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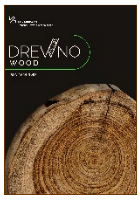

Change in Wood Color Due To The Use of Waste Vegetable Oils

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An investigation was carried out without the use of thermal treatment to determine whether waste oils have color-altering effects on wood material surfaces. Waste vegetable oils (walnut, sunflower, corn, and olive) were applied to the surfaces of wood materials from ayous (Triplochiton scleroxylon K. Schum), fukadi (Terminalia amazonia), guatambú (Balfourodendron riedelianum (Engl.) Engl.), mahogany (Swietenia mahagoni (L.) Jacq.), and rengas (Gluta renghas L.) tree species. Subsequently, a control group was established, and experimental samples were compared. Changes in color parameters (L*, Δa*, C*, ΔL*, a*, Δb*, h°, ΔH*, b*, ΔC*, and ΔE*) were investigated. The results of multivariate analysis of variance for color parameters (C*, h°, L*, a*, and b*) were found to be statistically significant. A decrease in h° and L* was observed for all wood types and waste oils. On the other hand, a* and b* values increased and C* values decreased in guatambú and ayous wood on application of all waste vegetable oils. However, in the case of mahogany and rengas wood, a* and b* values decreased while C* values increased.

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Introduction

Wood-based materials are highly popular and widely used materials in various fields, including furniture manufacturing, interior decoration, automotive interior panels, and many more [Bekhta et al. 2022]. Plant-based oils solidify at higher temperatures than mineral oils, which have pour points below 40 °C. Freezing temperatures differ between oils due to their distinct compositions. Elevated saturated content in oils results in an increased freezing point. For unsaturated oils, the point at which they start to flow lies between 10 and 20 °C [Rafiq et al. 2015; Dubey 2010].

Applying oil to wood surfaces improves the wood's dimensional stability by making it more resistant to water, which in turn reduces moisture absorption. Nevertheless, the utilization of fungal and UV agents potentially affects decay resistance and coloration. To achieve a desired color, pigments can be introduced into the oil [Pousette et al. 2009].

Surface treatment with vegetable oils proves to be an effective method for enhancing the physical properties of wood. Treatment conducted under high heat conditions using oils such as palm oil, soybean oil, or oily wax enhances wood's water absorption, moisture uptake, and resistance to shrinkage [Nonomura et al. 2021; Wang and Cooper 2005].

Ayous wood is used for creating molds, and also for crafting skirting boards, furniture, and shelves. It acquires a polished surface. It is advisable not to

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utilize it prior to kiln drying [Boulton and Price 1931]. Despite being lightweight, the timber exhibits excellent strength attributes owing to its inherent density [Bosu and Krampah 2005].

Fukadi wood is used in heavy general construction, both indoor and outdoor, carpentry, bridge foundations, flooring, beams, cladding, barrels, fences, parquet, railway ties, and ships. It is also suitable for papermaking [Llach 1971a,b; Longwood 1971; Picado et al. 1983]. In fukadi wood, tangential shrinkage is 2.49%, radial shrinkage is 1.87%, volumetric shrinkage is 4.82%, the fiber saturation point is 23.38% [Munoz-Acosta and Moreno-Perez 2013], dichloromethane solubility is 1.00%, cold water solubility is 8.20%, 1% NaOH solubility is 22.40%, hot water solubility is 15.30%, ethanol solubility is 3.40%, lignin content is 31.35%, pH is 3.79, holocellulose content is 66.44% [Moya et al. 2015], shear strength parallel to fibers is 142.00 kg/m^2, compression strength parallel to fibers is 437.70 kg/m^2 [Moya et al. 2009], the elastic modulus is 15700.00 N/mm^2, and bending strength is 151.00 N/mm^2 [Comvalius 2001].

Guatambú wood, known for its pale hue, appealing aesthetics, and moderate mechanical strength, is a suitable choice for furniture, decorative veneers, frames, intricate carvings, sporting pieces, and various artistic creations. It is used in construction for such elements as beams, rafters, laths, skirting boards, and floor tiles, and is also suitable for crafting tool handles and similar items [Anonymous 1986].

Mahogany wood is utilized in both interior and exterior joinery work [Şanıvar and Zorlu 1980]. Moreover, mahogany varieties are employed within the timber sector to create intricate cabinets and furniture, capitalizing on the wood's appealing color, texture, and durability [Gilman and Watson 1994]. The tangential surface screw holding capacity of mahogany wood has been determined as 38.36 N/mm^2 [Bal et al. 2018a] and its thermal conductivity as 0.152 W/m·K [Çavuş et al. 2019].

Rengas wood is commonly used for columns, beams, housing, bridges, buildings, furniture, panels, flooring, and resin coating for varnishing purposes [Pratiwi 2000].

The inherent hue displayed by a specific wood species is often predominantly influenced by the type of extractives it contains, typically concentrated in the heartwood. Color assumes a pivotal role, particularly when selecting species for diverse engineering applications such as crafting plywood, furniture, and flooring. However, it needs to be borne in mind that wood color can alter upon exposure to light [Olorunnisola 2018].

In this study, an investigation was made of color changes induced by certain waste vegetable oils (sunflower, olive, corn, and walnut) applied to surfaces of various wood species: fukadi (*Terminalia amazonia*), ayous (*Triplochiton scleroxylon* K. Schum), mahogany (*Swietenia mahagoni* (L.) Jacq.), guatambú (*Balfourodendron riedelianum* (Engl.) Engl.), and rengas (*Gluta renghas* L.).

Materials and methods

1. Wood material

This study utilized ayous (*Triplochiton scleroxylon* K. Schum), fukadi (*Terminalia amazonia*), guatambú (*Balfourodendron riedelianum* (Engl.) Engl.), mahogany (*Swietenia mahagoni* (L.) Jacq.), and rengas (*Gluta renghas* L.) wood as the primary experimental material. The specimens, measuring 150 x 100 x 20 mm and of premium quality, were sourced from a commercial supplier. Subsequently, the specimens were prepared following the guidelines stipulated in TS ISO 13061-1 [2021]. The materials were then subjected to air-conditioning procedures in accordance with the TS 642 ISO 554 [1997] standard.

2. Application of waste vegetable oils to wood material surfaces

The wooden material surfaces were sanded with 80, 120, and 180 grit sandpapers before application of waste vegetable oils derived from walnut, corn, and olive sources. These oils were administered on the surfaces of the wood materials using a brushing method. Specific characteristics of the waste vegetable oils utilized in the investigation are given in Table 1.

Table 1. Some properties of the waste vegetable oils used in the study

Feature (per 100 g)	Olive	Corn	Sunflower	Walnuts
Saturated fatty acid	15.15	12.00	10.00	9.10
Monounsaturated fatty acid	74.00	28.00	33.00	-
Polyunsaturated fatty acid	10.50	51.00	57.00	-

3. Color measurements

Color changes in the samples were measured using a CS-10 device (CHN Spec, China) with the CIE 10° standard observer and CIE D65 light source, using an 8/d (8°/diffuse illumination) setup as specified in the ASTM D 2244-3 (2007) standard. The CIELAB color system was employed for analysis. The quantification of total color variations was determined using the following formulae as presented by Ayata et al. [2021a,b].

$$\Delta a^* = [a^*_{\text{waste oil applied}}] - [a^*_{\text{no waste oil applied}}] \quad (1)$$

$$\Delta L^* = [L^*_{\text{waste oil applied}}] - [L^*_{\text{no waste oil applied}}] \quad (2)$$

$$\Delta b^* = [b^*_{\text{waste oil applied}}] - [b^*_{\text{no waste oil applied}}] \quad (3)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2]^{1/2} \quad (4)$$

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (5)$$

$$\Delta C^* = [C^*_{\text{waste oil applied}}] - [C^*_{\text{no waste oil applied}}] \quad (6)$$

$$h^\circ = \arctan\,[b^*/a^*] \quad (7)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2} \quad (8)$$

ΔC^* represents changes in chroma or saturation. Positive values indicate increased vibrancy and luminance compared with the reference, while samples with negative values display reduced vividness and distinctiveness relative to the reference. ΔH^* signifies variations in hue angle or shading. For ΔL^*, positive values indicate a lighter shade than the reference, and negative values a darker shade. For Δa^*, positive values indicate a more pronounced red tone than the reference, whereas negative values imply a greener hue. For Δb^*, positive values indicate increased yellowness, while negative values denote enhanced blueness [Lange 1999].

Additionally, the color alteration benchmarks listed in Table 2, taken from Barański et al. [2017], will be used in evaluating the findings presented in Table 5.

Table 2. Color change criteria according to Barański *et al.* [2017]

Color change criteria	▶	**ΔE^* value**
Invisible color change	▶	$\Delta E^* < 0.2$
Slight change of color	▶	$2 > \Delta E^* > 0.2$
Color change visible in high filter	▶	$3 > \Delta E^* > 2$
Color change visible with average quality of filter	▶	$6 > \Delta E^* > 3$
High color change	▶	$12 > \Delta E^* > 6$
Different color	▶	$\Delta E^* > 12$

4. Statistical analysis

This study utilized the capabilities of SPSS software to compute various parameters, including minimum and maximum values, groups with similar characteristics, standard deviations, percentage fluctuations (%), multivariate coefficient of variations, and mean results.

Results and discussion

The results of the multivariate analysis of variance, calculated using measurements pertaining to color parameters before and after the application of waste vegetable oils, are presented in Table 3. Significant effects were obtained for wood type (A), type of waste vegetable oil (B), and their interaction (AB).

Table 3. Multivariate analysis of variance results for color parameters

Source	Dependent variable	Sum of squares	df	Mean square	F	Sig.
Wood type (A)	*L**	54008	4	13502	44788	0.000*
	*a**	2442	4	611	2941	0.000*
	*b**	21143	4	5286	17217	0.000*
	*C**	15163	4	3791	1011	0.000*
	h°	60226	4	15057	9772	0.000*
Waste vegetable oil type (B)	*L**	8107	4	2027	6723	0.000*
	*a**	87	4	22	105	0.000*
	*b**	120	4	30	97	0.000*
	*C**	127	4	32	8	0.000*
	h°	3913	4	978	635	0.000*
Interaction (AB)	*L**	1103	16	69	229	0.000*
	*a**	1402	16	88	422	0.000*
	*b**	3029	16	189	617	0.000*
	*C**	3914	16	245	65	0.000*
	h°	1467	16	92	60	0.000*
Error	*L**	68	225	0		
	*a**	47	225	0		
	*b**	69	225	0		
	*C**	844	225	4		
	h°	347	225	2		
Total	*L**	611331	250			
	*a**	31888	250			
	*b**	121265	250			
	*C**	151658	250			
	h°	885494	250			
Corrected total	*L**	63286	249			
	*a**	3978	249			
	*b**	24360	249			
	*C**	20048	249			
	h°	65953	249			

*: Significant

The results for total color difference values (Δ*a**, Δ*L**, Δ*b**, Δ*H**, Δ*C**, and Δ*E**), calculated using the color formulae provided in the materials and methods section, after the application of waste vegetable oils to all wood types, are presented in Table 4.

Table 4. Results for total color differences

Waste vegetable oil type	Wood type	Δ*L** ▼	Δ*a** ▼	Δ*b** ▼	Δ*C** ▼	Δ*H** ▼	Δ*E** ▼	Color criteria (Baranski et al. 2017)
Sunflower	Guatambú	-8.07	5.06	7.61	8.79	2.48	12.19	X
	Mahogany	-12.89	-5.46	-10.32	-11.07	3.70	17.39	X
	Ayous	-18.54	3.50	1.04	2.26	2.86	18.89	X
	Rengas	-12.98	-0.95	-8.35	-5.91	5.98	15.47	X
	Fukadi	-18.97	6.68	2.10	4.14	5.65	20.22	X
Walnut	Guatambú	-7.12	3.91	7.04	7.59	2.68	10.75	Y
	Mahogany	-12.71	-5.53	-10.11	-11.02	3.40	17.16	X
	Ayous	-17.89	3.46	0.42	1.67	3.05	18.22	X
	Rengas	-14.30	-3.50	-10.23	-9.09	5.85	17.93	X
	Fukadi	-17.07	6.52	3.65	5.49	5.07	18.63	X
Corn	Guatambú	-7.71	3.29	5.87	3.55	5.72	10.24	Y
	Mahogany	-12.98	-8.97	-11.45	-14.50	1.08	19.49	X
	Ayous	-16.30	7.11	7.93	10.00	3.66	19.47	X
	Rengas	-10.84	-2.69	-7.62	-7.01	4.02	13.52	X
	Fukadi	-22.64	4.16	-3.15	-1.68	4.94	23.23	X
Olive	Guatambú	-8.06	4.54	7.86	8.85	1.99	12.14	X
	Mahogany	-13.26	-9.31	-11.72	-15.04		20.00	X
	Ayous	-15.78	7.29	7.89	9.83	4.33	19.09	X
	Rengas	-13.10	-3.70	-8.63	-8.42	4.15	16.12	X
	Fukadi	-23.18	3.53	-4.15	-2.79	4.68	23.81	X

X: High color change (12>Δ*E**>6), Y: Different color (Δ*E**>12)

The ΔL^* values were consistently negative (darker than the reference) for all wood and waste vegetable oil applications. In the case of ΔE^*, the values of 10.75 (waste walnut oil application on guatambú wood) and 10.24 (waste corn oil application on guatambú wood) correspond to the "***High color change (12 > ΔE* > 6)***" category of Baranski *et al.* (2017), while the values for all other waste oil applications and wood types correspond to the "***Different color (ΔE* > 12)***" category. On application of all waste oils to guatambú wood, the ΔE^* values were consistently lower than with the other wood types. Conversely, for fukadi wood, applications of all waste oils consistently gave higher ΔE^* values than for other wood types. For mahogany and rengas wood, all waste vegetable oil applications resulted in negative values of Δa^* (greener than the reference), Δb^* (bluer than the reference), and ΔC^* (cloudier than the reference). In contrast, for guatambú and ayous wood types, the values of these parameters were positive (indicating respectively: redder than the reference, yellower than the reference, and clearer or brighter than the reference). For fukadi wood, Δa^* values were consistently positive for all waste vegetable oil applications, and Δb^* and ΔC^* values were negative after applications of waste sunflower and walnut oils, but positive after applications of waste corn and olive oils (Table 4).

Throughout the process of oil thermal treatment, wood assimilates the oil and encounters elevated temperatures as a result of the oil's high boiling point, resulting in specific alterations in the chemical attributes of wood constituents [Umar et al. 2016].

The measured L^* values are provided in Table 5. Decreases in L^* values were observed for all wood types following applications of waste vegetable oils. The lowest L^* values among all wood types were obtained in the control samples. In descending order, L^* values for guatambú, ayous, fukadi, rengas, and mahogany woods were 73.60, 72.08, 62.93, 43.81, and 38.57, respectively. The percentage reductions in this value for rengas, ayous, mahogany, and guatambú wood types were similar for all waste oil applications. The lowest L^* values were determined as 65.53 for guatambú wood after waste sunflower oil application, 25.31 for mahogany wood after waste olive oil application, 53.54 for ayous wood after waste sunflower oil application, 29.51 for rengas wood after waste walnut oil application, and 39.75 for fukadi wood after waste olive oil application (Table 5).

In various studies reported in the literature, decreases in the L^* parameter resulted from the application of waste oils: for black locust [Çamlıbel and Ayata 2023b], Anatolian chestnut [Peker and Ulusoy 2023], merbau [Peker et al. 2023a], American walnut [Peker et al. 2023c], iroko [Çamlıbel and Ayata 2024], bamboo [Peker 2023b], Scots pine [Peker 2023a], wild pear [Çamlıbel and Ayata 2023c], and tiama [Çamlıbel and Ayata 2023a] (Table 10).

Measurement results for the a^* parameter are shown in Table 6. Increases in a^* were observed for guatambú, ayous, and fukadi wood after the application of waste vegetable oils, while the value decreased for mahogany and rengas. Guatambú (6.82), ayous (6.20), and fukadi (4.70) yielded the lowest a^* measurements in comparison to other woods on application of waste vegetable oils, while mahogany (12.85) and rengas (18.49) had the highest a^* values, similar to those of the control samples. The highest a^* values were 11.87 after waste sunflower oil application on guatambú wood, 13.49 after waste walnut oil application on ayous wood, and 11.38 after waste walnut oil application on fukadi wood (Table 6).

Table 5. Results for the L^* parameter

Oil type	Value	Wood type				
		Guatambú	**Mahogany**	**Ayous**	**Rengas**	**Fukadi**
Control	Mean	73.60	38.57	72.08	43.81	62.93
	Homogeneity Group	A*	N	B	K	E
	Standard Deviation	0.38	0.22	0.40	0.84	0.91
	Minimum	72.98	38.24	71.44	42.40	61.17
	Maximum	74.12	38.97	72.65	45.52	63.72
	Coefficient of Variation	0.52	0.57	0.55	1.92	1.45

Sunflower	Mean	65.53	25.67	53.54	30.82	43.96
	Change (%)	↓10.97	↓33.43	↓25.72	↓29.64	↓30.15
	Homogeneity Group	D	ST	I	P	K
	Standard Deviation	0.40	0.27	0.48	0.24	0.80
	Minimum	65.05	25.36	52.70	30.32	43.05
	Maximum	66.41	26.32	54.18	31.06	46.10
	Coefficient of Variation	0.61	1.05	0.90	0.78	1.82
Walnut	Mean	66.48	25.85	54.19	29.51	45.86
	Change (%)	↓9.67	↓32.97	↓24.82	↓32.64	↓27.12
	Homogeneity Group	C	S	H	R	J
	Standard Deviation	0.83	0.33	1.04	0.39	0.81
	Minimum	65.48	25.25	52.96	28.92	44.42
	Maximum	68.14	26.33	55.66	30.26	46.69
	Coefficient of Variation	1.25	1.28	1.92	1.32	1.77
Corn	Mean	65.89	25.59	55.77	32.97	40.29
	Change (%)	↓10.48	↓33.64	↓22.62	↓24.75	↓35.97
	Homogeneity Group	D	ST	G	O	M
	Standard Deviation	0.55	0.20	0.57	0.40	0.23
	Minimum	64.98	25.36	54.76	32.25	39.87
	Maximum	66.66	25.92	56.80	33.50	40.53
	Coefficient of Variation	0.83	0.78	1.02	1.21	0.57
Olive	Mean	65.54	25.31	56.30	30.70	39.75
	Change (%)	↓10.95	↓34.38	↓21.89	↓29.91	↓36.83
	Homogeneity Group	D	T**	F	P	M
	Standard Deviation	0.26	0.20	0.50	0.45	0.61
	Minimum	65.11	24.80	55.84	29.86	39.04
	Maximum	65.92	25.55	57.18	31.10	40.88
	Coefficient of Variation	s	0.79	0.89	1.47	1.53

* Highest value, ** Lowest value

The percentage reductions in *a** values after waste sunflower and walnut oil applications on mahogany wood (42.50% and 43.06%, respectively) were close to those obtained after waste corn and olive oil applications (69.81% and 72.48%, respectively). A similar pattern was observed for ayous wood: the reductions after waste sunflower and walnut oil applications (56.41% and 55.76%, respectively) were similar to those after waste corn and olive oil applications (114.67% and 117.69%, respectively) (Table 6).

Table 6. Results for the *a** parameter

Oil type	Value	Wood type				
		Guatambú	**Mahogany**	**Ayous**	**Rengas**	**Fukadi**
Control	Mean	6.82	12.85	6.20	18.49	4.70
	Homogeneity Group	O	F	P	A*	R
	Standard Deviation	0.17	0.17	0.24	0.66	0.57
	Minimum	6.55	12.56	5.82	17.80	3.89
	Maximum	7.16	13.19	6.47	19.76	5.34
	Coefficient of Variation	2.49	1.32	3.87	3.57	12.13
Sunflower	Mean	11.87	7.39	9.69	17.54	11.38
	Change (%)	↑74.14	↓42.50	↑56.41	↓5.14	↑142.19
	Homogeneity Group	G	N	K	B	H
	Standard Deviation	0.34	0.46	0.38	0.36	0.33
	Minimum	11.26	6.61	9.17	16.75	10.90
	Maximum	12.51	7.90	10.17	18.09	11.97
	Coefficient of Variation	2.86	6.22	3.92	2.05	2.90
Walnut	Mean	10.73	7.32	9.65	14.98	11.22
	Change (%)	↑57.41	↓43.06	↑55.76	↓18.94	↑138.70
	Homogeneity Group	I	N	K	D	H
	Standard Deviation	0.35	0.32	0.21	1.03	0.26
	Minimum	10.10	6.76	9.31	13.60	10.73
	Maximum	11.15	7.77	9.99	16.97	11.51
	Coefficient of Variation	3.26	4.37	2.18	6.88	2.32
Corn	Mean	10.11	3.88	13.30	15.79	8.86
	Change (%)	↑48.23	↓69.81	↑114.67	↓14.57	↑88.47
	Homogeneity Group	J	S	E	C	L
	Standard Deviation	0.57	0.48	0.33	0.98	0.14
	Minimum	8.91	3.16	12.78	13.76	8.64
	Maximum	10.91	4.50	13.88	17.16	9.03
	Coefficient of Variation	5.64	12.37	2.48	6.21	1.58

Olive	Mean	11.36	3.54	13.49	14.79	8.23
	Change (%)	↑66.60	↓72.48	↑117.69	↓20.02	↑75.00
	Homogeneity Group	H	S**	E	D	M
	Standard Deviation	0.27	0.54	0.26	0.33	0.21
	Minimum	10.91	2.58	13.04	14.23	7.94
	Maximum	11.82	4.53	13.80	15.25	8.51
	Coefficient of Variation	2.38	15.25	1.93	2.23	2.55

* Highest value, ** Lowest value

Literature reports indicate that the application of waste oils to wooden materials leads to an increase in the *a** parameter in some wood species – iroko [Çamlıbel and Ayata 2024], Anatolian chestnut [Peker and Ulusoy 2023], European spruce [Peker et al. 2023a], bamboo [Peker 2023b], Scots pine [Peker 2023a], wild pear [Çamlıbel and Ayata 2023c] – but a decrease in the case of others: tiama [Çamlıbel and Ayata 2023a], European larch [Ayata and Bal 2023], black locust [Çamlıbel and Ayata 2023b] (Table 10).

The values obtained for *b** are presented in Table 7. On application of all waste vegetable oils, increases in *b** were observed for guatambú and ayous woods, and decreases for mahogany and rengas. For fukadi wood, increases were recorded on application of waste sunflower oil (9.47%) and waste walnut oil (16.44%), and decreases on application of waste corn oil (514.18%) and waste olive oil (18.73%). The highest *b** values for mahogany (15.32) and rengas (18.70) were recorded in the control samples, while the lowest *b** values for guatambú (25.16) and ayous (23.94) were those of the control samples (Table 7).

Literature reports indicate that when waste vegetable oils are applied to wooden materials, there is an increase in the *b** value in certain wood species – Scots pine [Peker 2023a], bamboo [Peker 2023b], European spruce [Peker et al. 2023a], Anatolian chestnut [Peker and Ulusoy 2023], wild pear [Çamlıbel and Ayata 2023c], black locust [Çamlıbel and Ayata 2023b] – and a decrease in others: tiama [Çamlıbel and Ayata 2023a], European larch [Ayata and Bal 2023], iroko [Çamlıbel and Ayata 2024], merbau [Peker et al. 2023a], American walnut [Peker et al. 2023c] (Table 10).

The values of *C** calculated from the color formula are presented in Table 8. Increases in *C** were found after waste vegetable oil applications for ayous (6–40%) and guatambú (29–34%) woods, and decreases for rengas (19.34%) and mahogany (55–75%) woods. For fukadi wood, the value increased by 18.25% on waste sunflower oil application and by 24.20% on waste walnut oil application, but decreased by 7.39% on waste corn oil application and by 12.31% on waste olive oil application. The lowest *C** values for guatambú and ayous woods were determined in the control group (26.07 and 24.54, respectively), whereas the highest *C** values for mahogany and rengas woods were those of the control samples (20.00 and 26.31, respectively) (Table 8).

Table 7. Results for the *b** parameter

Oil type	Value	Wood type				
		Guatambú	**Mahogany**	**Ayous**	**Rengas**	**Fukadi**
Control	Mean	25.16	15.32	23.94	18.70	22.18
	Homogeneity Group	E	J	F	H	G
	Standard Deviation	0.32	0.19	0.80	0.73	1.16
	Minimum	24.66	15.02	23.18	17.52	20.35
	Maximum	25.63	15.77	26.04	19.83	23.29
	Coefficient of Variation	1.27	1.24	3.34	3.90	5.23

Sunflower	Mean	32.77	5.00	24.99	10.35	24.27
	Change (%)	↑30.24	↓67.35	↑4.35	↓44.66	↑9.47
	Homogeneity Group	A	N	E	L	F
	Standard Deviation	0.47	0.31	0.43	0.41	0.82
	Minimum	32.02	4.67	24.05	9.60	23.60
	Maximum	33.29	5.59	25.36	10.71	26.36
	Coefficient of Variation	1.43	6.20	1.72	3.96	3.38
Walnut	Mean	32.20	5.21	24.36	8.47	25.82
	Change (%)	↑27.97	↓66.00	↑1.76	↓54.70	↑16.44
	Homogeneity Group	B	N	F	M	D
	Standard Deviation	1.10	0.28	0.49	0.33	0.61
	Minimum	31.22	4.68	23.71	8.03	24.74
	Maximum	35.12	5.58	24.95	9.21	26.58
	Coefficient of Variation	3.42	5.37	2.01	3.90	2.36
Corn	Mean	31.03	3.88	31.87	11.09	19.03
	Change (%)	↑23.34	↓74.71	↑33.11	↓40.72	↓14.18
	Homogeneity Group	C	O	B	K	H
	Standard Deviation	0.64	0.31	0.23	0.50	0.29
	Minimum	29.74	3.25	31.33	10.43	18.63
	Maximum	31.94	4.15	32.20	11.80	19.60
	Coefficient of Variation	2.06	7.99	0.72	4.51	1.52
Olive	Mean	33.02	3.61	31.83	10.08	18.02
	Change (%)	↑31.23	↓76.47	↑32.95	↓46.13	↓18.73
	Homogeneity Group	A*	O**	B	L	I
	Standard Deviation	0.28	0.29	0.26	0.43	0.58
	Minimum	32.52	3.23	31.24	9.16	17.20
	Maximum	33.46	4.15	32.18	10.48	19.29
	Coefficient of Variation	0.85	8.03	0.82	4.27	3.22

* Highest value, ** Lowest value

Table 8. Results for the *C** parameter

Oil type	Value	Wood type				
		Guatambú	**Mahogany**	**Ayous**	**Rengas**	**Fukadi**
Control	Mean	26.07	20.00	24.54	26.31	22.67
	Homogeneity Group	DE	G	E	CDE	F
	Standard Deviation	0.34	0.14	0.36	0.52	1.25
	Minimum	25.53	19.88	23.98	25.57	20.72
	Maximum	26.52	20.25	24.92	26.92	23.87
	Coefficient of Variation	1.30	0.70	1.47	1.98	5.51
Sunflower	Mean	34.86	8.93	26.81	20.41	26.81
	Change (%)	↑33.72	↓55.37	↑9.22	↓22.45	↑18.28
	Homogeneity Group	A	J	CD	G	CD
	Standard Deviation	0.44	0.54	0.51	0.25	0.85
	Minimum	34.18	8.10	25.74	19.83	26.07
	Maximum	35.33	9.55	27.32	20.58	28.95
	Coefficient of Variation	1.26	6.05	1.90	1.22	3.17
Walnut	Mean	33.66	8.99	26.21	17.22	28.16
	Change (%)	↑29.13	↓55.08	↑6.80	↓34.56	↑24.20
	Homogeneity Group	A	J	DE	I	BC
	Standard Deviation	0.48	0.32	0.46	1.01	0.60
	Minimum	32.84	8.23	25.67	16.02	27.11
	Maximum	34.27	9.29	26.81	19.31	28.90
	Coefficient of Variation	1.43	3.56	1.76	5.87	2.13
Corn	Mean	29.62	5.50	34.54	19.30	20.99
	Change (%)	↑13.62	↓72.52	↑40.72	↓26.64	↓7.39
	Homogeneity Group	B	K	A	GH	FG
	Standard Deviation	9.25	0.53	0.24	0.93	0.30
	Minimum	3.36	4.62	34.12	17.26	20.54
	Maximum	33.35	6.13	34.85	20.82	21.59
	Coefficient of Variation	31.23	9.64	0.69	4.82	1.43

Olive	Mean	34.92	4.96	34.38	17.89	19.88
	Change (%)	↑33.97	↓75.22	↑40.05	↓32.00	↓12.31
	Homogeneity Group	A*	K**	A	HI	G
	Standard Deviation	0.31	0.67	0.66	0.41	0.48
	Minimum	34.44	3.70	32.68	17.11	19.23
	Maximum	35.49	6.13	34.90	18.33	21.01
	Coefficient of Variation	0.89	13.51	1.92	2.29	2.41

* Highest value, ** Lowest value

Table 9. Results for the h^o parameter

Oil type	Value	Wood type				
		Guatambú	**Mahogany**	**Ayous**	**Rengas**	**Fukadi**
Control	Mean	74.90	50.02	75.38	45.33	78.07
	Homogeneity Group	B	J	B	K	A*
	Standard Deviation	0.25	0.63	0.41	1.82	0.87
	Minimum	74.35	49.09	74.94	42.52	76.89
	Maximum	75.17	51.46	75.97	48.08	79.34
	Coefficient of Variation	0.33	1.26	0.54	4.02	1.11
Sunflower	Mean	70.08	34.12	68.77	30.49	64.87
	Change (%)	↓6.44	↓31.79	↓8.76	↓32.74	↓16.90
	Homogeneity Group	D	M	E	N	I
	Standard Deviation	0.63	0.89	0.57	1.32	0.50
	Minimum	68.91	33.17	68.14	28.13	64.22
	Maximum	70.95	35.81	69.49	32.36	65.57
	Coefficient of Variation	0.90	2.61	0.83	4.33	0.77
Walnut	Mean	71.41	35.47	68.38	29.54	66.51
	Change (%)	↓4.66	↓29.09	↓9.28	↓34.83	↓14.81
	Homogeneity Group	C	L	EF	N*	GH
	Standard Deviation	0.41	1.64	0.56	1.31	0.59
	Minimum	71.01	33.48	67.16	28.08	65.30
	Maximum	72.09	38.03	68.97	31.90	67.18
	Coefficient of Variation	0.57	4.62	0.82	4.43	0.89

Corn	Mean	71.97	45.01	67.34	35.11	65.03
	Change (%)	↓3.91	↓10.01	↓10.66	↓22.54	↓16.69
	Homogeneity Group	C	K	FG	LM	I
	Standard Deviation	0.68	2.46	0.53	1.78	0.37
	Minimum	70.80	41.70	66.51	32.60	64.61
	Maximum	73.32	49.34	68.06	37.32	65.70
	Coefficient of Variation	0.94	5.47	0.79	5.07	0.57
Olive	Mean	71.02	45.74	67.03	34.27	65.54
	Change (%)	↓5.18	↓8.54	↓11.07	↓24.41	↓16.04
	Homogeneity Group	CD	K	G	M	HI
	Standard Deviation	0.39	3.59	0.38	1.13	0.78
	Minimum	70.55	42.68	66.44	31.66	64.55
	Maximum	71.82	54.75	67.68	35.64	66.68
	Coefficient of Variation	0.55	7.85	0.57	3.30	1.19

* Highest value, ** Lowest value

In various studies, it has been reported that the application of waste vegetable oils to wooden materials leads to an increase in the C^* value in certain wood species – bamboo [Peker 2023b], European spruce [Peker et al. 2023a], Scots pine [Peker 2023a], iroko [Çamlıbel and Ayata 2024], wild pear [Çamlıbel and Ayata 2023c], Anatolian chestnut [Peker and Ulusoy 2023], black locust [Çamlıbel and Ayata 2023b] – and a decrease in others: tiama [Çamlıbel and Ayata 2023a], European larch [Ayata and Bal 2023], American walnut [Peker et al. 2023c], merbau [Peker et al. 2023a] (Table 10).

The results for the h^o parameter are presented in Table 9. These show that applications of waste vegetable oils to all wood types reduced the values of that parameter. The h^o values for control samples (in descending order) were 78.07 for fukadi, 75.38 for ayous, 74.90 for guatambú, 50.02 for mahogany, and 45.33 for rengas. For all wood types, the highest h^o values were obtained for the control samples. The percentage falls in value were significantly greater for mahogany and rengas than for the other species. The smallest reductions were recorded for guatambú wood (sunflower: 6.44%, walnut: 4.66%, corn: 3.91%, and olive: 5.18%) (Table 9).

Literature reports indicate that the application of waste vegetable oils to wooden materials results in a decrease in the h^o value in certain wood species: bamboo [Peker 2023b], wild pear [Çamlıbel and Ayata 2023c], tiama [Çamlıbel and Ayata 2023a], black locust [Çamlıbel and Ayata 2023b], Anatolian chestnut [Peker and Ulusoy 2023], Merbau [Peker et al. 2023a], American walnut [Peker et al. 2023c], iroko [Çamlıbel and Ayata 2024]. For others, an increase is reported: European spruce [Peker et al. 2023a], European larch [Ayata and Bal 2023], Scots pine [Peker 2023a] (Table 10).

The study has confirmed that the color parameters of wood materials are changed by the application of waste vegetable oils. The study successfully achieved its goal of investigating color alterations.

Literature reports of experiments involving thermal treatment using different oil types also indicate that alterations occur in the color parameters of wooden materials [Razak et al. 2011; Bak and Németh 2012; Nejad et al. 2019; Suri et al. 2021]. The findings of the present study align with those recorded in the literature.

Table 10 presents a comparison between the results of previous studies conducted using waste vegetable oils and those of the present research.

Table 10. Comparison of studies on waste vegetable oils

Wood type	Oil type	Change on application					Reference
		*L**	*a**	*b**	C*	*h*°	
Guatambú (*Balfourodendron riedelianum* (Engl.) Engl.)	Sunflower	↓	↑	↑	↑	↓	This study
	Walnut	↓	↑	↑	↑	↓	
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Mahogany (*Swietenia mahagoni* (L.) Jacq.)	Sunflower	↓	↓	↓	↓	↓	
	Walnut	↓	↓	↓	↓	↓	
	Corn	↓	↓	↓	↓	↓	
	Olive	↓	↓	↓	↓	↓	
Ayous (*Triplochiton scleroxylon* K. Schum)	Sunflower	↓	↑	↑	↑	↓	
	Walnut	↓	↑	↑	↑	↓	
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Rengas (*Gluta renghas* L)	Sunflower	↓	↓	↓	↓	↓	
	Walnut	↓	↓	↓	↓	↓	
	Corn	↓	↓	↓	↓	↓	
	Olive	↓	↓	↓	↓	↓	
Fukadi (*Terminalia amazonia*)	Sunflower	↓	↑	↑	↑	↓	
	Walnut	↓	↑	↑	↑	↓	
	Corn	↓	↑	↓	↓	↓	
	Olive	↓	↑	↓	↓	↓	
European spruce (*Picea abies* (L.) Karst.)	Walnut	↑	↑	↑	↑	↑	Peker et al. [2023a]
	Corn	↑	↑	↑	↑	↑	
	Olive	↑	↑	↑	↑	↑	
European larch (*Larix decidua* Mill.)	Walnut	↑	↓	↓	↓	↑	Ayata and Bal [2023]
	Corn	↑	↓	↓	↓	↑	
	Olive	↑	↓	↓	↓	↑	

Bamboo (*Phyllostachys* spp.)	Sunflower	↓	↑	↑	↑	↓	Peker [2023b]
	Walnut	↓	↑	↑	↑	↓	
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Scots pine (*Pinus sylvestris* L.)	Walnut	↓	↑	↑	↑	↑	Peker [2023a]
	Corn	↓	↑	↑	↑	↑	
	Olive	↓	↑	↑	↑	↑	
Wild pear (*Pyrus communis* L.)	Sunflower	↓	↑	↑	↑	↓	Çamlıbel and Ayata [2023c]
	Walnut	↓	↑	↑	↑	↓	
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Tiama (*Entandrophragma angolense*)	Sunflower	↓	↓	↓	↓	↓	Çamlıbel and Ayata [2023a]
	Walnut	↓	↓	↓	↓	↓	
	Corn	↓	↓	↓	↓	↓	
	Olive	↓	↓	↓	↓	↓	
Black locust (*Robinia pseudoacacia* L.)	Walnut	↓	↑	↑	↑	↓	Çamlıbel and Ayata [2023b]
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Anatolian chestnut (*Castanea sativa* Mill.)	Walnut	↓	↑	↑	↑	↓	Peker and Ulusoy [2023]
	Corn	↓	↑	↑	↑	↓	
	Olive	↓	↑	↑	↑	↓	
Merbau [*Intsia bijuga* (Colebr.) O. Kuntze]	Sunflower	↓	↓	↓	↓	↓	Peker et al. [2023a]
	Walnut	↓	↓	↓	↓	↓	
	Corn	↓	↓	↓	↓	↓	
	Olive	↓	↑	↓	↓	↓	
American walnut (*Juglans nigra* L.)	Sunflower	↓	↑	↓	↓	↓	Peker et al. [2023c]
	Walnut	↓	↓	↓	↓	↓	
	Corn	↓	↓	↓	↓	↓	
	Olive	↓	↑	↓	↓	↓	

Iroko	Walnut	↓	↑	↓	↑	↓	Çamlıbel
(*Milicia excelsa*	Corn	↓	↑	↓	↑	↓	and Ayata
Welw. C.C. Berg)	Olive	↓	↑	↓	↑	↓	[2024]

Conclusions

- Application of the same waste vegetable oils leads to varying results in terms of changes in color parameters across different wood species.
- Based on the outcomes of the study, multivariate analysis of variance yielded statistically significant results for color parameters.
- For all types of wood and waste oils, there was a reduction in h^o and L^* values. In guatambú and ayous wood, the application of all waste vegetable oils led to an increase in a^* and b^* values, accompanied by a decrease in C^* values. However, in the case of mahogany and rengas wood, the changes were in the opposite direction: a decrease in both a^* and b^* values and an increase in C^* values.
- It is recommended to conduct natural or artificial aging tests on wood materials treated with waste vegetable oils as in this study.

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