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IMPACT OF HEAT TREATMENT ON THE SURFACE COLOR AND GLOSSINESS OF YOUNG EUCALYPTUS WOOD

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ABSTRACT

The study analyzed the impact of heat treatment conditions (temperature and duration) on the surface color and glossiness of young eucalyptus wood. The young eucalyptus wood samples were treated at different treatment temperatures (165°C, 185°C, 205°C) and duration (2 h, 3 h, 4 h). The color of the young eucalyptus wood was determined using CIE $L^*a^*b^*$ system and the gloss was measured with glossmeter at 20°, 60°, and 85° incident angle before and after the heat treatment. The total color difference (ΔE^*), lightness (L^*), red-green index (a^*), and yellow-blue index (b^*), were investigated at different treatment conditions. The values of L^* and b^* decrease continuously with the increasing temperature and duration. The results of analysis of variance (two-way ANOVA) indicate that the heat treatment temperature has a significant effect on the colorimetric properties of the heat-treated young eucalyptus wood. The gloss decreased after the heat treatment for both perpendicular and parallel directions. ANOVA analysis showed that the treatment temperature duration have a significant effect on the parallel glossiness of 85°($p < 0.05$). These are probably due to differences in surface roughness between untreated and heat-treated wood. To achieve the desired color like teak wood, the preferred temperature is no more than 185°C.

KEYWORDS: Heat treatment, young eucalyptus, surface color, glossiness.

INTRODUCTION

Thermal modification of wood is an environment-friendly method of improving dimensional stability, hygroscopicity, durability as it avoids the use of toxic chemicals (Srinivas and Pandey

2012, De Moura et al. 2013). In the past decades, the thermal modification of wood has been used to change the aesthetic properties of wood (Johansson and Morén 2006). Wood darkens on heat treatment with the color homogeneous throughout that is important from an aesthetic point of view (Srinivas and Pandey 2012). With a light- to dark-brown appearance, heat-treated wood can substitute some of the tropical hardwoods such as teak wood (Gunduz et al. 2009). The dark color of the treated wood makes it possible to replace more expensive and exclusive wood materials with cheaper wood (Johansson and Morén 2006).

Color is one of the most important properties for consumers' attention, and the possibility of changing the natural color of wood without chemicals is important for some markets (Esteves et al. 2019). Esteves et al. (2008) suggested that color change resulting from heat treatment is advantageous for species with unappealing wood color like pine and eucalyptus wood. The color changes might make the wood more appealing to architects and designers (Yan and Morrell 2019). Heat treatment was a potential technique for eucalyptus and pine wood by a color change to add its value and broaden their market possibilities.

The color changes due to various heat treatment processes have been extensively studied. Most studies have suggested that the color change of heat-treated wood is highly dependent upon the wood species (Varga and van der Zee 2008) and treatment conditions (Ra et al. 2012). The CIELAB system (1976) is the most used method to evaluate color of materials (Vinha et al. 2015). Previous studies showed that lightness decreases with heat treatment (Unsal et al. 2003, Bekhta and Niemz 2003, Barcík et al. 2015). Zanuncio et al. (2014a,b) reported that heat treatment reduced the values of L^*, a^* and b^* of eucalyptus wood at 170, 200 and 230°C for 3, 5 and 7 hours. They thought the temperature was more effective than time to change the color of the timber. Sun et al. (2019) had studied the discoloration mechanisms of heat-treated *Eucalyptus pellita* wood at four different temperatures for 4 h and found that the color of thermally modified eucalypt wood became darker uniformly throughout with treatment temperature increasing. Their research showed that oxidation products and phenolic substances such as the quinines from lignin were formed during thermo-vacuum treatment and hemicellulose and extractives played an essential role in the formation of color substances in the heating process. Vinha et al. (2015) studied the influence of extractives on heat-treated wood for enhancing the applicability of heat treatment for changing wood color. The extractives should be considered in heat treatment processes due to the influence of the quantity and quality of extractives on the color of heat-treated wood.

As a fast-growing plantation, the difference between heartwood and sapwood is noticeable for eucalyptus wood, especially young eucalyptus wood, reducing the aesthetic wood value for high-value applications such as interior flooring and siding, furniture. Extensively studies have shown the effect of treatment conditions on the surface color of eucalyptus wood and pointed out the uniformity was a desirable trait for consumers (Griebeler et al. 2018a). Many studies pointed out the color obtained by heat treatment like some dark tropical hardwoods. Teak is one of the most commonly used tropical wood species with a wide range of uses because of its high durability and good aesthetic properties for outdoor and indoor uses (Kokutse et al. 2006, Garcia et al. 2014, Gasparik et al. 2019). The brown color of teak heart wood is an aesthetically pleasing color for consumers (Kokutse et al. 2006). In order to obtain such attractive aesthetic features, the effective way is through heat treatment. Griebeler et al. (2018b) proposed a new method that combines wood pre-grading by surface color followed by the application of homogeneity thermal treatments to reduce the surface color variability of the thermally modified blue gum wood. However, there are few studies about the uniformity of color change due to heat treatment, especially for young eucalyptus wood. There is lack of studies acquired color through heat treatment similar to those observed in tropical wood such as teak wood.

Gloss is one of the most important aesthetic properties to consumers. Heat treatment reduced the glossiness for all investigated wood species such as poplar, chestnut (Gurleyen et al. 2018), Scots pine (Aksoy et al. 2011), alder, beech, black locust, wild pear, linden (Esteves et al. 2019). The decrease of gloss depends on the wood species and the initial gloss of wood samples (Aksoy et al. 2011, Gurleyen et al. 2017), although some researchers discovered different results that gloss values of thermally densified wood increased with increasing densification temperature and pressure for all investigated species (Bekhta et al. 2014).

The aim of this study was to investigate the impact of the varying heat treatment conditions (heat treatment temperature and duration) on the surface color and glossiness of young eucalyptus wood. Wood samples were heat-treated at 165°C, 185°C, 205°C for 2 to 4 hours. The changes of surface color and glossiness due to heat treatment were evaluated. The young eucalyptus wood is a fast-growing plantation wood used mainly as raw materials for papermaking and wood-based panel production. Improved performance of young eucalyptus wood may make it worthwhile for relatively high-value applications such as interior flooring and siding, furniture to meet consumers' preferences and needs.

MATERIAL AND METHODS

*W*ood of 7 years old trees (*Eucalyptus urophylla* × *E. grandis*) from Guanxi province was used for the samples. The samples measuring 100 x 50 x 10 mm were used for the surface color and glossiness measurements. All the samples were air dried for more than three months. The average density and moisture content of samples was 545 $kg{\cdot}m^{-3}$ and 12 ± 2%, respectively.

Wood heat treatment

The heat treatment was performed according to the ThermoWood® method (Lahtela 2021). Heat treatment was carried out at 165°C, 185°C, 205°C for 2, 3, 4 h at the wood modification laboratory of Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences in Danzhou city, Hannan province (China) using a 0.3 m^3 thermal chamber (Jiangsu XINAN Wooddrying Systems Co., LTD, Nanjing, China). After treatment, the wood was slowly cooled until 40°C and conditioned at 20°C and relative humidity 65% before color and glossiness measurements.

Color measurement

The color of the control and heat-treated wood samples were measured by an X-Rite Ci60 Series Portable Spectrophotometer (X-Rite Pantone, Michigan, United States). A D65 light source and 10° observed angle were used with an 8 mm diameter sensor head. The color was measured on both sides of each sample (Jiang et al. 2020). The CIELAB system, characterized by the three axes L^*, a^*, and b^*, was used. The L^* axis represents lightness; a^* is the red-green index; and b^* is the yellow-blue index. The total color difference was calculated by:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} = \sqrt{(L^*_{HT} - L^*_{CT})^2 + (a^*_{HT} - a^*_{CT})^2 + (b^*_{HT} - b^*_{CT})^2} \qquad (1)$$

where: ΔL^* - the lightness difference, Δa^* - the red-green difference, Δb^* - the yellow-blue difference, L^*_{CT} - the lightness values of the control wood, a^*_{CT} - the red-green values of the control wood, b^*_{CT} - the yellow-blue values of the control wood.

FTIR analysis

Instrument: Thermo Nicolet iS50 FTIR (Thermo Fisher Scientific, Waltham, MA, USA) spectrometer equipped with an attenuated total reflection (ATR) unit. Scanning range: 4000 and 400 cm^{-1}; 32 scans; resolution 16cm^{-1}. The spectral range 1800-800 cm^{-1} was evaluated.

Glossiness measurement

Gloss measurements were performed using the glossmeter MG268-F2 (KSJ Photoelectrical Instruments Co. Ltd., Quanzhou, China) in parallel and perpendicular directions at 20°, 60° and 85° respectively.

Statistical analysis

R software (Version 4.1.1) was used for two-way ANOVA. The data distributions were examined for normality and homogeneity of variance. Glossiness and color parameters were measured using three replicates of each sample, and each sample was measured six times.

RESULTS AND DISCUSSION

The colorimetric parameters (L^*, a^*, b^*, ΔE^*) of the control and heat-treated eucalyptus wood measured are presented in Tab. 1.

Tab. 1: Colorimetric parameters of control and heat-treated eucalyptus wood under different treatment conditions. Values in parentheses are standard deviations.

No	Treatment conditions		L^* mean	a^* mean	b^* mean	ΔE^*_e	ΔE^*_t
	Temperature (°C)	Duration (h)					
1	165	2	65.35 (2.29)	8.97 (1.59)	20.77 (1.19)	8.43 (2.20)	14.58 (2.07)
2	165	3	64.44 (2.40)	9.34 (0.94)	22.10 (1.32)	9.83 (1.99)	14.17 (2.07)
3	165	4	64.62 (1.58)	9.60 (0.54)	20.90 (1.11)	9.08 (2.25)	13.96 (1.99)
4	185	2	58.91 (2.19)	9.70 (1.41)	21.88 (2.58)	14.79 (2.65)	8.83 (2.06)
5	185	3	54.43 (2.83)	10.26 (0.83)	20.50 (1.21)	18.97 (2.74)	5.34 (1.71)
6	185	4	50.26 (2.76)	10.78 (0.54)	20.33 (1.26)	23.12 (2.54)	4.75 (2.55)
7	205	2	44.78 (2.25)	9.89 (1.62)	18.29 (0.99)	28.45 (1.66)	7.02 (1.35)
8	205	3	41.32 (2.49)	9.33 (0.90)	16.05 (1.34)	32.00 (2.71)	10.45 (1.23)
9	205	4	39.99 (2.62)	9.06 (0.58)	15.59 (1.08)	33.36 (2.67)	11.77 (2.68)
10	Control (teak wood)		51.14 (2.99)	7.42 (1.55)	18.82 (2.32)	-	-
11	Control (eucalyptus wood)		73.20 (0.68)	9.31 (1.11)	18.51 (0.23)	-	-

The initial values of lightness, red-green index, yellow-blue index of control eucalyptus wood and teak wood are 73.20, 9.31, 18.51, and 51.14, 7.42, 18.82, respectively. The heat-treated eucalyptus wood exhibited low lightness than the control eucalyptus wood. The most remarkable difference is seen between control and heat-treated eucalyptus wood at 205°C for 4 h. The lowest difference between control teak wood and heat-treated eucalyptus wood was at 185°C for 4 h (Fig. 1).

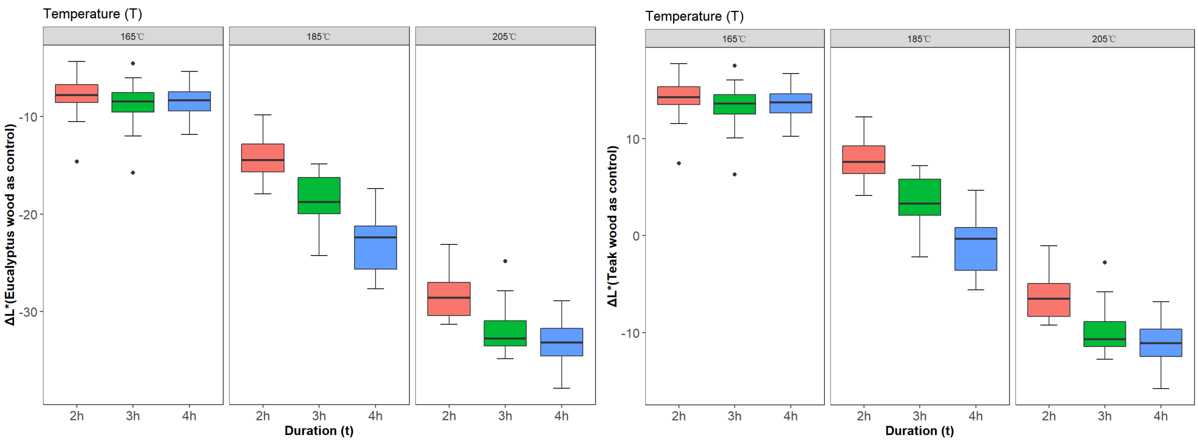

Fig. 1: Effect of heat-treated conditions on the lightness (L^*) of eucalyptus wood.

As can be seen from Tab. 2, the results of two-way ANONA showed that L^* values are significantly different for treatment temperature (*T*), duration (*t*), and interaction (*Tt*), at the level of significance ($P < 0.001$). A significant interaction effect means that the impact of one factor depends on the other factor. In this case, the effect of heat treatment temperature on color varies with duration. This confirms that, in order to impart a darker color to wood, the treatment temperature should be tailored to duration.

Tab. 2: Results of two-way ANOVA analysis for L^*, a^*, b^*, ΔE^*.

Variable	Variance sources	Type sum of squares	Mean square	F value	*P*	Significance
L^*	T	14047.00	7024.00	1214.49	$< 2.00\times10^{-16}$	***
	t	615.00	307.00	53.15	$< 2.00\times10^{-16}$	***
	Tt	288.00	72.00	12.45	8.65×10^{-9}	***
a^*	T	28.21	14.11	12.11	1.31×10^{-5}	***
	t	2.28	1.14	0.98	0.38	-
	Tt	18.40	4.60	3.95	0.0044	**
b^*	T	712.10	356.00	178.15	$< 2.00\times10^{-16}$	***
	t	51.00	25.50	12.76	7.49×10^{-6}	***
	Tt	69.10	17.30	8.65	2.55×-10^{-6}	***
ΔE_e^*	T	13308.00	6654.00	1150.46	$< 2.00\times10^{-16}$	***
	t	597.00	299.00	51.65	$< 2.00\times10^{-16}$	***
	Tt	275.00	69.00	11.89	1.94×10^{-8}	***
ΔE_t^*	T	1708.90	854.40	209.30	$< 2.00\times10^{-16}$	***
	t	1.00	0.50	0.12	0.89	-
	Tt	393.40	98.30	24.09	1.81×10^{-15}	***
Different symbols (***, **, *, .) indicate significant difference at the 0.001, 0.01, 0.05, 0.1 level respectively according to ANOVA.						

As can be seen from Tab. 1 and Fig. 2, there is an increase in a^* followed by a decrease with the increasing treatment temperature. Change differences in a^* are minor for the different duration at the same treatment temperature. These are consistent with the results of the analysis of two-way ANONA. The treatment temperature had a significant effect on the a^* values, while the duration had no effect (Tab. 2).

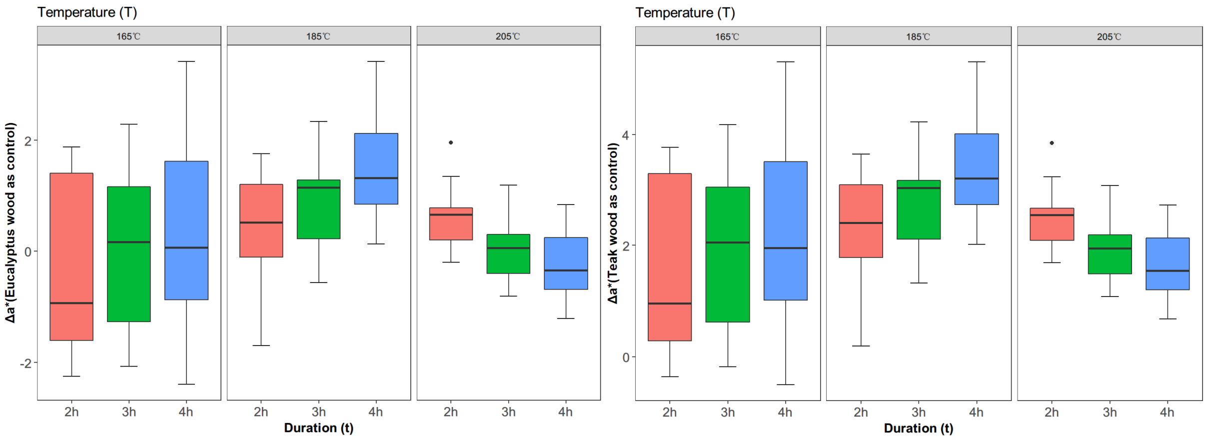

Fig. 2: Effect of heat-treated conditions on the red-green index (a^*) of eucalyptus wood.

The b^* values decreased with higher heat-treated temperature and longer duration (Tab. 1 and Fig. 3). Similar changes in b^* have been reported before by several authors (Esteves et al. 2008, Aksoy et al. 2011, Barcík et al. 2015). Two-way ANOVA (Tab. 2) showed that the treatment temperature and duration had a significant effect on the b^* values ($P < 0.001$).

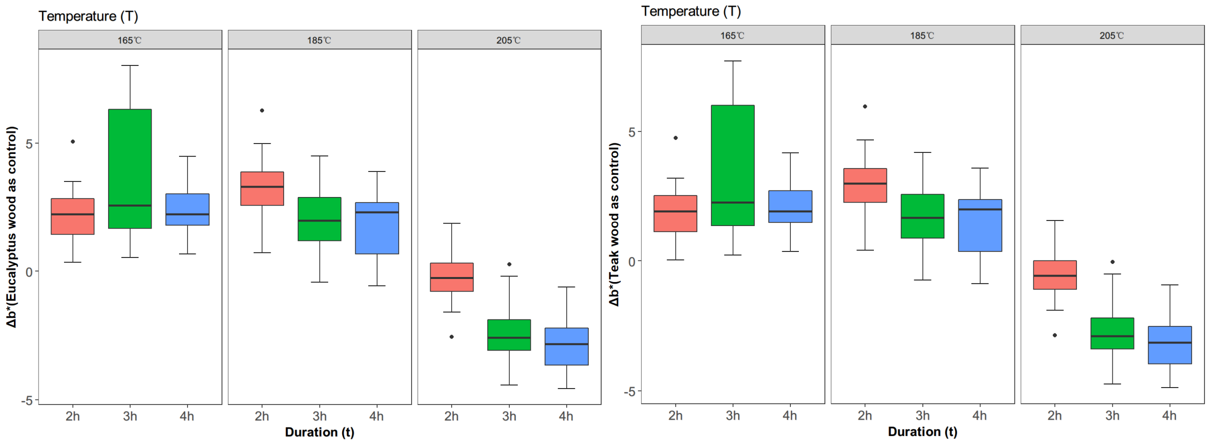

Fig. 3: Effect of heat-treated conditions on the yellow-blue index (b^*) of eucalyptus wood.

Fig. 4 shows the changes in total color difference (ΔE^*) of eucalyptus wood concerning treatment temperature and duration compared to untreated eucalyptus and teak wood. The values of ΔE^* decreased initially and later increased with high temperature compared to teak wood. In contrast, its values increased with the increasing treatment temperature and duration compared to eucalyptus wood. The heat treatment changes the original surface color of eucalyptus wood. Two-way ANOVA (Tab. 2) showed that the treatment duration did not significantly affect the ΔE^* values compared to teak wood. A minimum change in ΔE^* values for heat-treated eucalyptus wood was observed at temperature 185°C compared to control teak wood. Therefore, to achieve the desired color like teak wood, the preferred temperature is no more than 185°C.

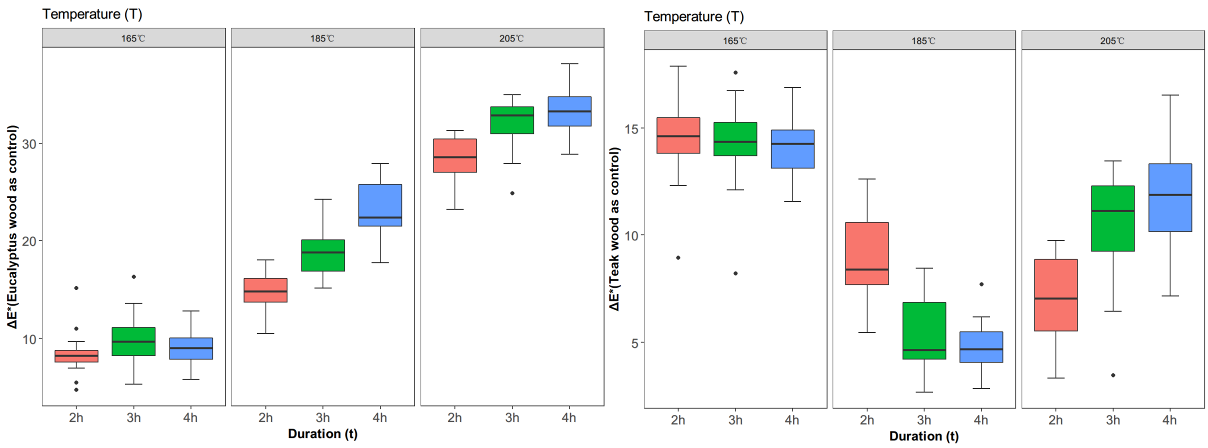

Fig. 4: Effect of heat-treated conditions on the total color difference (ΔE^*) of eucalyptus wood.

The results of the FTIR-ATR spectra of the control eucalyptus wood samples (No. 11) and heat-treated eucalyptus wood samples (No.3, 6, 9) treated at 165°C, 185°C, 205°C for 4 hours are shown in Tab. 3 and Fig. 5.

Tab. 3: Main bands of infrared spectrum of eucalyptus wood and their assignment to functionality (Ganne-Chédeville et al. 2012, Esteves et al. 2013, Özgenç et al. 2017, Lagaňa et al. 2021).

Wavelength (cm^{-1})				Description
Control	165°C - 4 h	185°C - 4 h	205°C - 4 h	
3343	3342	3337	3341	O-H stretch, hydrogen bonding (H-bonded)
2899	2895	2898	2898	C-H stretch
1734	1734	1731	1717	Non-conjugated C=O groups, Carbonyl groups of acetoxy groups in xylan
1592	1592	1595	1601	Aromatic skeletal vibrations plus C=O stretch (lignin)
1503	1504	1511	1514	Aromatic skeletal vibrations (lignin)
1456	1457	1457	1456	C=C and C-H bond, extractives, O-H in plane deformation, CH_3 asymmetric bending in (lignin)
1422	1422	1423	1424	Aromatic skeletal vibrations (lignin) and CH_2 bending deformation (cellulose)
1370	1369	1368	1367	C-H bending, -CH_3 (lignin), -CH_2 (carbohydrates), lignin-carbohydrate complexes bonds
1325	1324	1321	1318	Syringyl ring plus guaiacyl ring, phenol group, OH in plane bending (cellulose)
1230	1229	1225	1218	Alkyl-aryl-ether bonds, lactones
1156	1156	1156	1157	C-O-C vibration in cellulose and hemicell.
1104	1105	1105	1104	Arom. skeletal vibration and C-O stretch
-	-	1050	1053	C-O vibrations in cellulose and hemicellulose
1028	1030	1031	1031	C-O deformation in cellulose, symmetric C-O-C stretching of dialkyl ethers, aromatic C-H deformation in lignin
898	897	899	900	Aromatic C-H out-of-plane deformation in cellulose and hemicellulose

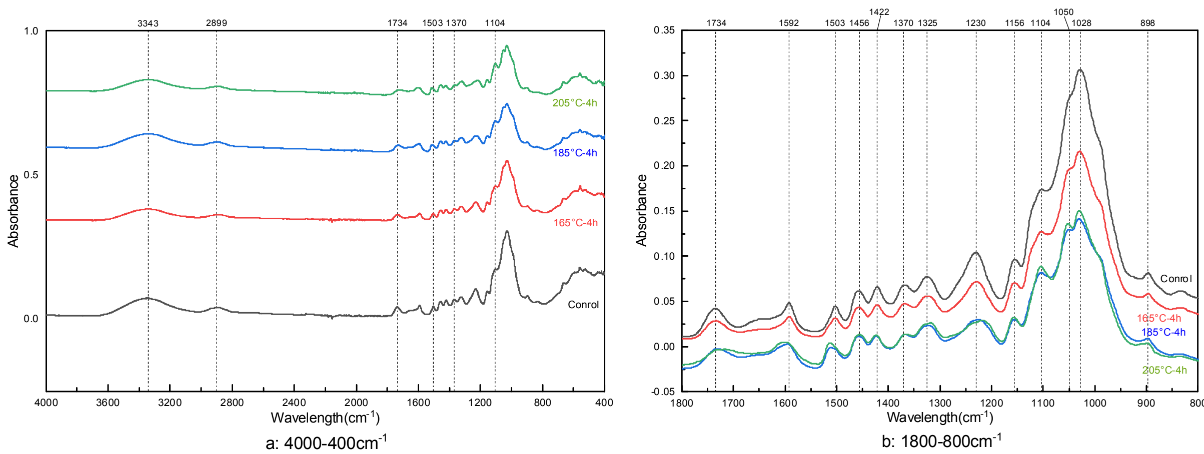

Fig. 5: IR spectra of untreated and treated eucalyptus wood at 165°C, 185°C, 205°C for 4 hours (a: 4000-400cm^{-1}, b: 1800-800cm^{-1}).

It can be seen that the position of the absorption peak of eucalyptus wood in the range of 4000-800 cm^{-1} is almost not shifted after heat treatment, but the intensity of the absorption peak changes significantly (Tab. 3, Fig. 5). The band at the 3343 cm^{-1} is assigned to the hydroxyl (OH) of cellulose. With the increase of temperature, the absorption peak intensity weakens obviously. This band shifted to lower wave number with the increase of treatment temperature.

The fingerprint region of 2000-800 cm^{-1} is mainly analyzed because it reflects a large amount information of the changes of functional groups of wood components (Sun et al. 2017). There is an obvious absorption peak at 1734 cm^{-1}, assigned to the stretching vibration (C=O) of the non-conjugated acetyl or carbonyl groups in xylan. With the increase of temperature, eucalyptus wood hemicellulose began to undergo deacetylation ($CH_3C=O$) reaction, so the intensity of its absorption peak gradually weakened, resulting in a decrease in hemicellulose content.

The band at 1503 cm^{-1}, assigned to the stretching vibrations of the C=C bonds of aromatic skeletal in lignin, showed a decrease after heat treatment, suggested that the amorphous carbohydrates degraded and that the relative amount of lignin in the samples increased with the increase of treatment temperature. A gradual shift in this band was observed from 1503 to 1514 cm^{-1} with the increase of treatment temperature, suggesting the splitting of aliphatic side chains and cleavage of β-O-4 linkages in the lignin structure, followed by condensation reactions (Chen et al. 2012).

Gloss is one of the most critical aesthetic properties to consumers. The results of gloss of untreated and heat-treated eucalyptus wood (Tab. 4) were obtained according to the standards of GB/T 9754-2007 and ISO 2813: 1994 at the angles of 20°, 60° and 85°. The differences were slight even non-existent among 2 h, 3 h, and 4h at the same treated temperature. The result is in accordance with other wood species, including black locust, wild pear, linden, alder, willow (Esteves et al. 2019), scots pine (Aksoy et al. 2011, Gurleyen et al. 2017), wild cherry wood (Korkut et al. 2013), and so on.

The glossiness of eucalyptus wood under different treated temperatures and duration at 60° angle were bigger than that at 20°, but the differences are similar to that at 20°. The glossiness of eucalyptus wood treated at 165°C increased firstly and decreased with the increasing duration in perpendicular and parallel directions. The glossiness of timber is affected by the direction of measurement and the natural features of the wood substrate (Scrinzi et al. 2011). The glossiness at 60° has no practical meaning since the angle of 60° is just a reference angle (Esteves et al. 2019).

At the 85° angle, the glossiness decreased with the heat treatment. There is a continuous decrease for the longer duration (perpendicular and parallel for 2 h, 3 h, 4 h), while there is a decrease followed by an increase with the increasing treatment temperature. These are probably due to differences in surface roughness between untreated and heat-treated wood (Esteves et al. 2019). The wood surface roughness decreased with the increasing treated temperature and duration reported by some researchers previously (Kamdem et al. 2002, Korkut and Budakci 2010).

Tab. 4: Gloss at 20°, 60° and 85° (perpendicular and parallel) for untreated and heat-treated eucalyptus wood.

No.	**Duration**	**⊥20°**	**⊥60°**	**⊥85°**
1	165°C-2h	0.88 (0.10)	3.40 (0.39)	2.43 (0.79)
2	165°C-3h	0.95 (0.13)	3.74 (0.58)	1.96 (0.60)
3	165°C-4h	0.85 (0.14)	3.35 (0.59)	2.31 (0.66)
4	185°C-2h	0.75 (0.12)	3.21 (0.52)	2.14 (0.96)
5	185°C-3h	0.74 (0.07)	3.23 (0.32)	2.43 (0.64)
6	185°C-4h	0.67 (0.10)	3.00 (0.63)	2.30 (0.79)
7	205°C-2h	0.56 (0.13)	2.82 (0.47)	2.59 (0.74)
8	205°C-3h	0.56 (0.07)	2.81 (0.25)	2.64 (0.47)
9	205°C-4h	0.50 (0.09)	2.37 (0.54)	2.06 (0.64)
10	**control**	1.08 (0.11)	4.15 (0.44)	3.03 (1.02)
No.	**Duration**	**//20°**	**//60°**	**//85°**
1	165°C-2h	0.97 (0.12)	4.32 (0.45)	6.82 (1.89)
2	165°C-3h	1.04 (0.11)	4.73 (0.63)	6.87 (1.52)
3	165°C-4h	0.92 (0.14)	4.26 (0.73)	8.51 (2.12)
4	185°C-2h	0.79 (0.11)	3.99 (0.69)	5.34 (2.88)
5	185°C-3h	0.75 (0.14)	4.05 (0.67)	7.61 (1.54)
6	185°C-4h	0.70 (0.15)	3.58 (0.81)	8.15 (1.98)
7	205°C-2h	0.62 (0.12)	3.77 (0.76)	6.29 (1.71)
8	205°C-3h	0.57 (0.08)	3.81 (0.47)	5.68 (2.16)
9	205°C-4h	0.55 (0.13)	3.25 (0.70)	5.95 (2.05)
10	**control**	**1.17** (0.12)	**5.20** (0.66)	8.57 (2.44)

The gloss values were belonged to the zone 'matt' for the values lower than 10 GU. Therefore, the correct angle for measuring gloss is 85° geometry, although three angles were test. The gloss decreased after the heat treatment for both perpendicular and parallel directions. Tab. 5 presents the results of two-way ANOVA for perpendicular and parallel gloss at 85°. According to the results of ANOVA, the treatment temperature and duration have a significant effect on the glossiness of // 85° ($p < 0.05$).

Tab. 5: Two-way ANOVA for glossiness at 85° (perpendicular and parallel).

Variable	Variance sources	Type sum of squares	Mean square	F value	*P*	Significance
⊥85°	T	0.61	0.31	0.59	0.56	-
	t	0.43	0.21	0.41	0.66	-
//85°	T	29.10	14.57	3.37	0.039	*
	t	32.90	16.47	3.81	0.026	*
Different symbols (***, **, *, .) indicate significant difference at the 0.001, 0.01, 0.05, 0.1 level respectively according to ANOVA.						

CONCLUSIONS

The impact of heat-treated conditions (temperature and duration) on the surface color and glossiness of eucalyptus wood was analyzed. Lightness decreases continuously with the increasing temperature and duration, with the greatest differences seen between the control and heat-treated eucalyptus wood at 205°C, and the lowest differences seen between control teak wood and heat-treated eucalyptus wood at 185°C.

Change differences in a^* are small for the different duration at the same treatment temperature. The b^* values decreased with higher heat-treated temperature and longer duration. The values of ΔE^* increased with the increasing treatment temperature and duration compared with eucalyptus wood. In contrast, its values decreased initially and later increased with high temperatures compared with teak wood. The heat treatment changes the original surface color of eucalyptus wood. To achieve the desired color like teak wood, the preferred temperature is no more than 185°C.

The values of L^*, b^*, ΔE_e^* are significantly different for treatment temperature (T), duration (t), and interaction (Tt) at the selected level of significance ($P < 0.001$). The treatment temperature (T) has a significant effect on the values of a^* and ΔE_t^* while the duration (t) has no effect.

The values of gloss of untreated and heat-treated eucalyptus wood were lower than 10 GU, so the correct angle for measuring gloss is 85° geometry, although three angles were test. The gloss decreased after the heat treatment for both perpendicular and parallel directions. ANOVA analysis showed that the treatment temperature duration have a significant effect on the parallel glossiness of 85° ($p < 0.05$). These are probably due to differences in surface roughness between untreated and heat-treated wood.

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