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Effect of heat treatment on colour and glossiness properties of zebrano, sapelli and merbau woods

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Abstract

Heat treatment is one of the methods of wood modification and it is known that it changes the technological properties of wood. In this study, the determination of the colour and glossiness values on the wood species which heat treated according to ThermoWood method (at 212^{o}C for 1 hour and 2 hours) that is obtained from, zebrano (*Microberlinia brazzavillensis*), sapelli (*Entandrphragma cylindrocum*) and merbau (*Intsia bijuga*) was aimed. The colour and glossiness values were determined on samples prepared from different tree species. Lightness (*L**) and yellow colour (*b**) tone values were decreased by heat treatment. The glossiness values of the test specimens were also changed by heat treatment application. According to these results; the highest total colour difference value (Δ*E**) was determined on merbau samples, the lowest total colour difference value (Δ*E**) was determined on sapelli samples. According to obtained data; it can be said that the colour and glossiness values of wood of zebrano, sapelli and merbau was affected by heat treatment.

Keywords: Heat treatment, colour, glossiness, sapelli, zebrano, merbau

Zebrano, sapelli ve merbau odunlarının renk ve parlaklık özellikleri üzerine ısıl işlemin etkisi

Öz

Isıl işlem uygulaması odun modifikasyon yöntemlerinden birisidir ve odunun teknolojik özelliklerini değiştirdiği bilinmektedir. Bu çalışmada, zebrano (*Microberlinia brazzavillensis*), sapelli (*Entandrphragma cylindrocum*) ve merbau (*Intsia bijuga*)'dan elde edilen ve ThermoWood yöntemine (212^{o}C'de 1 saat ve 2 saat) göre ısıl işlem görmüş odun türlerinde renk ve parlaklık değerlerinin belirlenmesi amaçlanmıştır. Farklı ağaç türlerinden elde edilen örneklerin renk ve parlaklık değerleri ölçülmüştür. Işıklılık (*L**) ve sarı renk (*b**) tonu değerleri ısıl işlem tarafından azalmıştır. Isıl işlem uygulaması ile deney örneklerinin parlaklık değerleri de değişmiştir. En yüksek toplam renk farkı değeri (Δ*E**) merbau odununda belirlenirken, en düşük toplam renk farkı değeri (Δ*E**) sapelli odununda belirlenmiştir. Elde edilen verilere göre; zebrano, sapelli ve merbau ağaçlarının renk ve parlaklık değerlerinin ısıl işlemden etkilendiği söylenebilir.

Anahtar kelimeler: Isıl işlem, renk, parlaklık, sapelli, zebrano, merbau

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1. Introduction

Wood materials have different glossiness and colour values. The CIE $L^*a^*b^*$ system was used to describe colour parameters and changes from untreated to heat treated wood. This system is characterized by three parameters, L^*, a^*, and b^*. The L^* axis represents lightness varying from 100 (white) to 0 (black), $+a^*$ is the red, $-a^*$ green, $+b^*$ yellow and $-b^*$ blue (Zhang et al. 2009). The lightness (L^*), red colour (a^*) tone, yellow colour (b^*) tone values and glossiness values of a wood type are changed after the heat treatment. These changes are very important for the place of use of wood material such as park furniture, garden furniture, lumber industry.

The reason for the heat treatment application is to protect the wood material. The colour of wood is darkened by heat treatment. The darkening of the colour depends on the amount of time and temperature in the heat treatment application. Various studies have been done on the colour change of wood. In previous studies, Ayata et al. (2017a) reported colour and glossiness values of heat-treated afrormosia (*Pericopsis elata*), doussie (*Afzelia bipindensis*), frake (*Terminalia superba*) and iroko (*Chlorophora excelsa*) wood species at 212°C for 1 hour and 2 hours using ThermoWood method.

When generally L^* and glossiness of the surface decreased, ΔE^* and a^* increased with the intensity of the treatment. Korkut et al. (2013) obtained that glossiness and colour properties of wild cherry (*Prunus avium*) wood samples heat-treated at 212°C for 1.5 hours and 2.5 hours (ThermoWood method). Zonuncio et al. (2014) determined that physical and colorimetric properties of *Eucalyptus grandis* after heat treatment at 140°C, 170°C, 200°C and 230°C for 3 hours. Heat treatment also reduced L^*, a^* and b^* values of the *Eucalyptus grandis* wood samples. Pincelli et al. (2012) obtained the effect of heating on L^*, a^*, b^*, C and H properties of heat-treated *Eucalyptus saligna* and *Pinus caribaea* var. *hondurensis* woods at 120ºC, 140ºC, 160ºC and 180ºC.

Chen et al. (2012) evaluated colour changes (L^*, a^*, b^* *and* ΔE^*) of black locust (*Robinia pseudoacacia*) wood heated at 120ºC for 24 hours in either nitrogen or oxygen atmosphere. a^* and b^*, total colour difference ΔE^* increased. Shi et al. (2011) determined the effect of high temperature on colour change (L^*, a^*, b^*) of heat-treated okan wood at 160°C, 180°C, 200°C, 220°C for 4 hours. Mitani and Barboutis (2014) examined the colour changes of heat-treated beech (*Fagus sylvatica* L.) wood at 180°C for 2 h, 4 h, 6 h, 8 h and 10 h under atmospheric pressure in the presence of air. Kučerová et al. (2016) examined colour properties of heat-treated European silver fir (*Abies alba* L.) wood at 100°C, 150°C, 200°C, 220°C, 240°C, 260°C, and 280°C for 60 min. Bal and Ayata (2018a,b) determined colour (L^*, a^*, b^* *and* ΔE^*) and glossiness changes of heat-treated poplar wood at 210°C for 3 hours and colour (L^*, a^*, b^* *and* ΔE^*) and glossiness changes of heat-treated black pine (*Pinus nigra*) wood at 220°C for 3 hours, respectively.

In the literature, there is no information about the effect of heat treatment at 212°C for 1 hour and 2 hours according to ThermoWood method on colour and glossiness values of zebrano (*Microberlini abrazzavillensis*), sapelli (*Entandrphragma cylindrocum*) and merbau (*Intsia bijuga*) wood species. This work is thought to be important for lumber industry, parquet industry, varnish industry, heat treatment industry and furniture industry.

2. Material and Method

2.1. Material

In this study, zebrano (*Microberlinia brazzavillensis*), sapelli (*Entandrphragma cylindrocum*) and merbau (*Intsia bijuga*) wood types were used. These wood species are important for the wood industry. Zebrano (*Microberlinia brazzavillensis*) wood type is frequently quarter-sawn and used as veneer, tool handles, boat building, and furniture (URL 1). Sapelli (*Entandrphragma cylindrocum*) wood type is used musical instruments, veneer, turned objects, plywood, cabinetry, furniture, boat building, flooring, and other small wooden specialty items (URL 2), and merbau (*Intsia bijuga*)wood type is used furniture, flooring, musical instruments, turned objects, and other specialty wood items (URL 3). They were supplied by Hasep Wood Veneer Industry and Trade Inc. in Düzce City, Turkey, in 110 cm x 12 cm x 2 cm. Wood specimens were carried out 12% moisture contents in a climatic chamber (20±2^{o}C), relative humidity (65% ±5) (ISO 554, 1976).

2.2. Method

2.2.1. Thermal process application

Heat treatment variations were applied according to ThermoWood process books (Anonymous 2003). ThermoWood® process was conducted at 212°C for 1 hour and 2 hours in Novawood factory in Gerede-Bolu City, Turkey. After, control and heat-treated wood specimens were kept to 12% moisture contents in a climatic chamber at 20±2^{o}C, relative humidity of 65% (±5) (ISO 554, 1976).

2.2.2. Determination of colour and glossiness measurements

Lightness (L^*), red colour (a^*) tone and yellow colour (b^*) tone values of heat-treated and untreated wood specimens were made by using Datacolour 110 Spectrophotometer meter, which was calibrated with light source D65, geometry measurement D/8°. The CIEL*, a^*, b^* colour (Commission Internationale de l'Eclairage, CIE) field is shown in Figure 1. ΔE^*, ΔL^*, Δb^* and Δa^*values were calculated (Eq.1, 2, 3, 4).

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

$$\Delta L^* = L^*_{\text{heat-treated}} - L^*_{\text{untreated}}, \quad (2)$$

$$\Delta b^* = b^*_{\text{heat-treated}} - b^*_{\text{untreated}}, \quad (3)$$

$$\Delta a^* = a^*_{\text{heat-treated}} - a^*_{\text{untreated}} \quad (4)$$

Parallel (//) and perpendicular (⊥) glossiness (20°, 60° and 85°) values of heat-treated and untreated wood materials were made by using a Novo-Gloss Trio instrument (Gloss-meter) according to ISO 2813 (1994) standard. Test samples with the dimension of 10 x 12 x 2 cm were used at the determination of colour and glossiness measurements.

2.2.3. Statistical analysis

A total of 10 measurements were taken for each group. In this study, SPSS 17 statistical package program was used for variance analysis and statistical analysis.

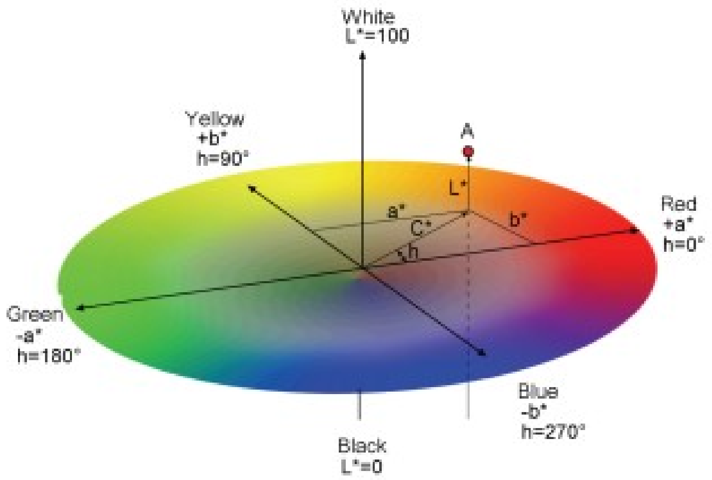

Figure 1. Three dimensional CIE *L**, *a**, *b** colour fields (Johansson 2005)

Figure 2. The colour measuring device (X-rite Ci62) (A) and the gloss meter (TQC PolyGloss GL0030) (B)

3. Results and Discussions

Variance analysis were done for *L**, *a**, *b**, perpendicular and parallel glossiness (20°, 60° and 85°) and the results are shown in Table 1. When Table 1 is examined, it is seen that wood type and the heat treatment factors and the interaction of these factors were significant in all tests (α = 0.05). The Δ*E**, Δ*L**, Δ*b** and Δ*a** values of the heat treated woods are given in Table 2. In all wood types, the Δ*E** values increased with the increase of the heat treatment time. Similar results were obtained in other studies (Dubey et al. 2011; Korkut et al. 2013; Mitani and Barboutis 2014; Hidayat et al. 2015; Kučerováet al. 2016; Gurleyen et al. 2017a,b,c; Ayata et al. 2017a,b; Sahin and Ayata 2018; Gurleyen et al. 2018; Bal and Ayata 2018a,b). The SPSS results of *L**, *a** and *b** values, are shown in Table 3. When examined in Table 3, the highest values of *L** and *b** were determined in control zebrano wood samples. The highest value of *a** was obtained in heat-treated sapelli wood at 212°C for 1 hour. The lowest values of *L**, *a** and *b** were obtained in heat treated merbau wood at 212°C for 2 hours. In a study conducted, it was determined that *L**, *a** and *b** values decreased after heat treatment when compared with control samples (Zonuncio et al. 2014). Esteves et al. (2008) found that in general *a** and *b** values decreased with the heat treatment (170°C, 180°C, 190°C and 200°C) on pine (*Pinus pinaster*) and eucalyptus (*Eucalyptus globulus*) wood species. *L* value* decreased significantly, when *a** and *b** values increased on heat-treated black locust (*Robinia pseudoacacia*) wood (Chen et al. 2012).

Table1. Variance analysis results of colour and glossiness values

Test	Source	Sum of Squares	df	Mean Square	F	Sig.
*L**	**Wood type (A)**	1479.892	2	739.946	564.330	0.000*
	Heat treatment (B)	6944.763	2	3472.381	2648.260	0.000*
	Interaction (AB)	223.575	4	55.894	42.628	0.000*
	Error	106.207	81	1.311		
	Total	173170.088	90			
*a**	**Wood type (A)**	283.014	2	141.507	710.123	0.000*
	Heat treatment (B)	49.763	2	24.881	124.862	0.000*
	Interaction (AB)	135.943	4	33.986	170.550	0.000*
	Error	16.141	81	0.199		
	Total	8075.988	90			
*b**	**Wood type (A)**	965.213	2	482.607	623.509	0.000*
	Heat treatment (B)	847.281	2	423.640	547.327	0.000*
	Interaction (AB)	287.795	4	71.949	92.955	0.000*
	Error	62.695	81	0.774		
	Total	25553.749	90			
⊥20°	**Wood type (A)**	1.803	2	0.901	100.979	0.000*
	Heat treatment (B)	6.633	2	3.316	371.539	0.000*
	Interaction (AB)	1.063	4	0.266	29.763	0.000*
	Error	0.723	81	0.009		
	Total	76.270	90			
⊥60°	**Wood type (A)**	29.005	2	14.502	117.504	0.000*
	Heat treatment (B)	5.133	2	2.566	20.794	0.000*
	Interaction (AB)	19.211	4	4.803	38.913	0.000*
	Error	9.997	81	0.123		
	Total	441.570	90			
⊥85°	**Wood type (A)**	36.091	2	18.045	132.844	0.000*
	Heat treatment (B)	10.216	2	5.108	37.604	0.000*
	Interaction (AB)	19.561	4	4.890	36.000	0.000*
	Error	11.003	81	0.136		
	Total	406.730	90			
//20°	**Wood type (A)**	0.985	2	0.492	61.164	0.000*
	Heat treatment (B)	4.609	2	2.304	286.275	0.000*
	Interaction (AB)	0.535	4	0.134	16.606	0.000*
	Error	0.652	81	0.008		
	Total	59.680	90			
//60°	**Wood type (A)**	21.284	2	10.642	42.848	0.000*
	Heat treatment (B)	4.017	2	2.008	8.086	0.001*
	Interaction (AB)	8.879	4	2.220	8.937	0.000*
	Error	20.118	81	0.248		
	Total	570.780	90			
//85°	**Wood type (A)**	92.511	2	46.255	20.075	0.000*
	Heat treatment (B)	52.068	2	26.034	11.299	0.000*
	Interaction (AB)	54.164	4	13.541	5.877	0.000*
	Error	186.636	81	2.304		
	Total	1752.720	90			

*: Significant (according to α=0.05).

Table 2. Δ*E**, Δ*L**, Δ*b** and Δ*a** values

Wood type	Heat treatment	Δ*L**	Δ*a**	Δ*b**	Δ*E**
Zebrano (*Microberliniabrazzavillensis*)	**212°C for 1 hour**	-18.07	0.78	-4.67	18.68
	212°C for 2 hours	-19.21	0.50	-5.25	19.92
Sapelli (*Entandrphragmacylindrocum*)	**212°C for 1 hour**	-14.12	0.14	-2.50	14.34
	212°C for 2 hours	-15.20	-0.20	-3.06	15.51
Merbau (*Intsiabijuga*)	**212°C for 1 hour**	-21.88	-4.79	-10.78	24.86
	212°C for 2 hours	-23.44	-5.57	-12.48	27.13

Table3. SPSS results for colour (*L**, *a** and *b**) values

Test	Wood Type	Heat Treatment	N	*X*	*HG*	Standard Dev.	Minimum	Maximum
Lightness (*L)**	**Zebrano (*Microberlinia brazzavillensis*)**	**Control**	**10**	58.65	A*	1.71	56.24	61.58
		212°C for 1 hour	**10**	40.58	D	1.27	38.87	42.44
		212°C for 2 hours	**10**	39.44	E	0.87	37.88	40.51
	Sapelli (*Entandrphragma cylindrocum*)	**Control**	**10**	54.60	B	0.31	54.09	55.24
		212°C for 1 hour	**10**	40.84	D	1.19	39.40	42.51
		212°C for 2 hours	**10**	39.40	E	0.63	38.51	40.69
	Merbau (*Intsiabijuga*)	**Control**	**10**	52.16	C	1.90	48.75	54.57
		212°C for 1 hour	**10**	30.28	F	0.89	28.81	31.89
		212°C for 2 hours	**10**	28.72	G	0.41	28.05	29.28
Red colour (*a) tone**	**Zebrano (*Microberlinia brazzavillensis*)**	**Control**	**10**	8.79	D	0.32	8.31	9.24
		212°C for 1 hour	**10**	9.57	C	0.44	8.70	10.38
		212°C for 2 hours	**10**	9.29	C	0.60	8.44	10.30
	Sapelli (*Entandrphragma cylindrocum*)	**Control**	**10**	11.36	A	0.12	11.12	11.58
		212°C for 1 hour	**10**	11.50	A*	0.30	11.15	12.11
		212°C for 2 hours	**10**	11.16	A	0.19	10.92	11.55
	Merbau (*Intsiabijuga*)	**Control**	**10**	10.45	B	0.49	9.66	11.02
		212°C for 1 hour	**10**	5.66	E	0.50	4.81	6.65
		212°C for 2 hours	**10**	4.88	F	0.72	4.02	5.98
Yellow colour (*b) tone**	**Zebrano (*Microberlinia brazzavillensis*)**	**Control**	**10**	21.86	A*	0.72	20.76	23.07
		212°C for 1 hour	**10**	17.19	DE	1.14	14.78	19.24
		212°C for 2 hours	**10**	16.61	E	0.95	15.11	18.10
	Sapelli (*Entandrphragma cylindrocum*)	**Control**	**10**	20.17	B	0.32	19.71	20.69
		212°C for 1 hour	**10**	17.67	D	0.89	16.47	19.16
		212°C for 2 hours	**10**	17.11	DE	0.51	16.56	18.18
	Merbau (*Intsiabijuga*)	**Control**	**10**	19.25	C	0.92	17.45	20.43
		212°C for 1 hour	**10**	8.47	F	1.02	6.59	10.31
		212°C for 2 hours	**10**	6.77	G	1.09	5.16	8.46
X: Arithmetic Mean, N: Number of measurements, HG: Homogeneity group, *: Highest value.								

The SPSS results for perpendicular and parallel glossiness (20°, 60° and 85°) values are shown in Table 4. According to Table 4, perpendicular glossiness values at 20° and 60°, and parallel glossiness values at 20° were the highest on control zebrano wood samples. Highest glossiness values of 85° in perpendicular and parallel were determined in the sapelli heat-treated at 212°C for 2 hours. The highest glossiness value of parallel 60° was obtained in the sapelli heat-treated at 212°C for 1 hour. Korkut et al. (2013) found that glossiness values decreased by heat treatment, when perpendicular and parallel glossiness values of heat-treated wild cherry (*Prunu savium*) wood at 212°C for 1.5 hours and 2.5 hours (ThermoWood method) were compared with the control specimens.

Table 4. SPSS results for perpendicular and parallel glossiness values

Test	Wood Type	Heat Treatment	N	*X*	*HG*	Standard Dev.	Minimum	Maximum
⊥20°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	1.52	A*	0.11	1.30	1.70
		212°C for 1 hour	10	0.63	E	0.07	0.50	0.70
		212°C for 2 hours	10	0.70	E	0.08	0.60	0.80
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	1.16	B	0.05	1.10	1.20
		212°C for 1 hour	10	0.87	D	0.07	0.80	1.00
		212°C for 2 hours	10	0.86	D	0.15	0.70	1.20
	Merbau (*Intsiabijuga*)	Control	10	1.04	C	0.11	0.90	1.20
		212°C for 1 hour	10	0.44	F	0.05	0.40	0.50
		212°C for 2 hours	10	0.49	F	0.11	0.40	0.70
⊥60°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	3.18	A*	0.36	2.60	3.60
		212°C for 1 hour	10	1.47	CD	0.24	1.10	1.80
		212°C for 2 hours	10	1.68	C	0.31	1.10	2.20
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	2.19	B	0.09	2.00	2.30
		212°C for 1 hour	10	2.88	A	0.49	2.20	3.70
		212°C for 2 hours	10	3.07	A	0.60	2.30	4.40
	Merbau (*Intsiabijuga*)	Control	10	1.73	C	0.14	1.60	2.00
		212°C for 1 hour	10	1.02	E	0.20	0.80	1.50
		212°C for 2 hours	10	1.23	DE	0.40	0.80	1.90
⊥85°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	2.16	C	0.25	1.90	2.50
		212°C for 1 hour	10	1.39	DE	0.44	0.90	2.40
		212°C for 2 hours	10	1.63	D	0.16	1.40	1.80
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	1.67	D	0.19	1.40	2.10
		212°C for 1 hour	10	2.76	B	0.58	1.90	3.70
		212°C for 2 hours	10	3.87	A*	0.61	3.20	4.90
	Merbau (*Intsiabijuga*)	Control	10	0.99	F	0.11	0.80	1.20
		212°C for 1 hour	10	1.11	EF	0.26	0.80	1.50
		212°C for 2 hours	10	1.65	D	0.34	1.20	2.20
//20°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	1.21	A*	0.07	1.10	1.30
		212°C for 1 hour	10	0.58	D	0.04	0.50	0.60
		212°C for 2 hours	10	0.63	D	0.05	0.60	0.70
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	1.04	B	0.05	1.00	1.10
		212°C for 1 hour	10	0.81	C	0.12	0.70	1.10
		212°C for 2 hours	10	0.76	C	0.16	0.60	1.10
	Merbau (*Intsiabijuga*)	Control	10	1.01	B	0.09	0.90	1.10
		212°C for 1 hour	10	0.44	E	0.05	0.40	0.50
		212°C for 2 hours	10	0.42	E	0.09	0.30	0.60
//60°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	2.84	BC	0.33	2.60	3.40
		212°C for 1 hour	10	1.64	E	0.36	1.30	2.30
		212°C for 2 hours	10	2.47	CD	0.58	1.70	3.20
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	2.77	BC	0.26	2.40	3.10
		212°C for 1 hour	10	3.31	A*	0.88	2.50	4.80
		212°C for 2 hours	10	3.00	AB	0.38	2.30	3.60
	Merbau (*Intsiabijuga*)	Control	10	2.29	D	0.19	2.00	2.60
		212°C for 1 hour	10	1.41	E	0.22	1.10	1.80
		212°C for 2 hours	10	1.83	E	0.77	1.00	3.00
//85°	Zebrano (*Microberlinia brazzavillensis*)	Control	10	4.52	BC	1.12	3.50	6.70
		212°C for 1 hour	10	2.72	D	1.52	1.40	5.10
		212°C for 2 hours	10	4.49	BC	1.61	2.20	6.10
	Sapelli (*Entandrphragma cylindrocum*)	Control	10	3.54	CD	0.39	2.90	4.30
		212°C for 1 hour	10	5.86	AB	2.41	3.00	9.50
		212°C for 2 hours	10	6.00	A*	1.18	3.90	7.40
	Merbau (*Intsiabijuga*)	Control	10	1.23	E	0.18	1.00	1.50
		212°C for 1 hour	10	2.45	DE	0.72	1.50	3.50
		212°C for 2 hours	10	4.27	C	2.58	1.60	8.00

X: Arithmetic Mean, N: Number of measurements, *HG*: Homogeneity group, *: Highest value

4. Conclusions

In this study, the changes in colour (L^*, a^*, b^*, ΔE^*, ΔL^*, Δb^* and Δa^*) and glossiness (parallel and perpendicular in 20^o, 60^o and 85^o) values of zebrano (*Microberlinia brazzavillensis*), sapelli (*Entandrphragma cylindrocum*) and merbau (*Intsia bijuga*) wood samples untreated and heat-treated at 212^{o}C for 1 hour and 2 hours were investigated.

- The wood type and heat treatment factors and the mutual interactions obtained from these factors were determined to be significant. When the total colour difference values of wood species were examined after heat treatment applications, the greatest total colour difference value was obtained in merbau wood, the lowest total colour difference value was determined in sapelli wood.
- As a result, in the study, lightness (L^*), red colour (a^*) tone value, yellow colour (b^*) tone value, perpendicular and parallel glossiness values (20^o, 60^o and 85^o) on the wood materials used, these parameters were changed with the heat treatment time according to ThermoWood method.
- With increasing heat treatment time, it was determined that a dark colour tone was formed on the wood materials.

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