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Effects of hydrogen peroxide (H_2O_2) chemical modification on the physical and optical properties of *Eucalyptus grandis* W.Hill wood

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Abstract

Background: Wood bleaching is used for applications such as the production of uncoated furniture and laminated boards. However, there has been limited research on applying this treatment to Eucalyptus wood, and existing studies often involve reagents that are harmful to both the environment and human health. This study aimed to evaluate the physical and optical properties of *Eucalyptus grandis* W.Hill veneers following chemical modification with hydrogen peroxide.

Methods: Twenty-seven H_2O_2 bleaching treatments were conducted, varying in time (30, 60, and 90 minutes), temperature (60, 70, and 80°C), and pH (4, 6, and 8), and were compared to a control treatment. Tests comprised measuring density, 24-hour water absorption, wettability, brightness, whiteness, yellowness, and CIELab* colour scale.

Results: Bleaching modified the wood's properties, particularly increasing brightness and whiteness. While density and water absorption did not significantly change with treatment, wettability increased after bleaching, promoting bonding quality for the production of laminated boards. The treatment conducted at 70°C, with an alkaline pH of 8 for 90 minutes, showed the most favourable results.

Conclusions: These findings demonstrated the potential of hydrogen peroxide bleaching as a technique for enhancing physical and optical properties of wood veneers.

Keywords: Bleaching; bightness; CIELab* colour scale; density; rose gum; veneer; water absorption; wettability

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Introduction

Wood can be used in advanced technological applications, but it is essential to enhance its properties beforehand — such as performance and durability— through chemical, biological, physical, or mechanical modifications. These processes alter the wood's physical structure by enabling chemical interactions with more reactive components, including hydroxyl groups present in the primary and secondary alcohols of cellulose, hemicelluloses, and lignin, as well as phenolic rings (Géradin 2016; Sandberg et al. 2017; Samani et al. 2021).

Wood bleaching is a chemical modification traditionally applied to wood pulp to enhance brightness for paper production. In recent years, however, there has been increasing interest in evaluating bleaching processes for lignocellulosic materials. The process can be used to alter material properties, making it more suitable for the development of higher-value products such as uncoated furniture, transparent wood, packaging films, and solar cells (Li et al. 2019; Yun et al. 2024). During the bleaching process, wood undergoes colour modification and partial delignification; however, this process can also generate harmful compounds such as methyl mercaptan, dimethyl sulphide, and hydrogen sulphide, when chlorine- and sulphur-based reagents are used (Wang et al. 2019). Hydrogen peroxide presents a safer alternative, enabling effective bleaching without the formation of these toxic by-products and offering greater efficiency in increasing the brightness of the material (Zhu et al. 2016).

The effect of chemical modification with hydrogen peroxide on Swedish hardwood veneers has been associated with a moderate to high degree of bleaching. The combination of hydrogen peroxide with sodium hydroxide enhanced the bleaching efficacy compared to the addition of ammonia (Herstedt & Herstedt 2017). Bleaching not only altered the colour of poplar, linden, and ayous woods, but also enhanced colour uniformity and increased surface wettability (Lu et al. 2023). When evaluated in bamboo laminates, the material exhibited increased natural durability due to alterations in its chemical composition, improved bonding quality, and modified surface properties, resulting in enhanced mechanical performance in terms of tensile shear strength along the glue line and flexural strength (Sharma et al. 2015; Shah et al. 2018; Reynolds et al. 2019; Guan et al. 2022).

However, limited research has been conducted on the bleaching of fast-growing woods, such as eucalypts. One of the few examples, Barbosa et al. (2024) experimented on the bleaching of *Eucalyptus grandis* W.Hill veneers with a mixture of five different reagents, including sulphur-based components, eventually posing environmental and health risks. Thus, the aim of this study was to evaluate the influence of hydrogen peroxide bleaching on the physical and optical properties of *Eucalyptus grandis* wood by varying the treatment time, temperature and pH.

Methods

Chemical modification

Eucalyptus grandis wood veneers with a thickness of 2.3 mm were donated by Miraluz Indústria e Comércio de Madeira Ltda., located in Sengés, Brazil. For the bleaching process, 12% 40 vol. hydrogen peroxide (EXODO©) and sodium hydroxide at a concentration of 40 g/L were used.

Eucalyptus grandis veneers were cut to dimensions of 50 mm x 50 mm. A total of 27 treatments were carried out varying the duration (30, 60, and 90 minutes), pH levels (4, 6, and 8), and temperature (60°C, 70°C, and 80°C). The results were compared to the untreated veneer. Ten samples were evaluated per treatment. The veneers were placed in Petri dishes and immersed in a solution of hydrogen peroxide and sodium hydroxide to adjust the pH, following the methodology of Lu et al. (2023). The veneers were rotated every 15 minutes, and at the end of the predetermined time, the specimens were washed with deionized water and stored in a climate-controlled environment until testing. The bleaching process is illustrated in Figure 1.

FIGURE 1: Bleaching of *Eucalyptus grandis* veneers in hydrogen peroxide solution

Physical and optical testing

Measurements were conducted to evaluate density, water absorption, wettability, brightness (according to TAPPI T452 om-08 standard, 2008), whiteness (according to TAPPI T525 om-22 standard, 2022), yellowing (according to DIN 6167, 1980), and the CIELab* colour scale.

For the density test, the veneers were measured using a digital calliper with a resolution of 0.01 mm and weighed on a semi-analytical balance with a resolution of 0.01 g. The density was determined by the ratio of mass to volume. Ten specimens were used for the test.

Water absorption was determined by the difference between the final and initial mass relative to the initial mass after immersion in water for 24 hours. Ten specimens were used for the test.

The wettability test was conducted by analysing the contact angle of the droplet on the bleached veneers. The test was performed in a controlled environment at a temperature of 20 ± 2°C. A droplet of deionised water of approximately 20 µL was placed onto the surface of the veneer using a syringe. Three droplets were evaluated on the surface of each veneer, with 20 readings taken for each, and the contact angle was measured using software of the digital goniometer from Ramé-Hart Instrument Co. The readings were taken immediately after the water droplet was placed onto the surface of the veneer. Three specimens were assessed for each treatment.

The optical tests for brightness, whiteness, yellowness, and the CIELab* colour scale of the veneers were conducted using the Datacolor ELREPHO© 1000 spectrophotometer. Ten specimens were used for the tests. In the CIELab* colour scale method, L* refers to luminosity, where 0 is black and 100 is white. The a* value ranges from negative to positive, with higher values indicating a redder colour and smaller values indicating a greener colour. The b* value also ranges from negative to positive, with higher values indicating a more yellow colour and smaller values indicating a bluer colour.

Statistical analysis

Analysis of variance and Tukey's tests were performed to verify whether there were significant differences between the treatment means at a 1% significance level. Regression analysis was carried out to verify whether there were correlations between the variations in treatment conditions (time, temperature, and pH) and wood property values. The statistical analysis was carried out using R software version 4.5.0 (R Core Team, 2025).

Results

Except for the mildest treatments, H_2O_2 bleaching decreased the contact angle (Figure 2) indicating increased surface wettability of the material (Table 1).
Hydrogen peroxide bleaching did not affect density or water absorption of the *E. grandis* veneers (Table 1). Table 2 presents the results of the multiple regression analysis relating the three treatment variables time, temperature, and pH to the physical properties of the *E. grandis* veneers. While pH had a significant positive effect on density, density was not affected by treatment temperature and duration. Wettability was also affected by pH, with a higher pH leading to better wettability, i.e. a smaller contact angle. Water absorption was independent of the treatment variables, consistent with the Tukey HSD results presented in Table 1.

Bleaching with hydrogen peroxide increased the brightness and whiteness of *E. grandis* veneers and reduced yellowing, especially in treatments carried out under alkaline conditions (Table 3).

Multiple regression analysis relating bleaching time, temperature, and pH to the optical properties of the *E. grandis* veneers are presented in Table 4. Veneers became brighter and whiter when bleached for longer and at higher pH. Only a higher pH caused a reduction in yellowing. Bleaching temperature did on affect optical properties.

Most H_2O_2 bleaching conditions increased the L* colour coordinate and reduced the a* and b* coordinates, resulting in whiter and more neutral tones of the *E. grandis* veneers (Table 5).

Table 6 presents the results of the multiple regression analysis relating the three treatment variables (time, temperature, and pH) to the CIELab* colour scale of the wood. All three variables increased in the L* coordinate. Bleaching time and pH reduced the a* coordinate, while time and temperature were positively and pH negatively connected to the b* coordinate.

FIGURE 2: Contact angle between water droplets and the *E. grandis* veneers bleached with H_2O_2 under different conditions (pH/temperature/time).

TABLE 1: Effect of H_2O_2 bleaching procedures on wood density, water absorption, and contact angle of *E. grandis* veneers. Standard deviation for each mean is presented in parentheses while different letters indicate significance ($p = 0.01$) of differences among means.

Treatment (pH/temperature/time)	Density (kg/m^3)	Water absorption (%)	Contact angle (°)
T1	560 ABCD (80)	63.11 A (7.12)	128.6 A (15.8)
T04/60/30	500 BCD (57)	74.39 A (11.69)	110.9 ABCD (18.4)
T04/60/60	485 CD (44)	74.65 A (7.24)	115.5 AB (24.5)
T04/60/90	520 ABCD (69)	77.30 A (14.91)	101.5 BCDEF (19.8)
T04/70/30	608 ABC (80)	70.76 A (11.00)	61.8 KLM (51.6)
T04/70/60	537 ABCD (62)	74.82 A (12.67)	84.5 FGHI (54.5)
T04/70/90	544 ABCD (98)	80.20 A (18.25)	51.7 MN (42.4)
T04/80/30	523 ABCD (84)	76.80 A (9.51)	95.7 CDEFG (29.2)
T04/80/60	496 CD (33)	73.91 A (4.73)	105.5 BCD (19.4)
T04/80/90	586 ABCD (65)	69.85 A (7.60)	80.5 GHIJ (43.8)
T06/60/30	603 ABC (67)	66.45 A (8.46)	100.1 BCDEF (16.9)
T06/60/60	528 ABCD (67)	84.83 A (5.52)	94.2 DEFGH (43.5)
T06/60/90	593 ABCD (105)	65.61 A (15.13)	79.1 GHIJK (48.9)
T06/70/30	644 A (57)	64.83 A (2.72)	31.2 O (43.9)
T06/70/60	458 D (15)	84.85 A (2.01)	94.0 DEFGH (36.5)
T06/70/90	633 AB (49)	66.58 A (9.89)	50.6 MN (49.5)
T06/80/30	607 ABC (69)	95.05 A (60.03)	96.1 CDEFG (48.0)
T06/80/60	535 ABCD (65)	74.72 A (8.79)	96.5 CDEFG (42.0)
T06/80/90	572 ABCD (64)	71.32 A (4.80)	113.7 ABC (22.5)
T08/60/30	610 ABC (105)	79.97 A (15.57)	41.1 NO (33.5)
T08/60/60	582 ABCD (106)	68.67 A (8.98)	76.8 HIJKL (43.8)
T08/60/90	643 A (101)	63.02 A (14.67)	104.9 BCD (20.8)
T08/70/30	566 ABCD (74)	75.73 A (7.49)	103.3 BCDE (49.1)
T08/70/60	549 ABCD (72)	75.88 A (10.11)	70.1 IJKL (45.4)
T08/70/90	536 ABCD (68)	81.41 A (5.60)	64.0 JKLM (54.3)
T08/80/30	562 ABCD (70)	74.60 A (9.46)	34.6 NO (53.2)
T08/80/60	612 ABC (67)	62.15 A (6.43)	85.1 EFGHI (48.0)
T08/80/90	635 AB (88)	63.84 A (14.36)	59.9 LM (47.8)

Discussion

Density of the *E. grandis* veneers was not affected by any of the H_2O_2 treatments evaluated by ANOVA. While pH showed a significant correlation with density this correlation was weak and potentially an artefact of the limited samples size ($n = 10$). Hydrogen peroxide can act as both, a delignifying and a bleaching agent, by partially removing lignin and converting certain chromophoric groups into colourless carboxylic groups (Colodette and Gomes 2015). In this case, the reagent acted primarily as a bleaching agent, as it did not compromise density or the physical integrity of the *E. grandis* material.

Water absorption was not affected by hydrogen peroxide bleaching in this experiment, as only superficial modification of the material occurred. However, more severe bleaching was reported to increase the water absorption of wood, due to changes in the chemical composition of the material (Jakob et al. 2020).

Bleaching decreased the contact angle of water droplets, increasing the wettability of the wood veneer. The surface changed from hydrophobic (contact angles 90° to 150°) to hydrophilic (contact angles 10° and 90°) according to Ferreira (2013). When bleaching was carried out in a basic medium, alkali comes into contact with the hydroxyl groups present in the wood causing the cell walls to swell. This facilitates the penetration of both the reagent and water (Gomide 1979). Greater wettability is beneficial for wood composite production as it aids the penetration of adhesives.

Whiteness and brightness of the *E. grandis* veneers increased with treatment pH and duration. While, as expected, a higher pH reduced the yellowness. In alkaline conditions hydrogen peroxide modifies lignin, stabilising the colour of the wood and reducing its tendency to yellow compared to acidic treatments (Paulsson & Parkås 2012). Increased brightness of H_2O_2 bleached *E. grandis* veneers was matched in the CIELab* colour scale, where L* values closer to 100 indicate white and values closer to 0 indicate black. Treatments lifted the L* value from ~70 to ~85. The CIELab* colour scale a* coordinate was influenced by bleaching time and pH, whereas the L* and b* coordinates were influenced by all three process factors. The a* coordinate decreased more sharply than the b* coordinate. In addition to the partial

TABLE 2: Multiple regression analysis relating time, temperature, and pH of the H_2O_2 bleaching process to the physical properties of *E. grandis* veneers.

DENSITY	
Regression equation	$536.00 - 0.01 * t - 0.57 * T + 11.78 * pH$
Adjusted R^2	4.60%
Global p-value	0.001
P-value (time)	0.943
P-value (temperature)	0.149
P-value (pH)	<0.001
WATER ABSORPTION	
Regression equation	$66.96 - 0.06 * t + 0.19 * T - 0.45 * pH$
Adjusted R^2	1.50%
Global p-value	0.063
P-value (time)	0.114
P-value (temperature)	0.011
P-value (pH)	0.411
WETTABILITY	
Regression equation	$125.58 + 0.05 * t - 0.29 * T - 4.56 * pH$
Adjusted R^2	20.7%
Global p-value	<0.001
P-value (time)	0.343
P-value (temperature)	0.005
P-value (pH)	<0.001

TABLE 3: Effect of H_2O_2 bleaching procedures on brightness, whiteness, and yellowness of *E. grandis* veneers. Standard deviation for each mean is presented in parentheses while different letters indicate significance (p = 0.01) of differences among means.

Treatment (pH/temperature/time)	**Brightness (%)**	**Whiteness (%)**	**Yellowness (%)**
T1	28.05 I (4.73)	28.08 J (4.73)	56.87 ABCD (6.22)
T04/60/30	36.06 EFGHI (2.41)	36.10 EFGHIJ (2.42)	52.62 ABCDEF (3.18)
T04/60/60	39.18 CDEFGH (2.78)	39.21 CDEFGH (2.79)	49.76 BCDEFGHI (3.44)
T04/60/90	39.99 CDEFG (2.81)	40.04 CDEFGH (2.81)	50.20 BCDEFGH (2.19)
T04/70/30	32.22 GHI (5.22)	32.26 HIJ (5.22)	57.38 ABC (7.33)
T04/70/60	37.33 CDEFGHI (5.37)	37.37 DEFGHIJ (5.38)	52.80 ABCDEF (6.36)
T04/70/90	40.45 CDEFG (4.54)	40.49 CDEFGH (4.55)	51.90 ABCDEF (4.92)
T04/80/30	37.57 DEFGHI (4.25)	37.62 DEFGHI (4.26)	52.05 ABCDEF (5.44)
T04/80/60	39.75 CDEFG (1.32)	39.80 CDEFGH (1.32)	50.38 BCDEFG (1.65)
T04/80/90	39.93 CDEFG (2.66)	39.96 CDEFGH (2.66)	52.68 ABCDEF (0.98)
T06/60/30	29.53 HI (2.75)	29.56 IJ (2.76)	58.86 AB (3.22)
T06/60/60	35.85 EFGHI (6.88)	35.89 EFGHIJ (6.90)	53.77 ABCDE (9.98)
T06/60/90	35.54 EFGHI (4.50)	35.57 FGHIJ (4.51)	55.03 ABCD (5.67)
T06/70/30	31.98 GHI (4.32)	32.00 HIJ (4.32)	57.44 ABC (6.31)
T06/70/60	39.59 CDEFG (2.96)	39.63 CDEFGH (2.97)	49.55 BCDEFGHI (2.81)
T06/70/90	33.01 FGHI (4.05)	33.03 GHIJ (4.06)	61.34 A (5.39)
T06/80/30	31.69 GHI (4.82)	31.71 HIJ (4.83)	56.18 ABCD (4.97)
T06/80/60	42.74 BCDEF (4.59)	42.77 BCDEF (4.60)	46.78 DEFGHIJ (5.49)
T06/80/90	44.39 ABCDE (5.70)	44.42 BCDEF (5.71)	47.51 CDEFGHIJ (5.98)
T08/60/30	44.47 ABCDE (5.64)	44.54 ABCDEF (5.65)	40.06 IJK (4.92)
T08/60/60	44.66 ABCDE (4.65)	44.72 ABCDEF (4.66)	42.75 FGHIJK (4.71)
T08/60/90	42.27 BCDEF (6.03)	42.33 BCDEFG (6.05)	44.21 EFGHIJK (5.94)
T08/70/30	44.13 ABCDE (7.45)	44.20 BCDEF (7.46)	41.33 GHIJK (7.73)
T08/70/60	46.68 ABCD (8.67)	46.75 ABCD (8.69)	40.13 HIJK (9.04)
T08/70/90	53.92 A (2.58)	54.02 A (2.60)	34.34 K (3.08)
T08/80/30	45.20 ABCDE (12.29)	45.27 ABCDE (9.87)	39.73 IJK (4.37)
T08/80/60	48.55 ABC (3.67)	48.62 ABC (3.68)	39.04 JK (3.01)
T08/80/90	50.56 AB (7.04)	50.60 AB (7.05)	39.13 JK (6.59)

TABLE 4: Multiple regression analysis relating time, temperature, and pH of the H_2O_2 bleaching process to the optical properties of *E. grandis* veneers

BRIGHTNESS	
Regression equation	$23.88 + 0.07 * t + 0.02 * T + 1.82 * pH$
Adjusted R^2	32.6%
Global p-value	<0.001
P-value (time)	<0.001
P-value (temperature)	0.531
P-value (pH)	<0.001
WHITENESS	
Regression equation	$23.85 + 0.07 * t + 0.02 * T + 1.82 * pH$
Adjusted R^2	31.7%
Global p-value	<0.001
P-value (time)	<0.001
P-value (temperature)	0.533
P-value (pH)	<0.001
YELLOWNESS	
Regression equation	$61.66 – 0.02 * t + 0.05 * T – 2.63 * pH$
Adjusted R^2	30.4%
Global p-value	<0.001
P-value (time)	0.312
P-value (temperature)	0.115
P-value (pH)	<0.001

TABLE 5: Effect of H_2O_2 bleaching procedures on CIELab* colour scale of *E. grandis* veneers. Standard deviation for each mean is presented in parentheses while different letters indicate significance (p = 0.01) of differences among means.

Treatment (pH/temperature/time)	L*	a*	b*
T1	71.53 J (3.89)	11.38 A (2.11)	21.29 CDEFGH (1.69)
T04/60/30	78.82 FGHI (2.71)	7.23 BCD (1.30)	23.72 BCDE (1.43)
T04/60/60	81.55 CDEFGH (1.27)	5.86 CDEFGH (0.96)	23.21 BCDEF (1.30)
T04/60/90	82.37 BCDEF (2.01)	5.99 CDEFGH (1.37)	23.72 BCDE (0.55)
T04/70/30	77.04 GHI (3.14)	8.75 ABC (2.26)	24.93 BC (2.80)
T04/70/60	80.67 CDEFGH (3.10)	6.86 CDE (2.07)	24.33 BCD (2.08)
T04/70/90	83.57 ABCDEF (2.39)	5.39 DEFGHIJ (1.41)	25.45 B (1.83)
T04/80/30	80.73 CDEFGH (2.14)	6.74 CDEF (1.67)	23.99 BCD (2.28)
T04/80/60	82.39 BCDEF (0.71)	5.73 CDEFGHI (0.68)	24.00 BCD (0.73)
T04/80/90	84.00 ABCDE (1.75)	5.37 DEFGHIJ (1.14)	26.86 AB (1.17)
T06/60/30	74.63 IJ (1.99)	9.93 AB (1.18)	24.36 BCD (1.23)
T06/60/60	79.24 EFGHI (4.57)	7.31 BCD (2.91)	24.15 BCD (3.06)
T06/60/90	80.02 EFGH (2.24)	6.88 CDE (1.59)	25.54 B (2.38)
T06/70/30	77.10 GHI (2.44)	8.20 BCD (1.33)	25.35 B (3.00)
T06/70/60	81.94 BCDEFG (1.80)	5.48 CDEFGHIJ (1.15)	23.49 BCDE (0.73)
T06/70/90	80.40 DEFGH (2.84)	6.53 CDEFG (1.80)	29.93 A (1.98)
T06/80/30	76.55 HIJ (3.38)	7.40 BCD (1.44)	24.84 BC (1.79)
T06/80/60	83.79 ABCDEF (2.48)	4.00 EFGHIJK (1.79)	23.07 BCDEFG (2.10)
T06/80/90	85.39 ABCD (2.86)	3.74 GHIJK (1.73)	24.06 BCD (2.32)
T08/60/30	82.59 BCDEF (2.91)	3.54 HIJK (1.41)	18.97 H (1.64)
T08/60/60	83.82 ABCDEF (2.22)	3.46 HIJK (1.13)	20.91 DEFGH (1.91)
T08/60/90	82.34 BCDEF (2.86)	3.85 FGHIJK (1.49)	21.21 CDEFGH (2.38)
T08/70/30	82.48 BCDEF (3.84)	4.10 EFGHIJK (1.98)	19.35 GH (2.56)
T08/70/60	84.11 ABCDE (4.07)	3.20 HIJK (2.00)	19.48 FGH (3.52)
T08/70/90	87.89 A (0.91)	1.33 K (0.36)	17.80 H (1.69)
T08/80/30	85.56 ABC (1.98)	2.57 JK (1.05)	19.92 EFGH (1.75)
T08/80/60	85.56 ABC (1.99)	2.85 IJK (0.86)	19.38 FGH (1.46)
T08/80/90	86.96 AB (3.04)	2.33 K (1.29)	19.96 EFGH (2.75)

TABLE 6: Multiple regression analysis relating time, temperature, and pH of the H_2O_2 bleaching process to the CIELab* colour scale of *E. grandis* veneers.

	L*
Regression equation	69.57 + 0.06 * t + 0.07 * T + 0.68 * pH
Adjusted R^2	44.1%
Global p-value	<0.001
P-value (time)	0.000
P-value (temperature)	0.000
P-value (pH)	0.000
	a*
Regression equation	12.75 – 0.03 * t – 0.02 * T – 0.74 * pH
Adjusted R^2	47.8%
Global p-value	<0.001
P-value (time)	<0.001
P-value (temperature)	0.030
P-value (pH)	<0.001
	b*
Regression equation	23.03 + 0.02 * t + 0.07 * T – 1.05 * pH
Adjusted R^2	30.2%
Global p-value	<0.001
P-value (time)	0.001
P-value (temperature)	<0.001
P-value (pH)	<0.001

removal and modification of lignin, hydrogen peroxide bleaching also solubilises and alters extractives, which have a significant impact on the redness of wood, i.e. the a* parameter (Mehats et al. 2021). Barbosa et al. (2024) found that L* coordinate values ranged from 47 to 60 in *E. grandis* wood bleached with sodium hydroxide, sodium sulphide, ethanol, hydrogen peroxide, and methyl methacrylate. These values are lower than those found in the present study, indicating that using more reagents, including sulphur is not advantageous for wood bleaching.

In birch wood, hydrogen peroxide treatment resulted in a colour shift towards white, along with a reduction in red tones (Mononen et al. 2005). The bleaching process also enhanced wood wettability by reducing the contact angle of water droplets on the surface. A similar outcome was observed in this study on *E. grandis* wood, confirming increased wettability and a colour adjustment towards a whiter, less red appearance due to hydrogen peroxide treatment.

Conclusions

Hydrogen peroxide bleaching influenced the physical and optical properties of *E. grandis* veneers. Density and water absorption did not show statistical differences when compared to the control treatment. However, the contact angle of water droplets decreased with chemical modification, particularly under alkaline conditions, indicating enhanced wettability. This can improve interactions with polymers and adhesives.

Optical properties such as brightness, whiteness, and yellowness increased significantly compared to the control, particularly in alkaline-treated samples. *Eucalyptus grandis* veneers bleached for 90 minutes at 70°C and pH 8 showed highest brightness and whiteness without compromising the physical integrity of the material. The treatment also improved wettability facilitating adhesive spread, making this chemical modification attractive for veneers intended for panel production.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MFFS, HRF, and CIC were responsible for the conceptualisation of the study. The chemical modification and the physical tests of density and water absorption, as well as the optical tests, were carried out by MFFS, VMMM, GSA, and GV. The wettability test was performed by MFFS, MCSB, and ECR. The first version of the manuscript was produced by MFFS and revised by GV, ECR, HRF, and CIC. All authors read and approved the final manuscript.

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