, Tyromyces palustris*. The percentage of weight loss induced by *T.* palustris was selected as a criterion variable (Y). Various properties of the woods which could affect the durability of timbers, such as extractives content, lignin content, pH, density, water absorption capacity, and morphological characteristics were analyzed. The factors selected as independent variables based on the significance of coefficients for the weight loss induced by *T. palustris* were the density (X1), water absorption capacity (X2), methanol extractives content (X3), and pH (X4). The weight loss calculated by the equation was the lowest in Chengal (*Neobalanocarpus heimii*). The regression equation obtained was Y = 18.546 – 37.028 (X1) + 0.016 (X2) – 1.056 (X3) + 8.056 (X4). The durability of the timbers estimated by the equation matched the natural durability obtained from field stake tests with minor differences.

Discipline: Forestry and forest products
Additional key words: decay fungus, extractives, natural durability

Introduction

Natural durability is one of the important factors to analyze the nature of wood. The durability of timbers is determined based on data obtained through field trials over a certain period of time. Very often these trials involve long-term exposure of the timbers to biodegrading organisms in the field. Such field tests give good estimates of the natural durability because the timbers are exposed to both types of biodegrading fauna and flora, i.e. insects and fungi, but it takes a long time before meaningful data can be obtained.

Although laboratory methods have been used for studies on the resistance of timbers to both fungal and insect attacks, they also require a long period of time and technical skill for dealing with fungi and insects. Therefore simple and rapid laboratory methods to predict the natural durability of tropical timber species should be developed[5]. The decay resistance of wood has been shown to be associated with the amount of extractives[6,15,20,24], the type of lignin[8,10,16], lignin content[19], density[13,17,20], capillary water uptake[7], and wood anatomy[19,22,23]. In order to study the possibility of predicting the resistance of tropical hardwoods to fungal decay without using fungi, various chemical and physical properties of the 24 timber species related to the durability, i.e. the amount of extractives, lignin content, pH, density, water absorption capacity, and morphological characteristics were determined. A multiple regression equation for predicting the natural durability was proposed by using several factors as independent variables.

Materials and methods

The 24 tropical timber species used in this study and shown in Table 1 were selected from the list of "Commercial timbers of Peninsular Malaysia"[1]. A modified version of the ASTM D2017 testing procedure for decay[2] was applied to evaluate the resistance of the timbers to the decay induced by 3 white-rot fungi, *Coriolus versicolor* (strain FFPRI 1030), *Ganoderma lucidum* (FFPRI Gl1), *Pycnoporus coccineus* (FFPRI Ps1h), and a brown-rot fungus, *Tyromyces palustris* (FFPRI 0507). Six wood blocks/timber/fungus, 2.0 by 2.0 by 0.5 cm, were subjected to the fungal decay test. The percentage of weight loss of each timber species obtained by the test during 12 weeks of incubation with the fungi was compared to the following characteristics to derive a multiple regression equation for the estimation of natural durability. Various characteristics of the timber species, namely cold water extractives content (JIS P8004-1976)[12], hot water

Table 1. Average weight loss percentage of 24 timber species subjected to decay by 4 fungi for 12 weeks

Trade name	Scientific name	*Coriolus versicolor*	*Tyromyces palustris*	*Pycnoporus coccineus*	*Ganoderma lucidum*
Balau	*Shorea* sp.	0.5	3.2	1.2	0.7
Chengal	*Neobalanocarpus heimii*	0.4	0.0	1.3	0.0
Giam	*Hopea* sp.	1.3	1.3	1.9	0.8
Keranji	*Dialium* sp.	2.4	2.9	3.3	3.1
Merbau	*Intsia palembanica*	3.4	0.2	3.5	1.3
Resak	*Vatica* sp.	1.3	7.6	1.6	1.4
Kapur	*Dryobalanops aromatica*	5.9	4.4	1.9	1.7
Kempas	*Koompassia malaccensis*	11.9	19.5	4.6	6.7
Keruing	*Dipterocarpus* sp.	10.5	45.1	5.3	5.1
Mata ulat	*Kokoona* sp.	25.5	39.0	11.4	7.2
Punah	*Tetramerista glabra*	26.1	46.0	15.3	12.0
Rengas	Anacardiaceae	3.4	2.8	3.5	3.3
Bintangor	*Calophyllum* sp.	31.0	27.8	16.3	3.1
Durian	*Durio* sp.	22.8	47.7	6.2	1.1
Jelutong	*Dyera costulata*	30.5	54.3	30.3	20.5
Meranti bakau	*Shorea* rugosa	16.7	37.2	9.5	7.7
Meranti, dark red	*Shorea* sp.	19.5	37.1	3.5	9.2
Meranti, white	*Shorea* sp.	42.2	46.9	9.4	1.9
Meranti, yellow	*Shorea* sp.	27.5	44.7	25.7	17.9
Merawan	*Hopea* sp.	3.1	3.7	0.5	1.0
Mersawa	*Anisoptera* sp.	16.8	44.0	15.0	16.3
Perupok	*Lophopetalum* sp.	53.7	48.7	25.1	35.7
Ramin	*Gonystylus* sp.	37.3	57.4	33.2	32.4
Rubberwood	*Hevea brasiliensis*	42.5	58.6	49.4	54.3

Table 2. Determination of various parameters in 24 timber species

Trade name	Scientific name	Density	Water absorption	Cold water extractives	Hot water extractives	EtOH-ben. extractives	Methanol extractives	pH	Lignin	Ratio of fibers	Ratio of parenchyma	Ratio of vessels	Fiber cell wall ratio
Balau	*Shorea* sp.	1.03	57	5.1	7.4	11.5	11.4	4.95	36.0	49.0	26.6	24.4	96.7
Chengal	*Neobalanocarpus heimii*	0.95	64	20.8	23.0	30.6	32.6	4.93	23.1	18.7	37.5	44.1	96.4
Giam	*Hopea* sp.	1.04	60	12.8	16.8	18.6	22.3	5.35	30.7	53.9	23.7	22.4	97.4
Keranji	*Dialium* sp.	1.32	83	3.4	5.6	5.7	6.3	5.88	34.2	69.1	22.3	8.6	98.5
Merbau	*Intsia palembanica*	0.88	177	13.9	16.5	8.5	19.1	5.49	35.7	38.8	36.0	25.2	68.6
Resak	*Vatica* sp.	1.02	96	5.5	9.0	16.0	16.5	4.60	28.6	35.5	38.3	26.2	95.3
Kapur	*Dryobalanops aromatica*	0.78	239	2.9	5.5	3.4	6.7	4.70	31.4	31.0	39.8	28.5	89.4
Kempas	*Koompassia malaccensis*	1.03	153	0.4	2.2	2.9	3.7	5.49	35.0	78.5	27.5	4.2	97.7
Keruing	*Dipterocarpus* sp.	0.98	133	0.9	2.2	4.2	4.0	5.63	30.5	52.2	20.5	27.6	98.2
Mata ulat	*Kokoona* sp.	0.99	145	0.4	1.9	4.2	4.2	6.37	30.5	56.0	24.1	20.0	96.9
Punah	*Tetramerista glabra*	0.75	1408	5.2	6.1	2.7	7.8	5.72	32.2	31.1	43.3	25.6	94.5
Rengas	Anacardiaceae	0.91	90	6.9	13.7	8.6	20.6	4.64	38.7	77.3	16.0	6.8	80.6
Bintangor	*Calophyllum* sp.	0.65	301	0.7	2.3	4.3	3.8	5.56	33.9	75.1	12.9	12.0	70.8
Durian	*Durio* sp.	0.76	230	1.2	2.1	6.4	4.8	5.97	39.4	62.9	25.3	11.8	59.1
Jelutong	*Dyera costulata*	0.44	486	2.0	3.8	4.8	5.8	5.39	29.5	76.0	17.2	6.8	44.5
Meranti bakau	*Shorea rugosa*	0.79	204	1.6	3.3	4.4	4.6	5.54	31.8	50.7	18.3	30.7	88.0
Meranti, dark red	*Shorea* sp.	0.61	191	0.8	2.1	3.9	4.9	4.82	35.0	77.5	15.9	7.1	64.6
Meranti, white	*Shorea* sp.	0.62	226	1.5	2.8	3.8	3.8	5.24	35.9	64.2	16.8	19.0	54.5
Meranti, yellow	*Shorea* sp.	0.59	258	2.4	3.8	6.1	8.3	5.40	29.4	51.2	24.2	24.6	69.2
Merawan	*Hopea* sp.	0.65	45	4.3	7.2	7.6	9.3	6.15	30.8	60.3	11.9	27.8	53.7
Mersawa	*Anisoptera* sp.	0.64	150	1.5	2.3	5.4	5.5	6.24	31.7	38.9	39.4	22.4	89.5
Perupok	*Lophopetalum* sp.	0.52	410	0.6	2.3	2.9	3.2	6.15	30.6	67.2	14.4	18.4	55.1
Ramin	*Gonystylus* sp.	0.70	929	1.9	2.8	3.1	3.1	6.52	27.8	78.1	18.0	4.1	64.3
Rubber-wood	*Hevea brasiliensis*	0.71	571	2.7	4.6	3.6	5.5	6.83	25.9	57.8	34.0	8.2	64.0

extractives content (JIS P8005-1976)[12], ethanol-benzene extractives content (JIS P8010-1976)[12], methanol extractives content, Klason lignin content (TAPPI standards T13wd-74)[18], pH value (wood to water ratio of 1:10)[21], density, water absorption capacity (JIS Z2104-1957)[12], proportion of wood elements, and ratio of cell-wall area of wood fiber were determined for each of the 24 timber species. The measurements of the wood element proportion and the fiber cell-wall area were carried out on cross-sections in 15 μm thick.

The natural durability of tropical timber species has been examined by field stake tests in different environments[1,3,4,11,13,14]. The estimated natural durability was compared to the durability classification obtained in the field tests.

Results and discussion

The average percentage of weight loss of the 24 timber species subjected to decay induced by *T. palustris, C. versicolor, P. coccineus*, and *G. lucidum* is given in Table 1. The value of weight loss was greater in most of the timber species degraded by *T. palustris* compared with the other fungi. Various characteristics measured such as cold water extractives content (%), hot water extractives content (%), ethanol-benzene extractives content (%), methanol extractives content (%), Klason lignin content (%), pH value, density (g/cm^3), water absorption capacity for one day (mg/cm^2), proportion of fibers (%), proportion of parenchyma cells (%), proportion of vessels (%), and ratio of cell-wall area of wood fiber (%) are indicated in Table 2. The correlation coefficients between the percentage of weight loss and the various parameters were generally higher in the samples subjected to decay by *T. palustris* than in those by the other 3 fungi (Table 3). Therefore, the percentage of weight loss induced by *T. palustris* was selected as a criterion variable (Y). Table 3 shows that there was a significant correlation between the values of the parameters such as density, water absorption, contents of ethanol-benzene extractives and methanol extractives, pH, and fiber cell-wall area and the weight loss for all 4 fungi. Among the 4 kinds of extractives content, methanol extractives content was an important factor for every fungus used. Decay resistance in tropical hardwood timbers appeared to be mainly

Table 3. Correlation coefficients between weight loss percentage induced by 4 decay fungi and various parameters

Parameters	Weight loss (%)			
	Tyromyces palustris	*Coriolus versicolor*	*Pycnoporus coccineus*	*Ganoderma lucidum*
Density	-0.626**	-0.683**	-0.551**	-0.465**
Water absorption	0.562**	0.541**	0.579**	0.517**
Cold water extractives	-0.623**	-0.538**	-0.341	-0.315
Hot water extractives	-0.623**	-0.594**	-0.383*	-0.315
Ethanol-benzene extractives	-0.589**	-0.557**	-0.399*	-0.375*
Methanol extractives	-0.685**	-0.615**	-0.410*	-0.375*
pH	0.562**	0.535**	0.615**	0.626**
Lignin content (%)	-0.157	-0.136	-0.433	-0.452*
Percentage of fibers	0.304	0.389*	0.263	0.236
Percentage of parenchyma	-0.181	-0.295	-0.069	-0.023
Percentage of vessels	-0.351	-0.391*	-0.400*	-0.383*
Ratio of fiber cell wall	-0.461*	-0.610**	-0.484**	-0.407*

* Significant at 5% level, ** Significant at 1% level.

Table 4. Corelation matrix among the characteristics of timbers

	Density	Water ab.	Cold w. ext.	Hot w. ext.	Et-ben. ext.	Metha. ext.
Density	——					
Water ab.	−0.372	——				
Cold w. ext.	0.343	−0.176	——			
Hot w. ext.	0.382	−0.244	0.979	——		
Et-ben. ext.	0.384	−0.383	0.864	0.850	——	
Metha. ext.	0.375	−0.303	0.949	0.978	0.905	——
pH	−0.194	0.360	−0.344	−0.415	−0.419	−0.489
Lignin	0.109	−0.198	−0.274	−0.201	−0.365	−0.211
Fibers	−0.199	−0.004	−0.555	−0.480	−0.509	−0.492
Parenchyma	0.264	0.204	0.393	0.328	0.291	0.334
Vessels	0.130	−0.204	0.532	0.468	0.556	0.485
Fiber wall	0.802	−0.192	0.267	0.274	0.346	0.310

	pH	Lignin	Fibers	Parenchyma	Vessels	Fiber wall
Density						
Water ab.						
Cold w. ext.						
Hot w. ext.						
Et-ben. ext.						
Metha. ext.						
pH	——					
Lignin	−0.241	——				
Fibers	0.213	0.390	——			
Parenchyma	−0.104	−0.257	−0.802	——		
Vessels	−0.261	−0.381	−0.867	0.417	——	
Fiber wall	−0.255	−0.081	−0.470	0.495	0.371	——

due to the presence of polyphenolic compounds which are soluble in methanol. The wood element proportion was not outstandingly important. Lignin content was not closely associated with decay resistance. The type of lignin is a factor more important in the slower degradation of woods than is the lignin content, or the anatomical structure itself[10]. The factors selected as independent variables based on the significance of the coefficients for weight loss and multicollinearity were the density (X1), water absorption capacity (X2), methanol extractives contents (X3), and pH (X4). Although the ratio of the cell-wall area of fiber showed a highly significant correlation coefficient, it was not used because it was not a independent variable. Table 4 shows the correlation matrix among the factors studied. The fiber cell-wall area ratio showed a high correlation coefficient with the density.

Multiple regression analysis enabled to derive the following regression equation for predicting natural durability:

$$Y = 18.546 - 37.028\,(X1) + 0.016\,(X2) - 1.056\,(X3) + 8.056\,(X4)$$

where Y; estimated percentage of weight loss induced by *Tyromyces palustris*, X1; density, X2; water absorption, X3; methanol extractives contents, X4; pH. The partial correlation coefficients of X1, X2, X3 and X4 were -0.522^{**}, 0.374^{*}, -0.509^{**} and 0.348, respectively. A multiple correlation coefficient of 0.86 and coefficient of determination of 0.74 were obtained for the regressors, X1, X2, X3, X4, indicating that these 4 factors, X1, X2, X3, X4 accounted for 74% of the variation in weight loss as a measure of resistance.

The measured value of resistance of 24 timber species indicated by the weight loss values obtained in the laboratory decay test and the estimated values obtained by the equation are shown in Table 5. These 2 sets of values showed small differences except for Merawan, Keruing and Kapur. Merawan showed a surprisingly large difference between the measured and calculated values. Hence the measured durability of Merawan was classified as very high, and the estimated one as moderate. Merawan was classified into a durable group, but in which the durability was reduced after extraction, according to the cluster analysis using the weight loss of the unextracted and extracted wood blocks[21].

Table 5. Measured and calculated weight loss values of 24 timber species used

Trade name	Measured value	Calculated value	Error
Balau	3.2	9.0	5.8
Chengal	0.0	−10.4	10.4
Giam	1.3	0.4	0.9
Keranji	2.9	11.6	8.7
Merbau	0.2	12.8	12.6
Resak	7.6	1.8	5.8
Kapur	4.4	24.2	19.8
Kempas	19.5	23.1	3.6
Keruing	45.1	25.4	19.7
Mata ulat	39.0	31.0	8.0
Punah	46.0	51.5	5.5
Rengas	2.8	1.8	1.0
Bintangor	27.8	40.0	12.2
Durian	47.7	37.0	10.7
Jelutong	54.3	47.4	6.9
Meranti bakau	37.2	32.2	5.0
Meranti, dark red	37.1	32.6	4.5
Meranti, white	46.9	37.3	9.6
Meranti, yellow	44.7	35.5	9.2
Merawan	3.7	34.8	31.1
Mersawa	44.0	41.6	2.4
Perupok	48.7	52.0	3.3
Ramin	57.4	56.9	2.5
Rubberwood	58.6	50.6	8.0

The estimated values from the regression equation were used for determining the natural durability classification. Timber species are usually grouped into 5 classes in terms of their durability[9]. The natural durability is grouped into 4 classes in Malaysia[1,11,14], and 5 classes in USA[4], England[3], and Japan[13]. The service life in the classification is also quite different depending on the exposure tests carried out in different environments. The service life in the highly durable class exceeds 10 years in Malaysia[1], 9 years in Japan[13], and 25 years in USA[4] and England[3]. In this experiment, a timber with less than 5% of estimated weight loss was classified as highly durable (code 1); 5–15% weight loss as durable (code 2); 15–35% weight loss as moderately durable (code 3); 35–45% weight loss as nondurable (code 4); and over 45% weight loss as perishable (code 5). The estimated durability classification thus obtained matched the classification obtained from field stake tests with minor differences (Table 6). Therefore the regression equation could be used to estimate the durability of a timber species whose resistance to decay is not known yet and where such data are required before field exposure tests are completed.

The natural durability of tropical timber species determined by field stake tests carried out in different countries is markedly different in some timbers such as Balau[1,3,4,11,13,14] (Table 6). It is generally recognized that there is a considerable variation in durability between different samples of the same species, and some samples of certain timber species fall into a class above or below that in which they are normally classified[9]. Balau which is classified as highly durable in Malaysia[1] and Japan[13] is classified as nondurable in USA[4]. This discrepancy is due to the fact that in these stake tests different species in a group are utilized and each species displays its own natural durability. It is important to assess the natural durability of each timber species using the

Table 6. Comparison of natural durability classification of 24 timber species

Trade name	Natural durability classification						
	Malaysia			USA[4]	England[3]	Japan[13]	This report
	A[1]	B[11]	C[14]				
Balau	1	3	2	(4)	–	1	2
Chengal	2	2	1	1	1	–	1
Giam	1	1	1	–	1	1	1
Karanji	3	3	3	3	3	–	2
Merbau	2	2	2	3	2	1	2
Resak	1	1	–	1 – 2	1 – 3	1	1
Kapur	2	4	3	3	1	3	3
Kempas	4	4	3	3	2	3	3
Keruing	3	4	3	3	3	3	3
Mata ulat	3	–	–	–	–	–	3
Punah	3	3	3	3 – 4	3	–	5
Rengas	3	3	–	3	2 – 3	2	1
Bintangor	3	4	3 – 4	4	3	4	4
Durian	4	4	4	4	4	–	4
Jelutong	4	4	–	5	4	5	5
Meranti bakau	3	3	–	–	–	–	3
Meranti, dark red	3	4	3	3	2	3	3
Meranti, white	4	3	3	4	3	2	4
Meranti, yellow	4	4	4	4	3	3	4
Merawan	3	3	–	2	2	–	3
Mersawa	3	2	–	3	3	4	4
Perupok	3	3	4	5	4	–	5
Ramin	4	4	4	5	4	5	5
Rubberwood	4	–	–	5	5	5	5

laboratory method proposed.

Conclusion

The regression equation obtained in this study could be used to estimate the durability of a timber species whose resistance to decay is not known yet and where such data are required before field exposure tests are completed. The regression equation could be further improved by using additional data from a large number of timber species.

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