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A FINITE ELEMENT APPROACH TO INVESTIGATE THE PERFORMANCE AND RELIABILITY OF AN EXTENSION STAND IN TABLE SAW MACHINES

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Abstract

The extension stand serves as an assistant to the single user on the table saw machine (TSM) without an inbuilt extension. This research developed and simulated an extension stand to estimate its performance reliability during operations. SolidWorks software 2021 was used in designing the stand. Simulation and modeling of the components were performed with SOLIDWORKS 2021 software to generate stress and strain analysis. The extension stand consists of medium wooden members (50 x 50 x 75 mm), having four (4) caster wheels at the upper part of the stand. The designed extension stand was fabricated and evaluated. The simulation analysis shows maximum directional deformation at 3.889e-00 mm, equivalent elastic strain at 2.667e-04, von Mises equivalent stress and yield strength at 6.421e+06 N/m^2 and 3.930e+07 N/m^2 respectively, with the factor of safety at 6.1. The produced extension stand performed optimally with the estimated cost of manufacturing at N17,000.00 (US$38.04) as of 2021. The extension, as evaluated, passed the reliability test; it was strong enough to support the weight of the applied load during the empirical and simulated processes. The stand provides safety; it is affordable and easy to use.

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A FINITE ELEMENT APPROACH TO INVESTIGATE THE PERFORMANCE AND RELIABILITY OF AN EXTENSION STAND IN TABLE SAW MACHINES

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1. Introduction

Complications involving the prediction of wood and wood-based products behavioural patterns in service have proven a challenging task until recently (Okpala and Okechukwu, 2015). Experts in the field relied on intuition and experience to predict the behaviour of wood (DeCristoforo, 1988). In developed countries, a lot of efforts have been made to develop non-destructive techniques for the prediction and reliability assessment of materials, including wood (Brischke, 2021). Assessments on the capacity of carpentry joints using finite element (FE) models had been investigated, compared to experimental results with acceptable prediction capacity (Massaro et al., 2022). Huber et al. (2022) presented a technique based on X-ray computed tomography scans for recreating the geometry, pith, knots, and local fibre orientations in wood boards. They suggest that in the future, adapting the method for logs could enable analyses of boards before sawing. Nailed connection in wood (Hong and Barrett, 2010), screws (Hu et al., 2022) crack propagation (Qiu et al., 2014), water absorption (Salin, 2008), wood fracture mechanics (2004), and many other behaviours have been presented (Blomqvist et al., 2023). Autengruber et al. (2021) developed a finite-element-based simulation concept to better understand the failure mechanics of wood-based composites and to support a targeted optimization of new cross-section types of I-joist beams. The performance of the modeling approach was reported as providing a very good prediction of stiffness values. Developing countries such as Nigeria are gradually catching up with the trend (Icha and Odey, 2024). Hence, applying this approach to investigate the performance of locally developed products gives the professionals the platform to compete with those around them.

Woodworking machines are dedicated equipment that are designed and used for a variety of wood processing activities (Landscheidt and Kans, 2016; Twede, 2005). Expert woodworkers, who make wood products including furniture, cabinets, doors, windows, and many other wood-based items in woodworking factories and workshops, often employ this equipment (Top et al. 2016; Camci et al. 2018; Kisseloff, 1969; Wacker, 1970). Many pieces of equipment and machinery used for processing wood are divided into categories based on their uses and include sanders, saws, planers, routers, jointers, and lathes, among others. According to Lucisano et al. (2016) and Landscheidt and Kans (2016), these machines are made to carry out specialized operations such as cutting, shaping, drilling, sanding, and polishing wood. Due to the high importation costs, access to this equipment is limited in low-income countries like Nigeria (ITC/ITTO, 2002). Industries and factories employ outdated versions of machinery from advanced nations, while those with little financial resources locally manufacture them for usage (Adewole, 2015; Oteng-Amoako et al. 2008).

One of the advantages of using woodworking machines is that they can increase the speed and accuracy of wood processing tasks (Adewole et al. 2017). For instance, a table saw machine (TSM) can cut wood pieces to the exact measurements required, and a router can shape and create intricate designs on wood pieces that would be difficult to achieve by hand. In addition, using woodworking machines reduces physical stress, making work more efficient and less strenuous (Richards, 1966). Conversely, improper use of woodworking equipment can result in dangers such as injury or damage to the tool or the wood processed (Kminiak et al. 2016; Marinov, 2014: Tomlinson, 1971). Hence, woodworkers must acquire the right training and tools and adhere to machinery safety precautions (Skills Institute Press, 2010).

TSM is a major wood conversion equipment and comes in many shapes and sizes (Adewole, 2015; Sokolovski and Deliiski, 2009). The ability to make accurate and precise cuts is one of the table saw's key advantages. Users could make bevels, grooves, and other specific cuts because of the blade's ability to adapt to different angles and depths (Cheng et al. 2010; Kminiak et al. 2016). The machine also cuts through thick, dense materials, which makes it the best tool for slicing through hardwoods, plywood, and other difficult materials (Krilec et al. 2014; Orlowski et al. 2020). It is adaptable and can be applied to several woodworking projects. It can generate customized cuts and shapes with the right jigs and fixtures, as well as for ripping, crosscutting, and precision cutting (Capotosto, 1983; De Cristoforo, 1988; Kminiak and Kubs, 2016; Odey and Icha, 2022).

The use of the TSM, as with others, requires safety precautions; otherwise, the implications are fatal. According to the Environmental Health and Safety Office (EHSO, 2017), kickbacks can happen, resulting in significant injury. Other disadvantages of some TSMs include noise and a messy work environment (Chukarin et al. 2017; Meskhi et al. 2014). One such safety measure applied to TSMs is the use of an extension stand when cutting long boards and large panels (Capototos, 1983; De Cristoforo, 1988). The added workspace helps to stabilize the wood and provide additional support, which can help to reduce the risk of kickback or other accidents during the cutting process (De Cristoforo 1988; Hamilton and Nubs, 2015). However, the reliability check for such stands has not been carried out to determine the performance capacity and possible failure modes. The study focuses on the use of the finite element method to simulate and evaluate the performance of the extension stand.

2. Materials and Methods

2.1. Outline

The manuscript considers the mechanical properties of the stand construction made of wood that could be used as an extension part of a TSM. The analysis was carried out using a finite element method. The literature, structural design, manufacturing costs, and mechanical loading acting on the support in real conditions were previously considered. The results of the numerical calculation are presented. Two different scales are presented with the FE-models to portray performance reliability and failure mode.

2.2. Materials

The materials used in this study were solid wood (mahogany) available within the environment of the research area (Calabar - Nigeria). The bolts used in the study were M20 and M4 end-to-end bolts with their hand-fabricated knobs. The screw used in this study was a GB wood screw made of steel. Figure 1 shows the pictorial view of the designed extension stand. A detailed drawing and an exploded view of the stand are shown in Figures 2 and 3, respectively. The specific configurations of the extension stand are also presented.

Figure 1: Pictorial view of the designed extension stand

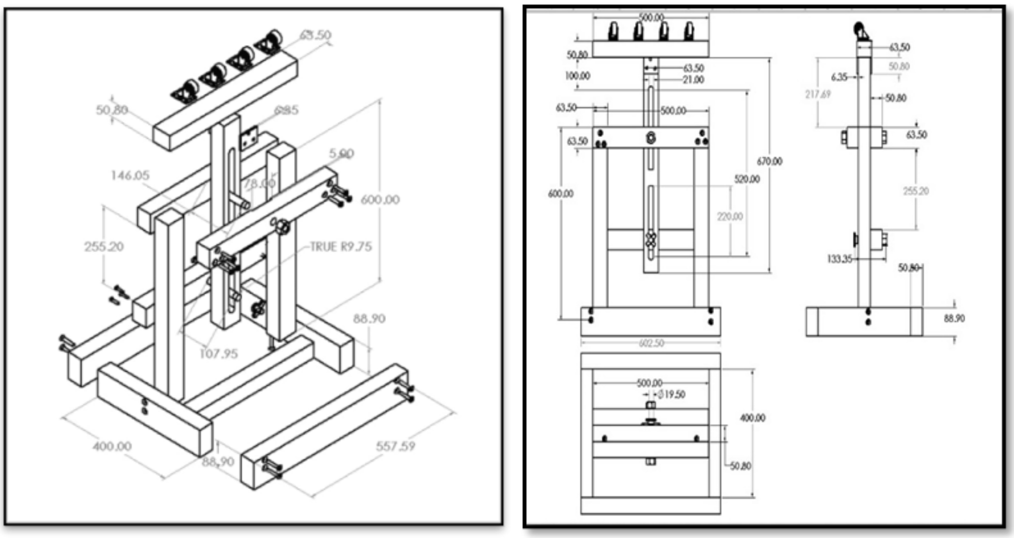
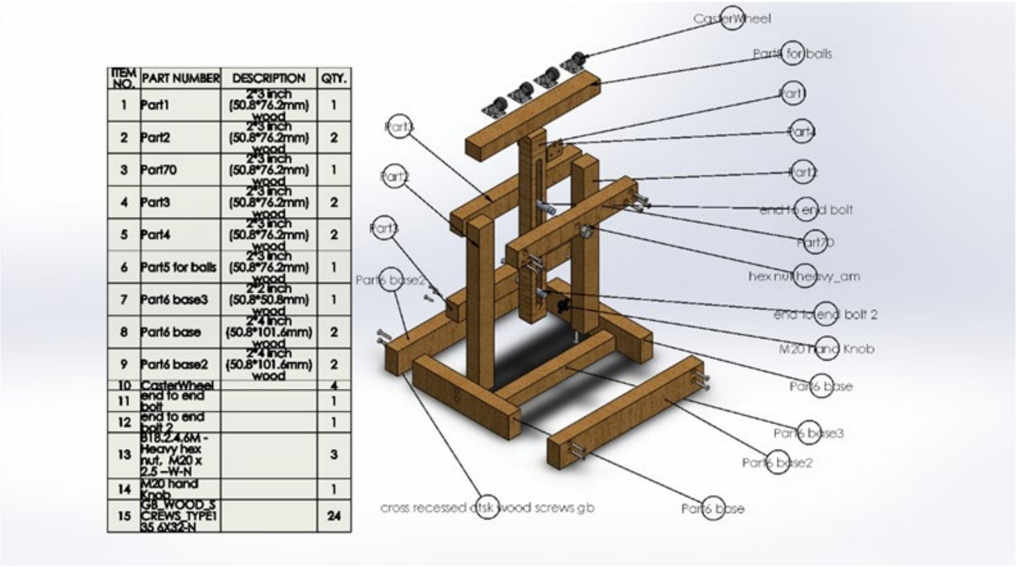


Figure 2: Detailed drawing of the designed extension stand



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Part1	2*3 inch (50.8*76.2mm) wood	1
2	Part2	2*3 inch (50.8*76.2mm) wood	2
3	Part70	2*3 inch (50.8*76.2mm) wood	1
4	Part3	2*3 inch (50.8*76.2mm) wood	2
5	Part4	2*3 inch (50.8*76.2mm) wood	2
6	Part5 for balls	2*3 inch (50.8*76.2mm) wood	1
7	Part6 base3	2*2 inch (50.8*50.8mm) wood	1
8	Part6 base	2*4 inch (50.8*101.6mm) wood	2
9	Part6 base2	2*4 inch (50.8*101.6mm) wood	2
10	CasterWheel		4
11	end to end bolt		1
12	end to end bolt 2		1
13	B18.2.4.6M - Heavy hex nut, M20 x 2.5 --W-N		3
14	M20 hand Knob		1
15	GB_WOOD_SCREWS_TYPE135 6X32-N		24

Figure 3: Exploded view of the designed extension stand

2.3. Design Considerations

The design of extension stand took into account estimates for the fasteners' resistance, screw-holding ability, and loading capacity. The fastener design processes outlined in Forest Products Laboratory's General Technical Report from 2021 were adhered to.

2.3.1. Bolts

The shear and bearing capacity under the bolt were computed using the formula of Seward (2014).

Shear capacity,

$$F_{v,\,Rd} = \frac{0.6\, f_{ub} A}{\gamma_{M2}} \tag{1}$$

Bearing capacity

$$F_{b,\,Rd} = \frac{f_{ub} d t}{\gamma_{M2}} \tag{2}$$

Where; f_{ub}= ultimate tensile strength of bolt, A = bolt tension area/full area, γM2 = partial safety factor = 1.25, d = nominal bolt diameter, t = plate thickness

2.3.2. Screws

Screws were commonly used in areas where withdrawal strength was important (Hu et al. 2022). Care was taken when tightening screws in the wood to avoid stripping the threads. The maximum amount of torque that was applied to a screw before the threads in the wood were stripped is given by

$$T = 3.16+0.0069X \text{ (Khurmi and Gupta, 2005)} \tag{3}$$

Where. T is torque (N–m) and X is the density of the board ($kg\ m^{-3}$).

Equation (T) is for 8-gauge screws with a depth of penetration of 15.9 mm. The maximum torque is fairly constant for lead holes: 0% to 90% of the root diameter of the screw.

Ultimate withdrawal loads P (N) of screws from wood was predicted by the equation given in Forest Products Laboratory's General Technical Report from 2010.

$$P = KD^{1/2}\,(L-D/3)^{3/4}\,G2 \tag{4}$$

Where. D = shank diameter of the screw (mm, in.), L = depth of embedment of the threaded portion of the screw (mm), and G = specific gravity of the board based on oven-dry weight and volume at current moisture content. K = 41.1 for withdrawals from the face of the board, and K = 31.8 for withdrawals from the edge. Other screw withdrawal load resistance considerations were following Hu et al. (2022).

2.4. Costing of Production

The materials used for the fabrication of the extension stand were estimated based on the list produced by the design software (Figure 3). Table 1 shows the cost of fabricating the extension stand. The stand cost a total of seventeen thousand, one hundred naira (N17,000) an equivalent of US$38 as of 2021. This shows that workshops within the town can afford the extension stand with the interest of fabricating the table saw machine.

Table 1: Material cost analysis of extension stand

Description of Item	**Qty**	**Unit**	**Rate**	**Amount (N)**
50mmx50mm wood	3	Pieces	400	1,200
Medium-size top bond glue	1	Jar	800	800
Bolt	2	Pieces	500	1,000
Knob	2	Pieces	100	200
50mmx75mm wood	1	Pieces	600	600
Screws	1	Pound	600	600
Washer	4	Pieces	100	400
Caster wheel	2	Pair	2600	5,200
Transportation				2,000
Workmanship				5,000
TOTAL				**17,000**

2.5. Fabrication of Extension Stand

Materials for the fabrication of the extension stand were sourced from the local wood market within the research location and taken to the University Wood Products Engineering workshop for the fabrication process. Full-lengths of mahogany wood with dimensions of 50 x 50 x 1200mm were first processed and cut into dimensions as specified in the design (Figure 2). Holes for bolts and knobs were drilled as detailed. Finally, the stand was assembled using an electric driver. Screws were driven into the blocks perpendicular to the face to ensure the screw threads were fully inserted into samples.

2.6. Experimental Evaluation

Figure 4 illustrates the setup of the extension stand on the table saw machine. The extension stand was placed on the floor perpendicular to the table saw machine. A full-length plywood board of 18 x 2240 × 1220 mm was used to perform the reliability test of the extension stand on the table saw machine using visual observations and on-the-job assessment methods. The worker was also observed for signs of difficulty during the operation. All observations were recorded.

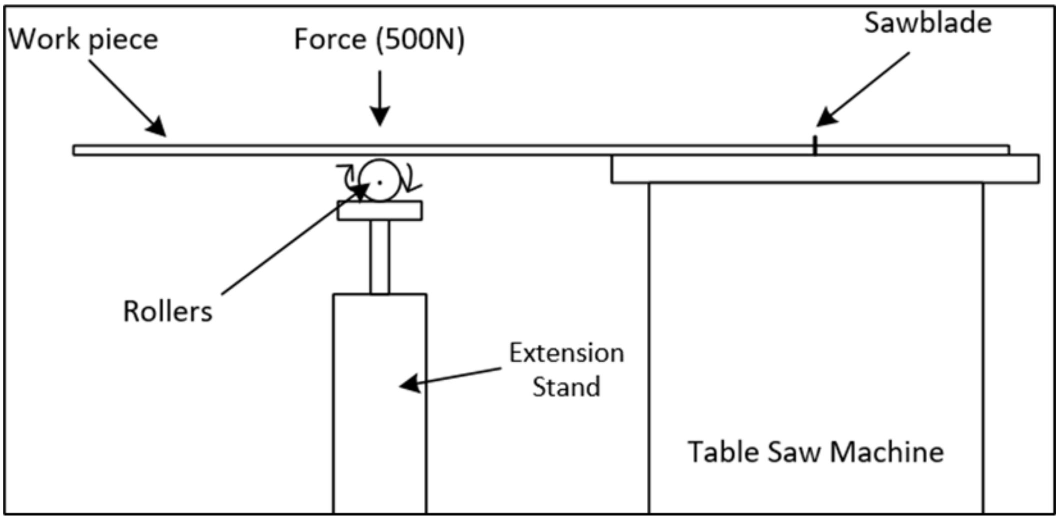


Figure 4: Experimental setup of the extension stand on the table saw machine

2.7. Finite Element Modelling

Finite element modelling (FEM) was employed in this study to simulate the extension stand performance in a TSM, closely resembling the real conditions of the experimental evaluation. The 3D finite element model (FE model) geometry is depicted in Figure 5. The simulations were conducted using the FE SolidWorks (2021) software interface. The mesh density of the wood-based sample was set at approximately 1.2 mm, ensuring adequate representation of the material's structural properties. The mechanical properties of solid wood, as detailed in Table 2 (NCP 1973), were specified within the FE model. The model used tetrahedral elements (Silid186) with degrees of freedom (d.o.f) per node, allowing for translations in the x, y, and z directions. For the extension stand connection, bolts and nuts were modelled as illustrated in Figure 3. Contact interactions were simulated using surface-to-surface elements with a friction coefficient of 0.33, as derived from the literature (Massaro et al., 2023). Finite sliding was assumed to accurately replicate the contact behavior between the rollers and the workpiece. Both linear and non-linear finite element analysis (FEA) were considered in this study. Non-linear analysis accounted for material and geometric non-linearities, reflecting the real-world behavior of the wood under loading conditions. The stress-strain behavior of the wood, essential for capturing the non-linear response, was defined based on experimental data (Figure 7), ensuring an accurate representation of material properties within the model. The base in the yz-plane was assigned as a fixed support geometry, anchoring the model to replicate the experimental setup shown in Figure 5. A displacement load (500N) was applied in the direction of the rollers, perpendicular to the TSM, until the maximum magnitude was reached (Figure 4). A mesh convergence study was conducted to ensure the accuracy of the FE model. Several mesh densities were tested, with the final mesh chosen based on achieving less than 1% change in the von Mises stress and reaction force outputs between successive refinements. The final mesh configuration provided an optimal balance between computational efficiency and solution accuracy. Two FE models were developed in this study: one representing the true scale of deformation and the other at a scaled factor of 23,6896 to highlight failure modes. The von Mises equivalent stress and the maximum reaction force at the reference point of the applied load were the primary outputs analysed. The FE model's accuracy was validated against experimental results, with a deviation of less than 19% in the key performance metrics, indicating high reliability of the simulations.

Table 2: Mechanical properties of wood used in the study

Property	Value	Units
Elastic modulus	9800	N/m^2
Poisson's Ratio	0.032	N/A
Tensile strength	2.04	N/mm^2
Compressive strength	6.9	N/mm^2
Yield strength	39.3	N/m^2
Mass density	600	kg/m^3
Shear modulus	3 x 10^8	N/m^2

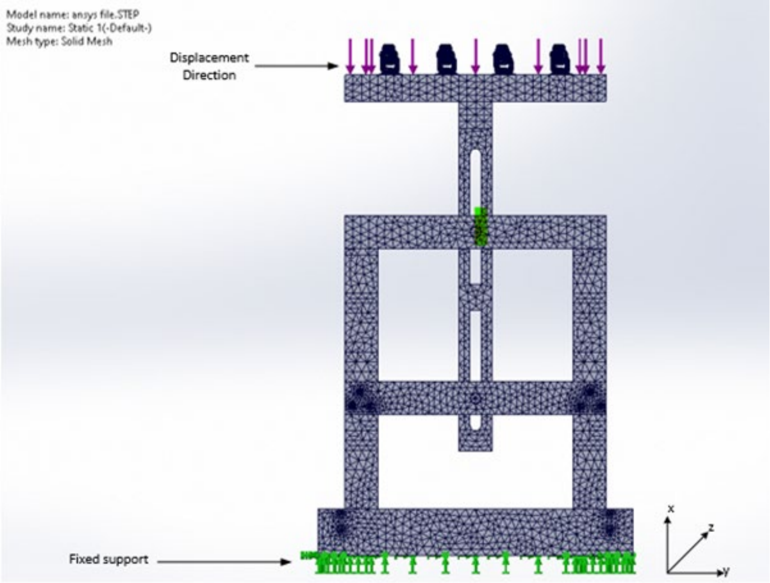


Figure 5: Mesh and boundary conditions in the numerical model

3. Results and Discussion

3.1. Fabrication and Evaluation of Extension Stand

The extension stand, as shown in Figure 6, was easy to fabricate using simple and portable tools. It is observed that using fabrication methods according to DeCristoforo (1988) and Capototos (1983) produced satisfactory results. For easy screwing, an improvised method was used to fabricate the knobs for the bolts. The evaluation process was done in the university departmental workshop using the table saw machine examined during the design process. Figure 7 shows the finished extension stand that is ready for use with the table saw. The extension stand was tested with a standard-length plywood board (Figure 7). The stand was observed to support the user adequately and satisfactorily after the evaluation process. There was no risk of not fixing the stand to the floor as the rollers allowed the boards to slide through the stand.

Figure 6. Extension stand ready for use with the table saw machine

Figure 7. Evaluation process of the extension stand on table saw machine

3.2. Simulation Analysis of the Extension Stand

Table 3 presents the data from the simulation analysis carried out on the modelled extension stand when a force of 500 N is applied. The directional deformation, elastic strain equivalent, and equivalent static stress are presented at minimum and maximum levels. The yield strength and safety factor are also presented in the table. The directional deformation values of the extension stand, which indicate the amount by which the object deforms or changes shape in a particular direction, range from a minimum of 1.000 x 10^{-30} mm to a maximum of 3.889 mm. The equivalent elastic strain values of the extension stand measure the ratio of deformation to the original length of the stand and provide an indication of its elasticity range from a minimum of 0 to a maximum of 2.667 x 10^{-4}. The stress experienced values of the extension stand, which indicate the internal forces acting on the stand resulting from external loads or deformation, range from a minimum of 0 N/m^2 to a maximum of 6.421 x 10^{6}. The yield strength of the extension stand, which is the maximum stress it can withstand without permanent deformation or failure, is 3.930 x 10^{07} N/m^2. The factor of safety associated with the extension stand is given as 6.1.

Table 3: Simulation results: maximum and minimum load values

Object Name	Directional Deformation	Equivalent Elastic Strain	Equivalent Stress	Yield Strength	Factor of Safety
Minimum	1.000e-30 mm	0.000e+00	0.000e+00 N/m^2	3.930e+07 N/m^2	6.1
Maximum	3.889mm	2.667e-04	6.421e+06 N/m^2		

3.2.1. Stress Distribution

Figure 8(a) shows the von Mises stress distribution around the simulated FE model of the extension stand when exposed to external loading of 500N. The stress distribution can be read by corresponding values on the legend. The stresses are observed to be highest at the base of the stand and around the braced neck region. Other areas were observed to have minimal stress distribution. To observe a physical deformation on the FE model ES, von Mises stress was scaled to 23,6896 (Figure 8b). A sway away from the central—axis is observed.

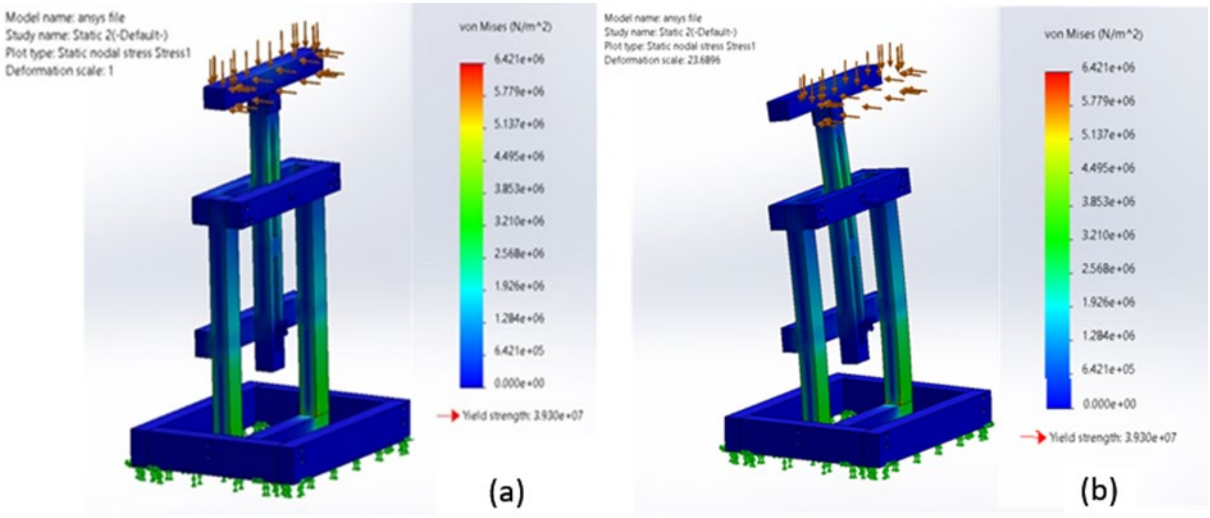


Figure 8. von Mises stress distribution of ES at deformation scale of 1(a) and 23,6896(b)

3.2.2. Strain Distribution

Figure 9(a) depicts the elastic strain distribution around the simulated FE model. The strain distribution follows a similar pattern to the stress distribution around the extension stand when subjected to external loading. The strain distribution on the extension stand covers larger areas than those seen on the stress diagram, spreading along the brace on the base post and down the neck post to the middle brace point. Other areas were observed to be in the minimal levels of strains, especially the base. To project physical deformation on the FE model ES, strain was scaled to 23,6896 (Figure 9b) showing a sway away from the central —axis.

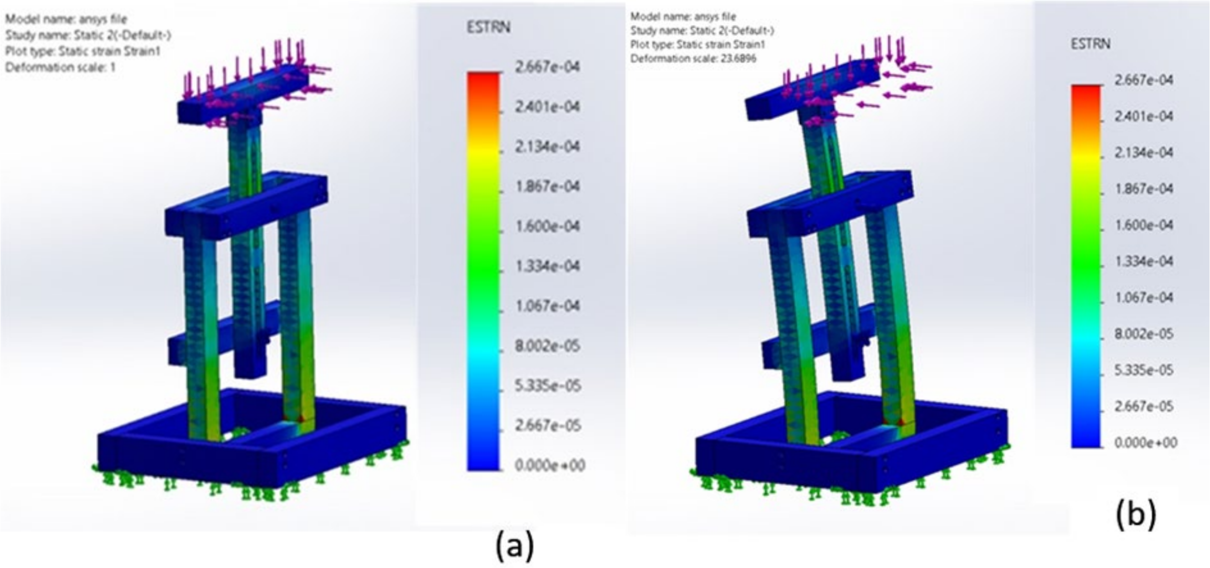


Figure 9. Strain distribution of ES at deformation scale of 1(a) and 23,6896(b)

3.2.3. Displacement Distribution

Figure 10(a) shows the displacement distribution analysis on the simulated ES FE model when an external load is acting on it. The distribution is observed to be highest at the top where the caster wheel is situated, spreading down toward the base but ending just about midway. From there downward is observed to be at the minimal levels of displacement, and no visual distortion is observed on the platform. To project physical deformation on the FE model ES, displacement was scaled to 23,6896 (Figure 10b) showing a sway away from the central —axis.

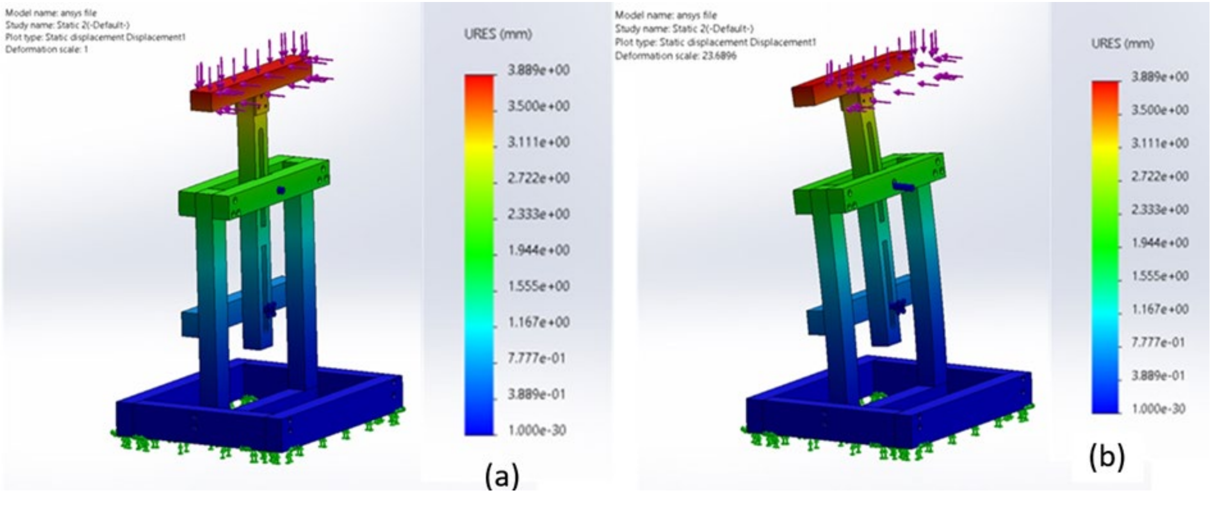


Figure 10. Displacement distribution of ES at deformation scales of 1(a) and 23,6896(b)

3.2.4. Factor of Safety

Figure 11 shows the safety value factor for the extension stand. When subjected to a force of 500N, the design has a minimum factor of safety of 6.1. This means the extension stand is 6.1 times stronger than the force acting on it.

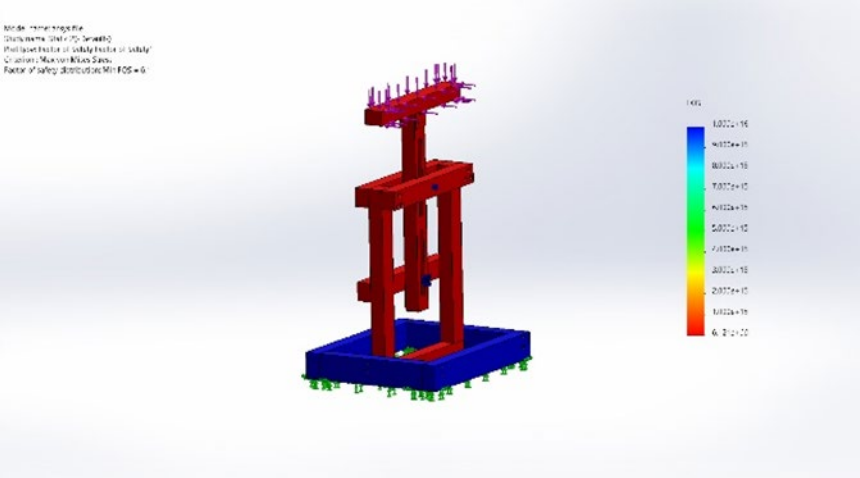


Figure 11: Factor of safety

4. Conclusion

This study successfully employed a FE approach to investigate the performance and reliability of an extension stand for TSMs. The results demonstrate that the ES enhances the usability and safety of the TSMs, which could encourage the development and use of the locally made TSMs. The FE model effectively simulated the behaviour of the ES in wood-based materials, providing insights into stress distributions and predicted potential failure modes, with validation against experimental results showing a deviation of less than 19% in key performance metrics. These insights can guide improvements in the design and reliability of the stand where necessary. The FE analysis serves as a preliminary tool for identifying key areas for enhancement. Future research should integrate optimization techniques to refine the design parameters and improve the stand's performance further. Also modifying and simulating the ES for use with other woodworking machines and on developing additional hardware such as storage compartments or shelves to increase the stand's functionality. The extension stand is affordable, easy to use, safe, and adaptable for educational and research purposes, potentially enhancing economic development. By utilizing this stand, woodworkers can improve their efficiency and precision and create high-quality wood products.

Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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INVESTIGATION OF COLOR CHARACTERISTICS OF SOME TYPES OF WOOD TREATED WITH COLORED VARNISH WOOD PRESERVATIVE

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Abstract

In this study, color parameters and total color differences were compared among wood species treated with colored varnish wood preservative (blue and rosewood colors, 2 coats) including Maritime pine (*Pinus pinaster*), Russian olive (*Elaeagnus angustifolia* L.), Persian silk (*Albizia julibrissin*), American walnut (*Juglans nigra*), mulberry (*Morus alba*), black alder (*Alnus glutinosa* L. Gaertn.), mahogany (*Swietenia mahagoni* (L.) Jacq.), and ayous (*Triplochiton scleroxylon* K. Schum). According to the obtained results, variance analyses were found to be significant. Decreases were observed in the L*, a*, b*, and C* values with the application of blue varnishes across all wood species, while increases were obtained in the ho values. Similarly, decreases were recorded in the L* and ho values with the application of rose varnishes on all wood species.

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INVESTIGATION OF COLOR CHARACTERISTICS OF SOME TYPES OF WOOD TREATED WITH COLORED VARNISH WOOD PRESERVATIVE

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1. Introduction

Wood is primarily made up of three organic polymeric components: cellulose, hemicellulose, and lignin, which mainly define its chemical and physical characteristics. In addition, wood contains small amounts of non-structural substances, known collectively as extractives. These include compounds like fats, sugars, resins, starches, oils, alkaloids, gums, and tannins. The amount of extractives can vary widely, ranging from less than 1% to up to 10% of the oven-dry weight of the wood (Tsoumis, 1992).

Applying varnish to wood surfaces used in furniture and decoration does not guarantee that they are adequately protected. To effectively establish a protective layer with varnish, it is important to take into account the possible effects the wood might encounter in its intended application. Choosing a varnish type that offers maximum durability against these potential challenges is essential, and the application must follow the appropriate techniques. Moreover, implementing various precautions before varnishing can extend the service life of the materials (Sönmez, 2000).

Before applying any coating onto the wood surface, a product that guarantees durability, beauty, and applicability of the coating must be found. Additionally, it should be ensured that the product provides a fast drying time, good elasticity, film adhesion, and thus excellent fiber penetration (Espinoza Calderón, 1993; Rivera, 2016).

When unpainted or unvarnished wood is exposed to external factors, it undergoes various deteriorations due to atmospheric effects. The exposed surfaces of a board or other piece of wood often exhibit a condition known as 'raised grain,' which causes the surface to become rough and wrinkled or fuzzy. Small cracks and splits appear, sometimes turning into large cracks that encompass the entire wood. The board tends to warp and even escape from the pieces holding it in place. Finally, the fibers on the surface disintegrate and disperse. In this way, the exposed layers of the wood gradually wear away (Deka et al., 2003; Guzmán Mejía, 2016).

At different times, a broad spectrum of materials has been used for "varnishing". A conventional classification could be pure drying oils, combinations of drying oils and resins, resins dissolved in turpentine spirits, and gums, which are substances soluble in water but insoluble in alcohol (Kurz, 1962).

In order to extend the aesthetic and economic lifespan of wood surfaces, paints, and varnishes are the most frequently used materials for liquid surface treatments that form a protective coating (Kurtoğlu, 2000).

Varnishes of varying compositions, when applied over different wood stains, can alter the color and shade of the stained wood surfaces. This effect may result in irreversible changes after application, leading to conflicts in furniture manufacturing (Çakıcıer, 1994). Wood is commonly coated with various decorative and protective treatments, such as penetrating finishes, semi-transparent stains, opaque paints, or clear varnishes that form a protective film, to ensure its long-term durability (George et al., 2005).

This study involved a comparison of color parameters and total color differences across various wood species treated with a colored varnish wood preservative (blue and rosewood colors, 2 coats). The wood species included in the analysis were Russian olive, maritime pine, Persian silk, mahogany, black alder, American walnut, mulberry, and ayous. An online literature review revealed that studies involving colored varnishes on these specific wood species are lacking. The findings from this study are expected to offer valuable information about both the wood species and the colored varnishes applied.

2. Materials and Methods

2.1. Materials

2.1.1. Wood Materials

Maritime pine (*Pinus pinaster*), Russian olive (*Elaeagnus angustifolia* L.), Persian silk (*Albizia julibrissin*), American walnut (*Juglans nigra*), mulberry (*Morus alba*), black alder (*Alnus glutinosa* L. Gaertn.) mahogany (*Swietenia mahagoni* (L.) Jacq.), and ayous (*Triplochiton scleroxylon* K. Schum) wood samples were prepared in dimensions of 100 mm x 100 mm x 15 mm. The samples were subjected to conditioning treatments (20±2°C with 65% relative humidity) according to ISO 554 (1976). The wood test samples were obtained through purchase.

2.1.2. Sandpapers

In this study, 80, 120, and 150 grit sandpapers were acquired through purchase.

2.1.3. Colored Varnish Wood Preservative Chemical

The type of varnish used in the study belongs to a specialized company and is available in two different colors: blue and rosewood. It is alkyd resin-based, transparent, and resistant to UV rays (touch dry: 2-3 h, dust-free: 3-4 h, hardening: 24 h, flash point: 38oC). These types of varnishes were obtained through purchase.

2.2. Method

2.2.1. Application of Colored Varnish Wood Preservative Chemicals on Wood Material Surfaces

Before applying the varnish, the wood surfaces were sanded using 80, 120, and 150 grit sandpapers. The sanded wood surfaces were cleaned with the help of a compressor. The varnish was applied in one coat at 12-15 m^2/L using a brush, and it was applied in 1 and 2 coats. A drying period of 24 hours was allowed between coats. The varnishing of the samples was carried out according to the manufacturer's recommendations and the ASTM D3023-98 (2017) standard.

2.2.2. Determination of Color Parameters Properties

The color changes in the wood samples were assessed using a CS-10 device (CHN Spec, China), following the CIELAB color system and ASTM D 2244-3 (2007) standard [CIE 10° standard observer; CIE D65 light source, illumination geometry: 8/d (8°/diffuse illumination)]. Definitions for ΔC*, Δa*, Δb*, and ΔL* are detailed in Table 1, adapted from Lange (1999).

Table 1: The definitions of Δa*, ΔC*, Δb*, and ΔL* (Lange 1999).

Test	Positive Description	Negative Description
Δb*	More yellow than the reference	Bluer than the reference
ΔL*	Lighter than the reference	Darker than the reference
Δa*	Redder than the reference	Greener than the reference
ΔC*	Clearer, brighter than the reference	More dull, matte than the reference
Δb*	More yellow than the reference	Bluer than the reference

Table 2 presents alternative criteria for comparing the visual assessment of the calculated ΔE* color difference, by DIN 5033 (DIN 1979) standards.

Table 2: Comparison criteria for ΔE* evaluation (DIN 5033 1979).

Visual	Total Color Difference	Visual	Total Color Difference
Undetectable	<0.20	Very Distinct	3.00 - 6.00
Very Weak	0.20 - 0.50	Strong	6.00 - 12.00
Weak	0.50 - 1.50	Very Strong	> 12.00
Distinct	1.50 - 3.00		

The results of total color differences were determined using the following formulas.

$$\Delta a^* = [a^*_{\text{varnish applied}}] - [a^*_{\text{control}}] \tag{1}$$

$$\Delta L^* = [L^*_{\text{varnish applied}}] - [L^*_{\text{control}}] \tag{2}$$

$$\Delta b^* = [b^*_{\text{varnish applied}}] - [b^*_{\text{control}}] \tag{3}$$

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

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

$$\Delta C^* = [C^*_{\text{varnish applied}}] - [C^*_{\text{control}}] \tag{6}$$

$$h^{o} = \arctan\,[b^*/a^*] \tag{7}$$

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

2.3. Statistical Analysis

Statistical analysis was performed using a statistical software package on the measurement data collected for the study. This included calculating identifying homogeneity groups, standard deviations, computing mean-associated measurement values, determining maximum and minimum mean values, and determining percentage (%) change rates, and conducting variance analyses.

3. Results and Discussion

The results of the analysis of variance are presented in Table 3. Upon examining the variance analyses, wood type (A), varnish color (B), and the interaction (AB) were found to be significant across all tests (Table 3).

Table 3: Results of variance analysis

Source	Test	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Sig. ($\alpha \le 0.05$)
Wood Type (A)	Lightness (L^*)	25506.013	7	3643.716	6168.479	0.000*
	Red (a^*) color tone	892.360	7	127.480	561.794	0.000*
	Yellow (b^*) color tone	4218.859	7	602.694	1519.868	0.000*
	Chroma (C^*)	4926.411	7	703.773	1731.312	0.000*
	Hue (h^o) tone	23645.310	7	3377.901	1083.026	0.000*
Varnish Color Type (B)	Lightness (L^*)	17437.839	2	8718.920	14760.336	0.000*
	Red (a^*) color tone	9470.109	2	4735.055	20866.992	0.000*
	Yellow (b^*) color tone	12261.109	2	6130.554	15459.975	0.000*
	Chroma (C^*)	17855.548	2	8927.774	21962.716	0.000*
	Hue (h^o) tone	63252.086	2	31626.043	10139.970	0.000*
Interaction (AB)	Lightness (L^*)	2095.654	14	149.690	253.411	0.000*
	Red (a^*) color tone	1856.398	14	132.600	584.356	0.000*
	Yellow (b^*) color tone	1675.036	14	119.645	301.721	0.000*
	Chroma (C^*)	2480.531	14	177.181	435.873	0.000*
	Hue (h^o) tone	23633.022	14	1688.073	541.231	0.000*

*: Significant

The results for total color differences are shown in Table 4. The ΔH^* values were calculable for all wood species as they emerged positively from the root degree. Δa^* values were found to be negative for both varnish colors applied to mahogany wood. For all other wood species, this parameter was obtained as negative (greener than the reference) with the blue-colored varnish, while it was determined as positive (redder than the reference) with the rose-colored varnish. In the Δb^* values, the rose-colored varnish applied to black alder wood was found to be positive (more yellow than the reference), while all other wood species and their varnished states were obtained as negative (bluer than the reference). For all wood species and varnish types, the ΔL^* values were obtained as negative (darker than the reference). The color change criteria were found to be “very strong (> 12.00)” for the varnishes applied to black alder, maritime pine, mahogany, ayous, mulberry, Persian silk, and American walnut wood species. In Russian olive wood, the criterion was determined as “very strong' (> 12.00)” with blue-colored varnish, while it was classified as “strong (6.00 - 12.00)” with rose-colored varnish. The ΔE^* values were calculated as 17.51 for blue-colored varnish and 13.79 for rose-colored varnish on mahogany wood, 31.20 for blue-colored varnish, and

19.90 for rose-colored varnish on ayous wood, 27.58 for blue-colored varnish and 12.98 for rose-colored varnish on mulberry wood, 37.53 for blue-colored varnish and 14.73 for rose-colored varnish on Persian silkwood, 24.11 for blue-colored varnish and 12.57 for rose-colored varnish on American walnut wood, 21.02 for blue-colored varnish and 10.40 for rose-colored varnish on Russian olive wood, 31.42 for blue-colored varnish and 18.33 for rose-colored varnish on black alder wood, and 36.14 for blue-colored varnish and 15.04 for rose-colored varnish on maritime pine wood (Table 4).

Table 4: Results related to total color differences

Wood Type	Type of Varnish	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	Color Criterion (DIN 5033, 1979)
Mahogany	Blue	-7.88	-11.06	-11.05	-15.30	3.22	17.51	Very Strong (> 12.00)
	Rose	-6.86	-7.19	-9.57	-11.89	1.33	13.79	
Ayous	Blue	-25.62	-6.77	-16.47	-17.46	3.53	31.20	
	Rose	-17.18	9.91	-1.56	2.84	9.62	19.90	
Mulberry	Blue	-18.72	-8.47	-18.40	-20.21	1.25	27.58	
	Rose	-8.64	8.50	-4.64	0.55	9.67	12.98	
Persian silk	Blue	-27.12	-11.18	-23.42	-23.41	11.18	37.53	
	Rose	-10.81	9.90	-1.47	3.12	9.51	14.73	
American walnut	Blue	-18.98	-6.54	-13.35	-14.60	2.76	24.11	
	Rose	-11.05	5.33	-2.74	0.24	5.99	12.57	
Russian olive	Blue	-14.57	-7.01	-13.42	-15.06	1.61	21.02	
	Rose	-8.55	3.77	-4.56	-1.75	5.65	10.40	Strong (6.0 - 12.0)
Black alder	Blue	-26.75	-8.14	-14.35	-16.20	3.11	31.42	Very Strong (> 12.00)
	Rose	-13.74	11.82	2.75	8.69	8.46	18.33	
Maritime pine	Blue	-27.33	-10.84	-21.02	-21.63	9.57	36.14	
	Rose	-10.43	10.64	-2.09	3.11	10.39	15.04	

The results for ho (hue tone) values are given in Table 5. After applying varnishes to all wood species, increases were observed in hue parameters associated with blue color, while decreases were found in ho parameters associated with rose color (mahogany: blue 50.31%, rose 12.54%, mahogany: blue 16.40%, rose 25.82%, mulberry: blue 6.22%, rose 26.92%, Persian silk: blue 83.57%, rose 25.65%, American walnut: blue 22.74%, rose 24.98%, Russian olive: blue 8.59%, rose 18.59%, black alder: blue 17.63%, rose 25.50%, and maritime pine: blue 69.99%, rose 28.88%). Samples of untreated wood species were determined to be sorted from low to high ho value as follows: mahogany (49.67) < black alder (66.36) < Russian olive (65.78) < mulberry (67.34) < American walnut (69.29) < Maritime pine (72.95) < Persian silk (73.03) < ayous (74.45) (Table 5).

Table 5: Results for h^o parameter

Wood Type	Type of Varnish	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
Mahogany	Control	49.67	-	N	0.74	48.74	50.97	1.48
	Blue	74.66	↑50.31	F	2.42	70.30	76.61	3.24
	Rose	43.44	↓12.54	O**	2.46	40.75	47.81	5.66
Ayous	Control	74.45	-	FG	0.35	73.80	74.83	0.47
	Blue	86.66	↑16.40	C	1.07	84.47	87.80	1.24
	Rose	55.23	↓25.82	K	0.21	54.80	55.53	0.38
Mulberry	Control	67.34	-	J	0.70	66.26	68.06	1.04
	Blue	71.53	↑6.22	H	1.04	70.33	73.30	1.46
	Rose	49.21	↓26.92	N	2.34	46.93	53.95	4.76
Persian silk	Control	73.03	-	FGH	0.35	72.58	73.71	0.48
	Blue	134.06	↑83.57	A*	3.55	130.04	139.97	2.65
	Rose	54.30	↓25.65	KL	1.04	52.57	55.78	1.92
American walnut	Control	69.29	-	I	0.57	68.31	70.14	0.83
	Blue	85.05	↑22.74	D	1.57	83.60	88.85	1.84
	Rose	51.98	↓24.98	M	1.25	50.05	54.10	2.40
Russian olive	Control	65.78	-	J	0.52	64.48	66.41	0.79
	Blue	71.43	↑8.59	H	1.40	69.96	73.74	1.96
	Rose	53.55	↓18.59	L	4.77	48.44	64.67	8.91
Black alder	Control	66.36	-	J	0.45	65.43	66.95	0.68
	Blue	78.06	↑17.63	E	1.74	74.52	80.09	2.23
	Rose	49.44	↓25.50	N	0.92	48.50	51.25	1.86
Maritime pine	Control	72.95	-	GH	0.96	71.98	75.15	1.31
	Blue	124.01	↑69.99	B	1.97	119.29	126.50	1.59
	Rose	51.88	↓28.88	M	1.42	50.20	53.89	2.74

Number of Measurements: 10, *: Highest result, **: Lowest result

Table 6: Results for L* parameter

Wood Type	Type of Varnish	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
Mahogany	Control	34.78	-	P	0.26	34.18	35.17	0.73
	Blue	26.90	↓22.66	T**	0.20	26.70	27.25	0.73
	Rose	27.93	↓19.70	S	0.22	27.65	28.15	0.80
Ayous	Control	67.52	-	C	0.29	67.19	68.03	0.42
	Blue	41.90	↓37.94	N	0.44	41.01	42.24	1.06
	Rose	50.34	↓25.44	I	0.38	49.43	50.88	0.76
Mulberry	Control	53.15	-	G	1.11	51.59	54.73	2.10
	Blue	34.43	↓35.22	P	0.36	33.85	34.88	1.05
	Rose	44.51	↓16.26	M	0.64	43.49	45.61	1.43
Persian silk	Control	72.65	-	B	0.39	71.77	73.12	0.53
	Blue	45.53	↓37.33	L	0.65	44.38	46.50	1.43
	Rose	61.84	↓14.88	F	0.89	60.66	63.52	1.44
American walnut	Control	49.65	-	J	1.17	48.04	51.56	2.35
	Blue	30.67	↓38.23	R	0.31	30.19	31.15	1.00
	Rose	38.60	↓22.26	O	0.96	37.11	39.49	2.48
Russian olive	Control	47.45	-	K	1.07	45.84	48.68	2.26
	Blue	32.87	↓30.73	Q	0.42	31.89	33.36	1.28
	Rose	38.89	↓18.04	O	1.85	36.24	41.21	4.74
Black alder	Control	65.15	-	D	0.39	64.59	65.69	0.60
	Blue	38.40	↓41.06	O	0.39	37.81	38.96	1.01
	Rose	51.41	↓21.09	H	1.18	49.98	53.36	2.29
Maritime pine	Control	74.17	-	A*	0.78	73.43	75.92	1.05
	Blue	46.84	↓36.85	K	0.61	45.39	47.56	1.31
	Rose	63.75	↓14.05	E	0.82	62.61	64.85	1.28

Number of Measurements: 10, *: Highest result, **: Lowest result

The results for a* (red color tone) value are shown in Table 7. For the a* value determined by the color device, the highest result was found in the black alder test samples treated with rose varnish (21.70), while the lowest a* value was detected in the samples of Persian silk wood treated with blue varnish (-3.08). The measured a* parameter showed decreases with the application of two different colored varnishes on mahogany wood (blue varnish: 93.33% and rose varnish: 60.68%). In all other wood species, decreases were observed with the application of blue varnish (Maritime pine 139.33% > Persian silk 138.07% > American walnut 93.83% > ayous 92.12% > black alder 82.31% > mulberry 72.39% > Russian olive 70.95%), while increases were seen with the application of rose varnish (Maritime pine 136.63% > ayous 134.65% > Persian silk 122.37% > black alder 119.41% > American walnut 76.61% > mulberry 72.65% > Russian olive 38.16%) (Table 7).

Table 7: Results for a* parameter

Wood Type	Type of Varnish	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
Mahogany	Control	11.85	-	G	0.29	11.39	12.39	2.48
	Blue	0.79	↓93.33	O	0.15	0.60	1.00	18.48
	Rose	4.66	↓60.68	L	0.80	3.80	5.77	17.26
Ayous	Control	7.36	-	J	0.22	7.08	7.73	2.95
	Blue	0.58	↓92.12	O	0.21	0.35	1.00	35.72
	Rose	17.27	↑134.65	D	0.21	16.90	17.55	1.20
Mulberry	Control	11.70	-	G	0.29	11.30	12.25	2.46
	Blue	3.23	↓72.39	M	0.33	2.68	3.56	10.24
	Rose	20.20	↑72.65	B	0.92	18.36	21.10	4.57
Persian silk	Control	8.09	-	I	0.23	7.64	8.42	2.88
	Blue	-3.08	↓138.07	P**	0.30	-3.91	-2.85	-9.76
	Rose	17.99	↑122.37	C	0.55	17.10	18.81	3.08
American walnut	Control	6.97	-	K	0.20	6.71	7.38	2.94
	Blue	0.43	↓93.83	O	0.13	0.10	0.54	30.12
	Rose	12.31	↑76.61	F	0.87	11.19	13.39	7.08
Russian olive	Control	9.88	-	H	0.20	9.58	10.27	1.98
	Blue	2.87	↓70.95	M	0.30	2.27	3.19	10.48
	Rose	13.65	↑38.16	E	0.65	12.82	14.71	4.75
Black alder	Control	9.89	-	H	0.33	9.44	10.41	3.34
	Blue	1.75	↓82.31	N	0.33	1.41	2.42	18.92
	Rose	21.70	↑119.41	A*	0.39	21.12	22.20	1.78
Maritime pine	Control	7.78	-	IJ	0.62	6.50	8.29	7.99
	Blue	-3.06	↓139.33	P	0.22	-3.34	-2.65	-7.05
	Rose	18.41	↑136.63	C	0.95	16.99	19.50	5.13

Number of Measurements: 10, *: Highest result, **: Lowest result

The results for b* (yellow color tone) values are given in Table 8. In the measured b* parameter, decreases were observed with both varnish applications in all wood species except for black alder wood. Additionally, the decrease rates were consistently higher with the application of blue varnish compared to rose varnish. In black alder wood, a decrease of 63.52% was detected with the application of blue varnish, while an increase of 12.17% was noted with rose varnish. The highest result for the b* test was found in the untreated mulberry test samples (28.05), while the lowest b* parameter was observed in mahogany wood treated with blue varnish (3.91) (Table 8).

Table 8: Results for b* parameter

Wood Type	Type of Varnish	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
Mahogany	Control	13.96	-	K	0.35	13.43	14.77	2.53
	Blue	2.91	↓79.15	P**	0.25	2.45	3.25	8.57
	Rose	4.39	↓68.55	O	0.51	3.75	4.97	11.63
Ayous	Control	26.44	-	B	0.24	26.07	26.75	0.90
	Blue	9.97	↓62.29	L	0.43	9.29	10.57	4.34
	Rose	24.88	↓5.90	D	0.37	24.31	25.39	1.50
Mulberry	Control	28.05	-	A*	1.03	26.50	29.35	3.66
	Blue	9.65	↓65.60	L	0.48	8.77	10.25	4.98
	Rose	23.41	↓16.54	E	0.88	22.47	25.22	3.76
Persian silk	Control	26.52	-	B	0.37	26.16	27.32	1.40
	Blue	3.10	↓88.31	P	0.33	2.61	3.45	10.70
	Rose	25.04	↓5.58	CD	0.49	23.90	25.38	1.96
American walnut	Control	18.46	-	H	0.66	17.42	19.37	3.57
	Blue	5.11	↓72.32	N	0.27	4.71	5.72	5.26
	Rose	15.72	↓14.84	J	0.99	14.18	16.72	6.28
Russian olive	Control	21.95	-	G	0.66	20.62	22.87	3.01
	Blue	8.53	↓61.14	M	0.35	7.78	8.96	4.05
	Rose	17.39	↓20.77	I	1.67	15.43	20.10	9.58
Black alder	Control	22.59	-	F	0.55	22.07	23.69	2.42
	Blue	8.24	↓63.52	M	0.46	7.54	9.02	5.53
	Rose	25.34	↑12.17	CD	0.53	24.54	26.31	2.10
Maritime pine	Control	25.53	-	C	0.69	24.24	26.26	2.69
	Blue	4.51	↓82.33	O	0.17	4.20	4.73	3.84
	Rose	23.44	↓8.19	E	0.21	23.12	23.80	0.89

Number of Measurements: 10, *: Highest result, **: Lowest result

The results for C* (chroma) values are presented in Table 9. The highest result for the C* value was found in the black alder test samples treated with rose varnish (33.35), while the lowest C* value was found in mahogany wood treated with blue varnish (3.10). Decreases in C* values were found in varnish applications on mahogany and Russian olive woods. In all other wood species, decreases were observed in the test samples coated with blue varnish (Persian silk 84.46% > Maritime pine 80.98% > American walnut 74.00% > mulberry 66.50% > black alder 64.69% > ayous 63.59%), while increases were detected in the wood samples coated with rose varnish (black alder 35.24% > Maritime pine 11.64% > Persian silk 11.25% > ayous 10.39% > mulberry 1.81% > American walnut 1.22%) (Table 9).

Table 9: Results for C* parameter

Wood Type	Type of Varnish	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
Mahogany	Control	18.31	-	K	0.40	17.87	19.02	2.17
	Blue	3.01	↓83.56	Q**	0.26	2.54	3.36	8.67
	Rose	6.42	↓64.94	N	0.92	5.41	7.62	14.33
Ayous	Control	27.44	-	E	0.27	27.01	27.78	1.00
	Blue	9.99	↓63.59	L	0.44	9.30	10.60	4.40
	Rose	30.29	↑10.39	CD	0.41	29.64	30.80	1.36
Mulberry	Control	30.39	-	BCD	1.00	28.95	31.74	3.30
	Blue	10.18	↓66.50	L	0.56	9.17	10.83	5.46
	Rose	30.94	↑1.81	B	0.16	30.75	31.20	0.50
Persian silk	Control	27.73	-	E	0.41	27.25	28.54	1.47
	Blue	4.31	↓84.46	P	0.22	3.99	4.56	5.15
	Rose	30.85	↑11.25	BC	0.49	30.10	31.61	1.58
American walnut	Control	19.73	-	J	0.66	18.75	20.64	3.35
	Blue	5.13	↓74.00	O	0.27	4.73	5.73	5.23
	Rose	19.97	↑1.22	J	1.24	18.12	21.25	6.22
Russian olive	Control	24.06	-	H	0.66	22.85	25.07	2.73
	Blue	9.01	↓62.55	M	0.40	8.11	9.48	4.47
	Rose	22.31	↓7.27	I	1.24	20.45	23.95	5.55
Black alder	Control	24.66	-	G	0.61	24.11	25.88	2.46
	Blue	8.46	↓65.69	M	0.46	7.86	9.21	5.39
	Rose	33.35	↑35.24	A*	0.39	32.76	33.86	1.15
Maritime pine	Control	26.71	-	F	0.80	25.26	27.54	2.98
	Blue	5.08	↓80.98	O	0.73	3.72	5.62	14.28
	Rose	29.82	↑11.64	D	0.63	28.83	30.60	2.10
Number of Measurements: 10, *: Highest result, **: Lowest result								

The structural properties of varnish layers can vary depending on the components used in their formulation. Differences in the types and quantities of primary binders and other layer-forming agents are key factors contributing to these variations (Sönmez 1989).

The components of the varnish could chemically react with the different wood species used in the study, potentially causing changes in color tones, particularly in relation to pigments and binders.

In studies on varnish in the literature, it has been reported that the color parameters change with the applied varnishes (Mitan et al., 2019; Çamlıbel and Ayata, 2024; Altıparmak, 2017; Vardanyan et al., 2015; Ayata et al., 2024a; b; Bekhta et al., 2022; Gall et al., 2023; Ayata and Ayata, 2024; Ayata and Bal, 2024; Bila et al., 2020; Ulay, 2018).

3. Conclusions

Decreases were observed in the L* parameter across all wood species when applying two different types of varnish. For the a* parameter, decreases were detected with the application of two different colored varnishes on mahogany wood while in all other wood species, the application of blue varnish resulted in decreases, and the application of rose varnish resulted in increases. In the b* parameter, decreases were observed with both varnish applications in all wood species except for black alder wood. For the C* values, decreases were found in the varnish applications on mahogany and Russian olive woods. In all other wood species, decreases were observed in the test samples coated with blue varnish, while increases were noted in the wood samples coated with rose varnish. For the ho values, increases were obtained with the application of blue varnish across all wood species, while decreases were observed with the application of rose varnish. It is recommended that aging tests be conducted on these wood materials coated with different colored varnishes in future studies.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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COLOR PARAMETERS COMPARISON IN VARNISHED HEARTWOOD AND SAPWOOD OF EUCALYPTUS AND RED PINE

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Abstract

This study compared the color parameters [Δa*, ΔC*, ΔH*, Δb*, ΔL*, and ΔE*, a* (red color tone), L* (lightness), b* (yellow color tone), ho (hue tone), and C* (chroma)] of synthetic-based furniture varnish coatings applied to the heartwood and sapwood of eucalyptus (*Eucalyptus camaldulensis*) and red pine (*Pinus brutia* Ten.). The results showed that the variance analyses were statistically significant. In all wood species and wood parts, the varnish application resulted in decreases in the Ho and L* parameters, while increases were observed in the A* and C* parameters. In the b* parameter, an increase was observed after varnish application on red pine heartwood and sapwood, as well as eucalyptus sapwood, while a decrease was found in eucalyptus heartwood. The total color differences (ΔE*) were measured as 9.49 for the heartwood of red pine, 9.20 for its sapwood, 7.41 for the heartwood of eucalyptus, and 12.55 for its sapwood. In red pine, the ΔE* values for heartwood and sapwood were found to be very similar, while a different result was observed for eucalyptus wood. The SPSS results from the study demonstrated the significance of the changes observed after the varnish application.

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COLOR PARAMETERS COMPARISON IN VARNISHED HEARTWOOD AND SAPWOOD OF EUCALYPTUS AND RED PINE

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1. Introduction

Wood has been the most accessible and renewable material throughout human history. Currently, wood consumption exceeds that of any other material. The wood product industry continues to grow rapidly. Green lumber, typically used as raw material for final products, has several characteristics that limit its use. For example, it shrinks and can crack during the drying process, it is highly hygroscopic, and it is susceptible to decay and combustion. Among the many wood treatment methods, two primary processes are commonly used in the production of wood products: one involves removing moisture (drying, through dehydration, or extraction), and the other introduces specific substances into the wood in either liquid or vapor form (Botannini, 2011).

Surface finishing is any process carried out to modify or improve the properties of objects (Nerey, 2002; 2007). The adhesion of liquid surface treatments largely depends on the properties of the substrate surface, which significantly affects their consumption and, consequently, the increase in production costs (Roffael, 1993; Carrasco, 2007). It is essential to properly adjust processing conditions to achieve the required surface quality; this means reducing raw material waste and, consequently, minimizing defects that lead to product rejection and unnecessary wear on tools, which in the long term foresees greater benefits for the wood industry (Reinoso et al., 2019).

Finishes are materials or products that are integrated, adhered, or overlaid onto the structural elements of architectural objects. They are used to enhance user comfort, emphasize the expression of spaces and forms, and protect against the harmful effects of temperature, rain, humidity, and environmental pollution. Finishes are defined for roofs, interior and exterior surfaces; ceilings, walls, and floors. They are selected based on the economic level of the architectural object, its appearance, resistance to wear, and comfort (Garza Contreras, 2019).

When exposed to external elements, unpainted or unsealed wood experiences various forms of deterioration due to atmospheric conditions. The surfaces of a board or other wooden piece may exhibit what is commonly known as raised grain, resulting in a rough, wrinkled, or fuzzy texture. This can lead to the emergence of small cracks and splits, which may sometimes develop into larger fissures that encompass the entire piece of wood. Additionally, wood is prone to warping, which can cause it to detach from the components that hold it in place. Ultimately, the fibers on the surface deteriorate and scatter, resulting in the gradual erosion of the exposed layers of wood (Deka et al., 2003; Guzmán Mejía, 2016).

Water adheres to cell walls because of the presence of hydroxyl groups (Giordano, 1971) and possesses a refractive index that differs from that of wood, which affects the quantity of light that is absorbed and reflected. Consequently, the wood's color changes as the water content in the cell walls fluctuates. This concept is valid when observing a limited area of wood that appears colorimetrically uniform (Cecchini, 2014).

Synthetic paints contain components such as petroleum derivatives and mineral substances. They are also often referred to by terms like acrylic, plastic, or water-based. In fact, manufacturers typically use the term "synthetic" mainly for paints based on organic solvents, particularly enamels and varnishes. Most of the paints available on the market today are synthetic (Trischler and Partner, 2004; Escala Martínez, 2018).

Coatings like varnishes and sealants serve an important function by forming a barrier that prevents moisture infiltration and reduces exposure to biological factors. Furthermore, choosing the appropriate wood species and performing regular maintenance help to prolong the life of wooden structures (Zacarias et al., 2024).

There are various studies in the literature that have focused on the application of different varnishes to wood surfaces. These studies have measured color properties on varnished surfaces, and the results obtained for the parameters have been discussed and explained. Examples of wood species studied include ayous (Ayata and Ayata, 2024), white oak, Korean red pine, walnut, merbau, Japanese larch, zelkova, and red oak (Kim and Kim, 2021), poplar, lati, mangga, balau red, and awoura (Ayata and Bal, 2024), cumaru and pau marfim (Mendes et al., 2016), sipo and mahogany (Ayata et al., 2024a), mahogany and Chinese white poplar (Liu et al., 2021), black locust (Ayata et al., 2024b), and Scots pine (Can and Sivrikaya, 2014).

This research focused on evaluating the color parameters and total color changes in various wood species (heartwood and sapwood) treated with a synthetic-based furniture varnish. The species studied were eucalyptus (*Eucalyptus camaldulensis*) and red pine (*Pinus brutia* Ten.). A review of the current literature revealed a lack of studies on the application of synthetic-based varnishes to these specific wood types. The outcomes of this study are expected to offer valuable information regarding the properties of the wood species, their distinct parts, and the impact of the varnish treatment.

2. Materials and Methods

2.1. Materials

2.1.1. Wood Materials

Wood samples of eucalyptus (*Eucalyptus camaldulensis*) and red pine (*Pinus brutia* Ten.) were cut to 100 mm x 100 mm x 15 mm. These samples underwent conditioning procedures at a temperature of 20±2°C and a relative humidity of 65%, following the guidelines set by ISO 554 (1976).

2.1.2. Sandpapers

In the research, sandpapers with grits of 80, 120, and 150 were obtained through purchase.

2.1.3. Synthetic-Based Furniture Varnish

In this research, a synthetic-based furniture varnish (colorless, with a solid content of 48±10% and a specific gravity of 0.90±1 g/cm^3) was obtained by purchasing it from a specialized company.

2.2. Method

2.2.1. Application of Synthetic Furniture Varnish on Wooden Material Surfaces

The varnished wood surfaces were thoroughly cleaned of dust, dirt, and oil. It was ensured that the wood surface was dry and free of moisture. Two layers of varnish were applied with a brush (coverage: 10-12 m^2/l, drying time: touch-dry in 8 h, fully dry in 24 h).

The samples were varnished following the manufacturer's guidelines and in compliance with the ASTM D 3023-98 (2017) standard.

2.2.2. Analysis of Color Parameter Properties

A CS-10 device (CHN Spec, China) was used to evaluate the color change of the samples, in accordance with the CIELAB color system and ASTM D 2244-3 (2007) standard [CIE 10° standard observer; CIE D65 light source, illumination geometry: 8/d (8°/diffuse illumination)]. Table 1, adapted from Lange (1999), provides definitions for Δa^*, ΔC^*, Δb^*, and ΔL^*.

Table 1: The definitions of Δa^*, ΔC^*, Δb^*, and ΔL^* (Lange 1999)

Test	Negative Description	Positive Description
Δb^*	Bluer than the reference	More yellow than the reference
ΔL^*	Darker than the reference	Lighter than the reference
Δa^*	Greener than the reference	Redder than the reference
ΔC^*	More dull, matte than the reference	Clearer, brighter than the reference

Table 2 illustrates alternative criteria for the visual assessment of the calculated ΔE^* color difference, following the DIN 5033 (1979) standards.

Table 2: Comparison criteria for ΔE^* evaluation (DIN 5033 1979)

Visual	Total Color Difference
Undetectable	<0.20
Very Weak	0.20 - 0.50
Weak	0.50 - 1.50
Distinct	1.50 - 3.00
Very Distinct	3.00 - 6.00
Strong	6.00 - 12.00
Very Strong	> 12.00

The following formulas were utilized to calculate the total color difference results.

$$\Delta a^* = [a^*_{\text{synthetic-based furniture varnish applied}}] - [a^*_{\text{control}}] \quad (1)$$
$$\Delta L^* = [L^*_{\text{synthetic-based furniture varnish applied}}] - [L^*_{\text{control}}] \quad (2)$$
$$\Delta b^* = [b^*_{\text{synthetic-based furniture varnish applied}}] - [b^*_{\text{control}}] \quad (3)$$
$$\Delta E^* = [(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2]^{1/2} \quad (4)$$
$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (5)$$
$$\Delta C^* = [C^*_{\text{synthetic-based furniture varnish applied}}] - [C^*_{\text{control}}] \quad (6)$$
$$h^o = \arctan [b^*/a^*] \quad (7)$$
$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2} \quad (8)$$

2.3. Statistical Analysis

Statistical analysis was conducted using a statistical software package on the measurement data gathered for the study. This involved identifying homogeneity groups, calculating standard deviations, computing mean values associated with the measurements, determining the maximum and minimum mean values, calculating percentage (%) change rates, and performing variance analyses.

3. Results and Discussion

In Table 3, the results of the variance analysis for red pine (Pinus brutia Ten.) are presented. The variance analysis conducted after the application of varnish to the heartwood and sapwood of red pine showed that the wood part (A), varnish application (B), and the interaction (AB) were found to be statistically significant (Table 3).

Table 3: Results of variance analysis (*: significant) for red pine (*Pinus brutia* Ten.)

Test	Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Sig.
L*	**Wood Part (A)**	2022.226	1	2022.226	1620.403	0.000*
	Varnish Application (B)	321.319	1	321.319	257.472	0.000*
	Interaction (AB)	12.045	1	12.045	9.652	0.004*
	Error	44.927	36	1.248		
	Total	173038.568	40			
	Corrected Total	2400.517	39			
a*	**Wood Part (A)**	337.329	1	337.329	2276.283	0.000*
	Varnish Application (B)	124.962	1	124.962	843.241	0.000*
	Interaction (AB)	7.552	1	7.552	50.958	0.000*
	Error	5.335	36	0.148		
	Total	5508.021	40			
	Corrected Total	475.177	39			
b*	**Wood Part (A)**	15.364	1	15.364	56.539	0.000*
	Varnish Application (B)	391.563	1	391.563	1440.981	0.000*
	Interaction (AB)	16.218	1	16.218	59.684	0.000*
	Error	9.782	36	0.272		
	Total	28501.201	40			
	Corrected Total	432.927	39			
C*	**Wood Part (A)**	12.848	1	12.848	87.794	0.000*
	Varnish Application (B)	523.669	1	523.669	3578.327	0.000*
	Interaction (AB)	5.573	1	5.573	38.079	0.000*
	Error	5.268	36	0.146		
	Total	34011.848	40			
	Corrected Total	547.359	39			
***h*º**	**Wood Part (A)**	1316.412	1	1316.412	1434.962	0.000*
	Varnish Application (B)	32.490	1	32.490	35.416	0.000*
	Interaction (AB)	12.600	1	12.600	13.735	0.001*
	Error	33.026	36	0.917		
	Total	182325.274	40			
	Corrected Total	1394.528	39			

Table 4 provides the results for color parameters of red pine (*Pinus brutia* Ten.). With the application of varnish to heartwood and sapwood of red pine, decreases were observed in *b** (heartwood: 21.30% and sapwood: 32.21%), *C** (heartwood: 24.72% and sapwood: 32.75%), and *L** (heartwood: 10.99% and sapwood: 6.12%) values, while increases were detected in *h*º (heartwood: 64.64% and sapwood: 0.93%) and *a** (heartwood: 36.91% and sapwood: 38.25%) values (Table 4).

The highest *L** and *h*º values were found in the samples where varnish was not applied, whereas the lowest results were detected on the varnished test samples. In addition, the lowest *C**, *b**, and *a** values were obtained in the samples without varnish, while the highest results were found in the varnished test samples (Table 4).

Table 4: Results for color parameters for red pine (*Pinus brutia* Ten.)

Test	**Wood Part**	**Varnish Application**	**Mean**	**Change (%)**	**Homogeneity Group**	**Standard Deviation**	**Mini-mum**	**Maxi-mum**	**Coefficient of Variation**
L^*	**Heart**	**No**	61.59	↓10.99	C	1.10	59.58	63.27	1.79
		Yes	54.82		D**	1.86	52.60	57.14	3.40
	Sap	**No**	74.71	↓6.12	A*	0.15	74.45	74.95	0.20
		Yes	70.14		B	0.53	69.45	70.83	0.75
a^*	**Heart**	**No**	11.92	↑36.91	B	0.34	11.36	12.50	2.83
		Yes	16.32		A*	0.61	15.47	17.05	3.72
	Sap	**No**	6.98	↑38.25	D**	0.08	6.85	7.09	1.10
		Yes	9.65		C	0.32	9.16	10.04	3.33
b^*	**Heart**	**No**	23.38	↑21.30	C	0.32	22.71	23.88	1.37
		Yes	28.36		B	0.87	26.94	29.66	3.07
	Sap	**No**	23.34	↑32.31	C**	0.28	22.97	23.91	1.22
		Yes	30.88		A*	0.38	30.24	31.31	1.24
C^*	**Heart**	**No**	26.25	↑24.72	C	0.18	25.93	26.50	0.68
		Yes	32.74		A*	0.52	31.73	33.45	1.58
	Sap	**No**	24.37	↑32.75	D**	0.28	24.01	24.92	1.16
		Yes	32.35		B	0.45	31.67	32.85	1.40
h^o	**Heart**	**No**	62.98	↓4.64	B	0.94	61.17	64.55	1.49
		Yes	60.06		C**	1.61	58.11	62.44	2.69
	Sap	**No**	73.33	↓0.93	A*	0.22	73.01	73.70	0.30
		Yes	72.65		A	0.37	72.20	73.23	0.51
10 measurements were taken from each group, *: Highest value, **: Lowest value									

Table 5 shows the results of the variance analysis for Eucalyptus (Eucalyptus camaldulensis). The results of the variance analysis conducted on the varnish application to the heartwood and sapwood of eucalyptus revealed that the factors of wood type (A), varnish treatment (B), and their interaction (AB) were all found to be statistically significant (Table 5).

Table 5: Results of variance analysis (*: significant) for eucalyptus (*Eucalyptus camaldulensis*)

Test	**Source**	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F Value**	**Sig.**
L^*	**Wood Part (A)**	3717.762	1	3717.762	17253.911	0.000*
	Varnish Application (B)	562.575	1	562.575	2610.877	0.000*
	Interaction (AB)	20.924	1	20.924	97.105	0.000*
	Error	7.757	36	0.215		
	Total	99792.208	40			
	Corrected Total	4309.018	39			
a^*	**Wood Part (A)**	345.098	1	345.098	4630.472	0.000*
	Varnish Application (B)	224.250	1	224.250	3008.951	0.000*
	Interaction (AB)	30.994	1	30.994	415.868	0.000*
	Error	2.683	36	0.075		
	Total	9223.413	40			
	Corrected Total	603.024	39			
b^*	**Wood Part (A)**	100.743	1	100.743	1684.083	0.000*
	Varnish Application (B)	20.420	1	20.420	341.361	0.000*
	Interaction (AB)	202.680	1	202.680	3388.134	0.000*
	Error	2.154	36	0.060		
	Total	11625.679	40			
	Corrected Total	325.997	39			
C^*	**Wood Part (A)**	23.409	1	23.409	304.750	0.000*
	Varnish Application (B)	190.969	1	190.969	2486.126	0.000*
	Interaction (AB)	169.168	1	169.168	2202.306	0.000*
	Error	2.765	36	0.077		
	Total	20853.792	40			
	Corrected Total	386.311	39			
h^o	**Wood Part (A)**	2947.231	1	2947.231	8454.834	0.000*
	Varnish Application (B)	691.143	1	691.143	1982.708	0.000*
	Interaction (AB)	43.410	1	43.410	124.531	0.000*
	Error	12.549	36	0.349		
	Total	101562.813	40			
	Corrected Total	3694.332	39			

Table 6 includes the results for color parameters of eucalyptus (*Eucalyptus camaldulensis*). When looking at the varnish application on heartwood and sapwood of eucalyptus, decreases were observed in h^o (heartwood: 22.57% and sapwood: 10.19%) and L^* (heartwood: 14.38% and sapwood: 14.20%) values, while increases were obtained in C^* (heartwood: 1.07% and sapwood: 48.21%) and a^* (heartwood: 18.47% and sapwood: 76.35%) values (Table 6).

As for b^* values, a decrease of 18.38% was found in heartwood, while an increase of 38.43% was detected in sapwood. The lowest C^* and a^* values were observed in the samples without varnish, while the highest results were obtained in the varnished test samples. Additionally, the highest L^* and h^o values were found in the samples without varnish, whereas the lowest results were seen on the varnished test samples (Table 6).

Table 6: Results for color parameters for eucalyptus (*Eucalyptus camaldulensis*)

Test	Wood Part	Varnish Application	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
L*	**Heart**	**No**	42.24	↓14.32	C	0.27	41.84	42.72	0.64
		Yes	36.19		D**	0.50	35.58	37.01	1.38
	Sap	**No**	62.97	↓14.20	A*	0.36	62.59	63.75	0.58
		Yes	54.03		B	0.64	52.25	54.43	1.18
a*	**Heart**	**No**	16.13	↑18.47	B	0.33	15.70	16.60	2.03
		Yes	19.11		A*	0.36	18.54	19.54	1.87
	Sap	**No**	8.50	↑76.35	D**	0.18	8.28	8.82	2.18
		Yes	14.99		C	0.17	14.69	15.28	1.14
b*	**Heart**	**No**	16.76	↓18.38	B	0.21	16.51	17.10	1.23
		Yes	13.68		D**	0.35	13.31	14.25	2.54
	Sap	**No**	15.43	↑38.43	C	0.19	15.02	15.63	1.26
		Yes	21.36		A*	0.20	21.07	21.60	0.91
C*	**Heart**	**No**	23.26	↑1.07	C	0.27	22.79	23.70	1.17
		Yes	23.51		B	0.37	22.91	24.05	1.57
	Sap	**No**	17.61	↑48.21	D**	0.24	17.16	17.89	1.34
		Yes	26.10		A*	0.20	25.73	26.39	0.78
***h*º**	**Heart**	**No**	46.08	↓22.57	C	0.65	44.98	46.97	1.42
		Yes	35.68		D**	0.83	34.36	36.81	2.33
	Sap	**No**	61.16	↓10.19	A*	0.39	60.47	61.90	0.64
		Yes	54.93		B	0.35	54.05	55.22	0.64
10 measurements were taken from each group, *: Highest value, **: Lowest value									

Finally, Table 7 presents the calculated results for total color differences (ΔH^*, Δa^*, ΔC^*, Δb^*, ΔL^*, and ΔE^*). The total color differences (ΔE^*) were determined as follows: 9.49 for red pine heartwood, 9.20 for red pine sapwood, 7.41 for eucalyptus heartwood, and 12.55 for eucalyptus sapwood. Upon examining the results for total color differences, it was found that the varnished samples of eucalyptus sapwood exhibited a very strong criterion (> 12.00), while the varnished samples of eucalyptus heartwood, as well as red pine heartwood and sapwood, showed a strong criterion (6.00 to 12.00) (Table 7).

For all varnished wood species and wood parts, the ΔL^* values were negative (darker than the reference), while the Δa^* values were positive (redder than the reference). In addition, the ΔC^* values were found to be positive (clearer, brighter than the reference). Regarding the Δb^* values, it was observed that for eucalyptus heartwood, the value was negative (bluer than the reference), while for the other samples, it was positive (more yellow than the reference). ΔH^* values were calculated as 4.27 for eucalyptus heartwood, 2.33 for eucalyptus sapwood, 1.45 for red pine heartwood, and 0.31 for red pine sapwood (Table 7).

Table 7: Calculated results for total color differences

Wood Type	Wood Part	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	Color Change Criteria (DIN 5033, 1979)
Red pine	**Heart**	-6.77	4.40	4.98	6.49	1.45	9.49	Strong (6.00 - 12.00)
	Sap	-4.57	2.67	7.53	7.98	0.31	9.20	
Eucalyptus	**Heart**	-6.05	2.97	-3.07	0.26	4.27	7.41	
	Sap	-8.95	6.50	5.93	8.48	2.33	12.55	Very Strong (> 12.00)

The study successfully met its aim. The type of varnish applied resulted in the formation of varying color parameters. The varnish component used in the study may have interacted with wood material, leading to the formation of different color characteristics.

Studies in the literature have reported that varnish applications lead to changes in the color properties of wood surfaces. These findings have been observed in various wood species, including mahogany and Chinese white poplar (Liu et al., 2021), ayous (Ayata and Ayata, 2024), cumaru and pau marfim (Mendes et al., 2016), Scots pine (Can and Sivrikaya, 2014), sipo and mahogany (Ayata et al., 2024a), poplar, lati, balau red, mangga, and awoura (Ayata and Bal, 2024), black locust (Ayata et al., 2024b), as well as Korean red pine, Japanese larch, merbau, zelkova, walnut, white oak, and red oak (Kim and Kim, 2021).

4. Conclusion

For the b^* parameter, varnish application led to an increase in red pine heartwood and sapwood, as well as eucalyptus sapwood, whereas a decrease was observed in eucalyptus heartwood. For all wood species and wood parts, the varnish application led to a reduction in Ho and L* parameters, whereas A* and C* parameters showed an increase. The ΔE^* values were measured as 9.49 for the heartwood of red pine, 9.20 for its sapwood, 7.41 for the heartwood of eucalyptus, and 12.55 for its sapwood. The SPSS results obtained in the study highlighted the significance of the changes following the varnish application.

According to the results, it is expected that the heartwood or sapwood will be used according to the consumer's taste in terms of desired color characteristics in the industry.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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