The Influence of Log Felling Season on the Extent of Discoloration in Rubberwood Sawn Timber during the Kiln Drying Process

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This study investigated the effects of felling season on the discoloration of rubberwood sawn timber during conventional kiln drying. The samples were collected throughout the year 2015 to monitor the variation of free sugars and starch content in the rubberwood logs. Two batches of logs, one from the rainy season and the other from the dry season, were felled and sawn for experimentation. The findings showed that discoloration was more prominent in sawn timber obtained from logs felled during the dry season. The amount of free sugars and starch in the logs had a strong influence on the extent of discoloration in the rubberwood sawn timber during the kiln drying process. A higher amount of free sugars and starch in the logs felled during the dry season increased the incidence of blue stain on these logs. The results of this study conclusively showed that discoloration in rubberwood can be minimized by the choice of log felling season and the use of an appropriate drying technique, which will inevitably improve the aesthetic appeal of the wood.

Keywords: Felling season; Rubberwood; Discoloration; Free sugars; Starch; Blue stain; Kiln drying

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INTRODUCTION

Rubberwood (*Hevea brasiliensis*) has emerged as the most important raw material for the value-added wood products industry in Southeast Asia. The large acreage of rubber plantation, particularly in Malaysia, Indonesia, and Thailand, has aided the rapid growth of the value-added wood products industry in this region. Shigematsu *et al.* (2011) explained that with more than 80% of the total rubber plantation area in Asia, these countries dominate almost 70% of the rubber production in the world. Rubberwood's pale-yellowish color, good machining, gluing, and finishing properties, as well as its environmentally friendly status have contributed to the extensive use of the material in furniture manufacturing (Ratnasingam and Grohmann 2014). In fact, rubberwood furniture export makes up 80% of the total furniture export from Malaysia and Thailand.

The most important phase in the rubberwood processing chain is the conversion of the logs into sawn timber and the subsequent drying process. Although the removal of water from wood improves its dimensional stability, workability, mechanical properties, and resistance to biotic agents, the discoloration of the wood during drying diminishes the aesthetic value of the wood. Discoloration as a result of drying is one of the major challenges in the wood processing industry (Terziev and Boutelje 1998; Mononen *et al.* 2002; Stenudd 2004; Klement and Marko 2009; Ratnasingam and Grohmann 2014).

Luostannen and Möttönen (2009) stated that log felling season and log storage influence the discoloration of wood during the drying process. The factors that are thought to influence wood discoloration have been explored in several studies (Mononen *et al.* 2002; Koch 2008; Klement and Marko 2009). The time for log felling and log storage influences wood color changes; however, the underlying cause is not well understood. It is a widely held view that microbial and non-microbial factors trigger discoloration. Microbial discoloration is normally attributed to microorganisms, namely fungi, mold, and bacteria. Meanwhile, non-microbial discoloration may be due to an oxidative reaction, enzymatic process, hydrolytic reaction, and extractives (Sandoval-Torres *et al*. 2010).

In the case of rubberwood logs, Ratnasingam and Grohmann (2014) pointed out that freshly cut rubber logs contain about 1.5% to 2.5% of total free sugars and up to 10% starch along the height and diameter of the tree. Consequently, the high content of carbohydrates such as sugar and starch, deposited in the parenchyma in the wood, makes it prone to attack by staining fungi within one day of felling. Among types of discoloration, the blue stain caused by fungi is the most common in rubberwood. Blue stain normally occurs in freshly felled logs or green sawn timber (Teoh *et al.* 2011). Humar *et al.* (2008) emphasized that the strength properties of wood are almost not affected, as the growth of fungal hyphae does not attack the internal cell wall of the wood.

The discoloration of rubberwood poses a challenge to the use of the wood in the manufacture of value-added wood products, particularly furniture. The loss in aesthetic appeal of the wood due to the non-uniformity of color has far-reaching implications on operational costs and product quality. Therefore, the objective of this study was to investigate the effect of felling season and drying activities on the extent of discoloration of rubberwood. The study also focused on discoloration due to blue stain and the chemical contents in green and kiln-dried sawn rubberwood timber.

EXPERIMENTAL

Materials

Rubberwood logs were felled from a local plantation in Peninsular Malaysia. The felling of logs was carried out every month throughout 2015. The rubberwood logs used in this study were divided into two batches; one batch was obtained immediately after the rainy season, while the other was harvested during the dry season. The dry season in Malaysia occurs between April and September, while the wet, rainy season is between January and March and between October and December. The rubberwood logs were sawn immediately in a commercial sawmill as soon as they arrived at the mill. The flat-sawn experimental boards were free from defects and were 25 × 100 × 1000 mm in dimensions. Fifteen specimens of rubberwood sawn timber were used in this study to assess the difference in discoloration between logs felled during the wet and dry seasons. The average moisture contents of the freshly felled logs were determined, which were 85% and 65% for logs obtained from the wet and dry seasons, respectively.

Methods

The study investigated the chemical contents, occurrence of blue stain, and discoloration in rubberwood logs and sawn timber from wood obtained during the wet and dry seasons for comparative purposes.

Assessment of chemical content

The hot-water-soluble extractive contents in the samples were established using TAPPI standard T-207 (TAPPI 1999), which provided the average contents of total free sugars and starch contents for comparative purposes.

Assessment of blue stain

The logs were assessed for any blue stain fungi growth, and the images of the rubberwood logs were captured using a digital color camera (Samsung WB350F, South Korea). The images were converted into a high-contrast greyscale and binary image to calculate the percentage of discoloration (Schubert *et al.* 2011).

Assessment of color development in rubberwood boards

The edge-matched specimens were treated with boric acid anti-sap-stain preservative, wrapped in plastic, and stored at 5 °C until kiln drying was carried out. The different batches of specimens were separately dried to a final moisture content of 10 ± 2% using the standard industrial kiln drying schedule for rubberwood shown in Table 1. The drying process was carried out in a laboratory kiln dryer with a constant air velocity of 1.5 m/s throughout the drying process to reflect industrial kiln drying conditions (Ratnasingam *et al.* 2010). The time taken to achieve the final desired moisture content was recorded. Each batch of the experimental samples consisted of 15 specimens. The kiln charge was dried for up to 12 days until a final average moisture content of 8% to 12% was achieved.

Table 1. Standard Rubberwood Drying Schedule

Dry Bulb Temperature (°C)	Wet Bulb Temperature (°C)
65.5	45
55	44
50	42
45	41
40.5	38

During the drying process, the other edge-matched specimens from each batch were removed from the kiln dryer when they achieved the target moisture contents of 20%, 40%, 60%, 80%, and 100%. These specimens were used to assess the development of color profiles during drying at the specific target moisture content.

Assessment of Color Profile

A 25 × 25 × 100 mm block was cut from each dried specimen and then sliced from the surface to center into 10 approximately 2.5-mm-thick consecutive slices to determine the color profile. A Konica-Minolta CM-2500d (Kyoto, Japan) surface reflectance spectrophotometer was used to measure the color of each slice. The color was represented using the CIE (1976) L^*, a^*, and b^* color space, where L is measure of lightness from 0 (black) to 100 (white), a is red-green share from -60 (green) to 60 (red), and b is blue-yellow share from -60 (blue) to 60 (yellow). The change in color after drying (ΔE^*) was expressed as the distance between two points in the color coordinate and was calculated from the split up values ΔL^*, Δa^*, and Δb^*. The measure of the total change in color (ΔE) of the wood was derived from the equation below:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad (1)$$

The classification magnitude of ΔE is described in Table 2.

Table 2. Color Profile

Profile	Description
0.2 < Δ*E*	No visible difference
0.2 < Δ*E* < 2	Small difference
2 < Δ*E* < 3	Color difference visible with quality screen
3 < Δ*E* < 6	Color difference visible with medium quality screen
6 < Δ*E* < 12	High color difference
Δ*E* > 12	Different colors
Source: Klement and Marko (2009)	

Data Analysis

The results were analyzed using the SPSS-statistics software (IBM, USA), particularly the t-test, to compare the effect of felling season on the average chemical content and blue stain occurrence in rubberwood.

RESULTS AND DISCUSSION

Chemical Compound Analysis

Figure 1 presents the pattern of starch and free sugar contents in rubberwood logs throughout the year, determined on the basis of three bore samples (of 20 mm depth) obtained from the standing trees as reported by Luostarinen and Möttönen (2009). The chemical analysis conducted on the log samples revealed varying contents of free sugars and starch throughout the year, a finding similar to the reports by Mononen *et al.* (2002) and Ratnasingam and Scholz (2009). Generally, the free sugar and starch contents were lower in trees felled immediately after the rainy season, as opposed to the trees felled during the dry season. When the dry season began, the amount of sugar and starch increased significantly. As the rainy season approached, the amount of free sugar and starch in the rubberwood logs decreased significantly.

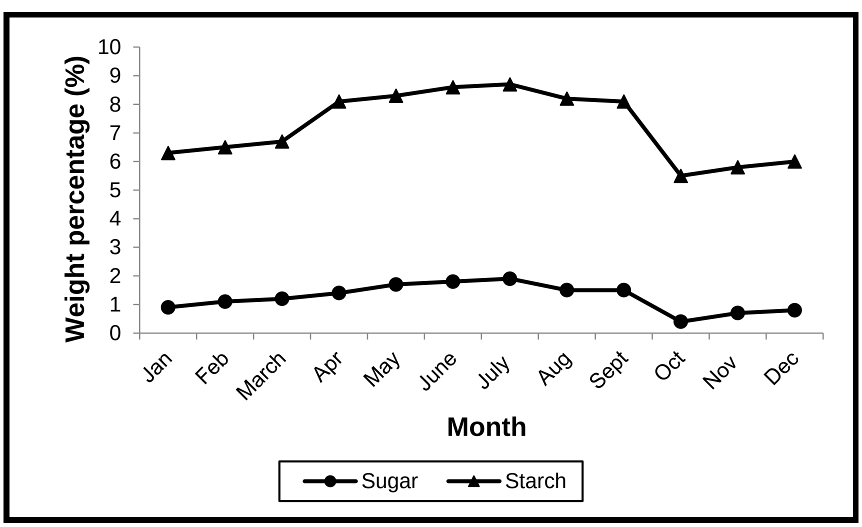

Fig. 1. The availability of starch and sugar content in felled rubberwood logs

The seasonal variations in starch and free sugar contents in rubberwood are shown in Fig. 1, while the average values of these chemicals in the logs are shown in Table 3. The analysis indicated that there was a significant difference between the rainy season and dry season in terms of free sugar and starch content, as the p-value was less than 0.05. Based on this analysis, the mean value of sugar content in logs felled during the dry season was 0.7% higher than the logs felled during the rainy season. A similar trend was also noted for starch content, in which the difference was 2.2%. Hence, it could be concluded that the rubberwood logs felled during the dry season have a higher amount of free sugars and starch.

Table 3. Effect of Felling Season on the Chemical Contents

Chemical contents	Felling season	Mean (Weight percentage)	Standard deviation	t	p-value
Free sugar	Rainy season	0.9	0.29	-5.501	0.000
	Dry season	1.6	0.20		
Starch	Rainy season	6.1	0.45	-10.384	0.000
	Dry season	8.3	0.26		

Development of Blue Stain

The incidence of blue stain on rubberwood logs felled throughout 2015 was inspected prior to kiln drying. Figure 2 presents the percentage of blue stain that occurred in the green logs. Similar to the free sugars and starch contents, the occurrence of blue stain on the rubberwood logs was strongly influenced by the presence of these chemicals in the logs. Koch (2008) pointed out that staining occurred as a result of the metabolic process of the fungi that decompose the soluble carbohydrates.

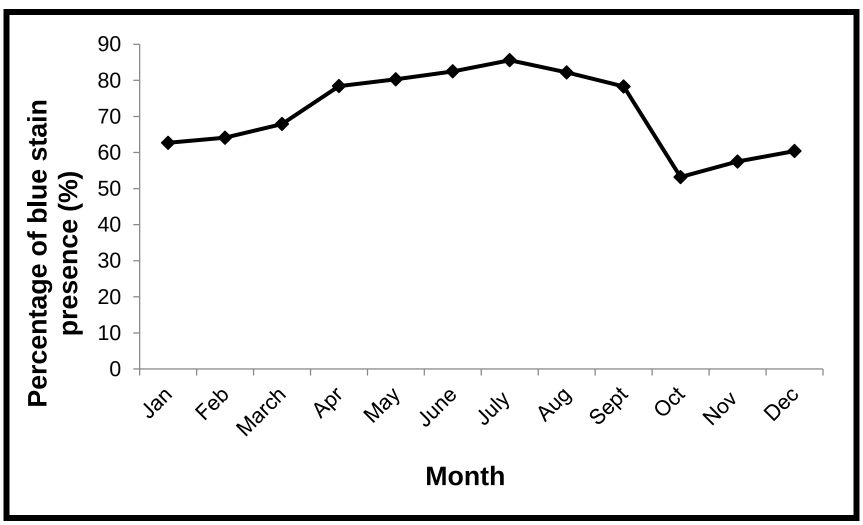

Fig. 2. The presence of blue stain in felled rubberwood logs

The analysis to determine the effect of felling seasons on the occurrence of blue stain is summarized in Table 4. The findings showed a significant difference, as the p-value was less than 0.05. It appeared that the incidence of blue stain on felled logs was influenced by the felling season. The mean values indicate that the occurrence of blue stain was significantly higher in logs felled during the dry season than the rainy season. This observation is likely due to the fact that the free sugars and starch contents will induce blue stain fungi growth, as long as there is sufficient moisture content (Teoh *et al.* 2011).

Table 4. Effect of Felling Season on the Occurrence of Blue Stain

Felling season	Mean (%)	Standard deviation	t	p-value
Rainy season	60.97	5.17	-8.441	0.000
Dry season	81.22	2.80		

Color Profile in Sawn Timber

The comparative average L^*, a^*, and b^* values of freshly felled green and kiln-dried rubberwood sawn timber obtained from logs felled during the rainy and dry seasons, respectively, are shown in Table 5. It is apparent from Table 5 that the rubberwood sawn timber's color begins to change when the sawn timber is kiln dried. The discoloration or darkening of rubberwood becomes obvious with increasing drying time, which means that the lightness of the sawn timber was reduced after kiln drying. The lightness of the sawn timber from logs obtained from the rainy season showed an average reduction of 8.80%, while the lightness of the sawn timber from logs harvested during the dry season was reduced by an average of 3.42%.

Table 5. Average values of CIE L^*, a^*, and b^* coordinates before and after drying

Felling season	Sawn timber	L^*	a^*	b^*
Rainy season	Green sawn timber	67.78	3.38	18.47
	Dried sawn timber	62.30	3.47	19.40
Dry season	Green sawn timber	77.04	3.88	19.54
	Dried sawn timber	74.49	4.14	20.04

Additionally, the color development of a^* and b^* values for the two different batches of materials increased after kiln drying. The value of a^* showed an average increment of 2.59% and 6.28% for sawn timber from the rainy and dry seasons, respectively. The increase in average color development of parameter b^* for sawn timber from the rainy and dry seasons was found to be 4.79% and 2.50%, respectively. These findings suggest that the color parameters a^* and b^* became more saturated as drying progressed (Klement and Marko 2009).

The measured color development for logs felled in the wet season and dry season at different moisture contents (as shown by the drying time) is presented in Table 6. It appears that drying at different moisture contents influenced color development in the two different batches of rubberwood.

Table 6. Color Development of Sawn Timber Based on Moisture Content

Drying Time	Color Development+ (Rainy season)				Color Development+ (Dry season)			
	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE
100%	-8	1	4	9.6	-10	2	6	13.7
80%	-6	1	3	7.3	-8	1	3	8.6
60%	-5	1	3	4.9	-6	1	4	6.9
40%	-4	1	2	3.9	-6	1	2	4.8
20%	-0	0	2	1.9	1	0	1	2.7

In this study, the sawn timber obtained from the rainy and dry seasons was kiln-dried using a similar drying schedule to achieve similar final moisture content for comparative purposes. The study has established the relationship between free sugars and starch contents in rubberwood, the occurrence of blue stain fungi, and the incidence of discoloration in the wood.

Effect of chemical reactions on surface color

Discoloration can be started through physiological reactions of living parenchyma cells (Koch 2008). Chemical analysis conducted on the two batches of sawn timber from different felling seasons revealed varying contents of free sugars and starch, which explains the varying extent of discoloration observed in the samples. It has been noted that a higher concentration of discoloration precursors, especially those from low molecular weight sugars, can cause discoloration in wood through a Maillard reaction (Sandoval-Torres *et al*. 2010). The drying process has also been found to redistribute the discoloration precursors in wood as a result of moisture movement processes. Kiln-dried wood with lower free sugars and starch contents would have a significantly reduced extent of discoloration (Ratnasingam and Scholz 2009).

The concentration of free sugars and starch on the wood surface could also lead to color change. The wood drying process moves the soluble sugars and starch to the wood surface as moisture is removed from the wood (Tarvainen *et al.* 2001). The chemicals react with air through an oxidation process, which results in the formation of polymers. These polymers manifest as the dark color of the wood. This process normally takes place in wood with a moisture content of more than 40% (Uzunovic *et al.* 2008).

The color measurement data was combined and compared with the chemical analysis study. Therefore, the relationship between the chemical contents (free sugars and starch) and the color changes of L^*, a^*, and b^* is presented in Table 7. The relationship was observed on the basis of felling seasons. The results show that there is a strong correlation between color profile and chemical composition for the rainy season specimens. The p-value of less than 0.05 was interpreted as significant correlation coefficient. The correlation revealed that the concentration of starch (to some extent) tended to darken the surface of the specimens.

Table 7. The Influence of Chemical Contents on Discoloration

Felling season	Chemical contents	L^*		a^*		b^*	
		r	p-value	r	p-value	r	p-value
Rainy season	Sugar	0.983	0.000	0.965	0.002	0.974	0.001
	Starch	0.990	0.000	0.992	0.000	0.986	0.000
Dry season	Sugar	0.833	0.040	0.848	0.033	0.899	0.015
	Starch	0.860	0.028	0.902	0.014	0.971	0.001

Industrial Implications

The results of this study have far-reaching implications on the rubberwood processing industry in Malaysia and the Southeast Asia region at large. It is clear that the discoloration of kiln-dried rubberwood sawn timber decreases the aesthetic value of the material (Ratnasingam *et al*. 2007), and efforts to minimize the discoloration will significantly improve the material's success as a premium raw material for value-added wood products manufacturing, especially furniture.

In a survey of 10 commercial sawmills using rubber logs felled after the rainy season, the extent of discoloration of the dried rubberwood was not as severe as in the boards obtained from rubber logs felled during the dry season. Previous works by Ratnasingam *et al.* (2010, 2014) and Ratnasingam and Grohmann (2014) have discussed different processing variables that could be introduced to minimize discoloration during rubberwood drying, but those techniques will incur additional costs (Table 8). Therefore, when high-quality, uniformly colored rubberwood boards are desired at minimal cost, the use of rubber logs felled after the rainy season and immediately processed into sawn timber is an alternative that is worthy of consideration.

Table 8. Comparison of Rubberwood Drying using Different Techniques

Drying technique	Average drying time (days) for 30 mm thickness boards)	Average % of drying defects	Average total discoloration (E)	Average drying cost/m^3 (US$)
Conventional kiln drying[1]	14	10	13.6	65
Modified kiln drying[2]	11	8	11.2	61
Superheated steam application in kiln drying[3]	9	8	10.9	58
Pre-steaming in kiln drying[4]	11	8	10.7	62
Conventional kiln drying of wood from logs felled after rainy season[5]	10	9	9.1	61

Sources: [1] - Ratnasingam and Scholz (2009); [2] - Ratnasingam and Grohmann (2014); [3] - Ratnasingam and Grohmann (2015); [4] - Ratnasingam *et al.* (2014); [5] - this study

CONCLUSIONS

1. The effects of log felling season on the discoloration of kiln-dried rubberwood sawn timber were investigated. The rubberwood logs felled in different seasons contained different amounts of free sugars and starch. Logs felled during the dry season had higher contents of free sugars and starch, which results in comparatively darker colored sawn timber possibly due to the oxidation or other reaction of these chemicals. Additionally, the higher contents of free sugars and starch make this material more prone to blue stain fungi attack.
2. This study shows that discoloration in rubberwood can be minimized by choosing the felling season of the logs together with an appropriate kiln drying technique to ensure the highest possible quality of kiln-dried sawn timber at the lowest cost.
3. The appearance of rubberwood sawn timber is the most important criterion in the rubberwood-based value-added wood products industry. The results of this study conclusively showed that discoloration in rubberwood can be minimized by observing the log felling season, which will improve the aesthetic appeal of the wood in the final product.

REFERENCES CITED

Humar, M., Vek, V., and Bučar, B. (2008). "Properties of blue-stained wood," *Drvna Industrija* 59(2), 75-79, (hrcak.srce.hr/file/40069).

Klement, I., and Marko, P. (2009). "Colour changes of beech wood (*Fagus sylvatica* L.) during high temperature drying process," *Wood Research* 54(3), 45-54.

Koch, G. (2008). "Discoloration of wood in the living tree and during processing," *Proceedings of the Conference in COST E53 'Quality Control for Wood and Wood Products,* W. F. Gard and J. W. G. van de Kuilen (eds.), Delft, The Netherlands.

Luostarinen, K., and Möttönen, V. (2009). "Effect of felling season, storage and drying on colour of silver birch (*Betula pendula*) wood from four different growing sites," *Silva Fennica* 43(4), 699-709. DOI: 10.14214/sf.190

Mononen, K., Alvila, L., and Pakanen, T. T. (2002). "Measurements to determine the role of felling season, log storage and kiln drying on coloration of silver birch wood," *Scandinavian Journal of Forest Research* 17(2), 179-191. DOI: 10.1080/028275802753626827

Ratnasingam, J., and Grohmann, R. (2014). "Color development in rubberwood *(Hevea brasiliensis)* during kiln drying," *European Journal of Wood and Wood Products* 72(4), 555-557. DOI: 10.1007/s00107-014-0801-0

Ratnasingam, J., and Grohmann, R. (2015). "Superheated steam application to optimize the kiln drying of rubberwood *(Hevea brasiliensis)*," *European Journal of Wood and Wood Products* 73(3), 407-409. DOI: 10.1007/s00107-015-0898-9

Ratnasingam, J., and Scholz, F. (2009). *Rubberwood: An Industrial Perspective,* World Resources Institute, Washington, DC.

Ratnasingam, J., Ioras, F., and Macpherson, T. H. (2007). "Influence of wood species on the perceived value of wooden furniture: The case of rubberwood," *Holz als Roh- und Werkstoff* 65(6), 487-489. DOI: 10.1007/s00107-007-0186-4

Ratnasingam, J., Grohmann, R., and Scholz, F. (2010). "Drying quality of rubberwood: An industrial perspective," *European Journal of Wood and Wood Products* 68(1), 115-116. DOI 10.1007/s00107-009-0353-x

Ratnasingam, J., Grohmann, R., and Scholz, F. (2014). "Effects of pre-steaming on the drying quality of rubberwood," *European Journal of Wood and Wood Products* 72(1), 135-137. DOI: 10.1007/s00107-013-0747-7

Sandoval-Torres, S., Jomaa, W., Marc, F., and Puiggali, J. R. (2010). "Causes of color changes in wood during drying," *Forest Studies in China* 12(4), 167-175. DOI: 10.1007/s11632-010-0404-8

Schubert, M., Mourad, S., and Schwarze, F. W. M. R. (2011). "Automated image processing for quantification of blue-stain discolouration of Norway spruce wood," *Wood Science and Technology* 45(2), 331-337. DOI: 10.1007/s00226-010-0328-4

Shigematsu, A., Mizoue, N., Kajisa, T., and Yoshida, S. (2011). "Importance of rubberwood in wood export of Malaysia and Thailand," *New Forests* 41(2), 179-189.

Stenudd, S. (2004). "Color response in silver birch during kiln-drying," *Forest Products Journal* 54(6), 31-36. DOI: 10.1007/s11056-010-9219-7

TAPPI T-207 (1999). "Water solubility of wood and pulp," TAPPI Test Methods, TAPPI Press, Atlanta Georgia, USA.

Tarvainen, V., Saranpää, P., and Repola, J. (2001). "Discoloration of Norway spruce and Scots pine timber during drying," *Proceedings of the 7th International IUFRO Wood Drying Conference,* Tsukuba, Japan.

Teoh, Y. P., Don, M. M., and Ujang, S. (2011). "Assessment of the properties, utilization, and preservation of rubberwood (*Hevea brasiliensis*): A case study in Malaysia," *Journal of Wood Science* 57(4), 255-266. DOI: 10.1007/s10086-011-1173-2

Terziev, N., and Boutelje, J. (1998). "Effect of felling time and kiln-drying on color and susceptibility of wood to mold and fungal stain during an above-ground field test," *Wood and Fiber Science* 30(4), 360-367.

Uzunovic, A., Byrne, T., Gignac, M., and Dian-Qing, Y. (2008). *Wood Discolourations and their Prevention*, FPInnovations, Canada.

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