Journal of Forestry Research and Management. Vol. 22 (2). 70-79; 2025, ISSN 0189-8418
www.jfrm.org.ng

OPTIMIZING ALKALINE SULFITE TREATMENT FOR DIMENSIONAL STABILITY OF *Triplochiton scleroxylon* K. SCHUM WOOD

Adebawo F.G.[1], Ajala O. O.[1], Adegoke, O. A.[1], Appah O. R[1], Adekunle E. A.[2]

[1]Department of Wood and Paper Technology, Federal College of Forestry, P. M. B. 5087, Jericho, Ibadan, Nigeria
[2*]Forestry Research Institute of Nigeria, PMB 5054, Dugbe, Jericho Hill, Ibadan.
adebawofunke@yahoo.com/adebawo.fg@fcfibadan.edu.ng

ABSTRACT:

Triplochiton scleroxylon K. Schum (Obeche), a widely used tropical hardwood, is limited in high-value applications due to its high hygroscopicity and poor dimensional stability. Alkaline chemical treatments offer an eco-friendly strategy for enhancing Obeche wood performance; however, optimal conditions for Obeche wood remain poorly defined. This study investigated the influence of alkaline sulfitetreatment on Obeche wood, with particular emphasis on identifying the optimal treatment duration. Wood samples were treated with 1 M NaOH and 0.5 M Na2 SO3 for 1, 3, and 5 hours, alongside untreated controls. Properties assessed include mass loss, density, water absorption, volumetric swelling, Anti-Swell Efficiency (ASE), and Water Repellent Efficiency (WRE). The data was analyzed using one-way ANOVA. Treatment duration had a highly significant effect ($p < 0.05$) on all parameters. Mass loss increased with time, ranging from 1.65% (1 h) to 10.06% (5 h). The 3-hour treatment yielded the best balance of performance, reducing 7-day water absorption from 390.29% (control) to 160.97%, with an ASE of 79.99% and a WRE of 58.76%. However, at 5 hours, WRE fell sharply to 22.73%, suggesting structural over-degradation and micropore formation. Overall, a 3-hour alkaline sulfite treatment is identified as the optimal threshold for enhancing Obeche's dimensional stability, offering a practical parameter for industrial wood modification.

Keywords: *Triplochiton scleroxylon*, alkaline sulfite treatment, dimensional stability, water

Introduction

Wood stands as one of humanity's most enduring and versatile natural materials, playing an indispensable role in global industries ranging from construction and furniture manufacturing to artistic carving and packaging. Its enduring appeal is rooted in its renewable nature, excellent strength-to-weight ratio, biodegradability, and aesthetic warmth (Hill, 2006; Sandberg *et al*., 2017). In an era increasingly defined by the urgent need for sustainable material solutions, wood offers a compelling alternative to energy-intensive, non-renewable materials like metals and plastics. Its capacity to act as a carbon sink throughout its service life further enhances its environmental credentials, aligning with global climate change mitigation goals (Sathre and Gustavsson, 2009).

Despite these advantages, the inherent hygroscopicity of wood poses a significant challenge to its durability and dimensional stability. This behaviour is attributable to the chemical composition of the cell wall, which is rich in hydroxyl (-OH) groups within cellulose and hemicellulose polymers. These groups form strong hydrogen bonds with water molecules, leading to the absorption and release of moisture in response to environmental changes in relative humidity (Rowell, 2012). This cyclical process results in swelling and shrinkage, which can manifest

as warping, cracking, checking, and a loss of mechanical integrity. Consequently, the performance of untreated wood is often unreliable in applications exposed to moisture fluctuations, severely limiting its potential use (Militz and Lande, 2009).

The challenges of dimensional instability are particularly acute in low-density tropical hardwoods. *Triplochiton scleroxylon* K. Schum, commonly known as Obeche or African Whitewood, is a prime example. Prized throughout its native West Africa and in international markets for its low density, pale colour, uniform texture, and exceptional workability, Obeche is a species of significant economic importance for applications in light construction, panelling, veneer, and especially artistic carving (Ogunsanwo and Onilude, 2000). However, its open microstructure and relatively high hemicellulose content render it highly susceptible to moisture ingress, leading to pronounced swelling and a susceptibility to biological degradation (Adebawo *et al*., 2020). Without effective modification, its use is largely restricted to protected interior environments, underutilizing its potential.

To overcome these limitations, a variety of wood modification techniques have been developed. These include thermal treatments, impregnation with resins, and chemical modifications such as acetylation and furfurylation. For instance, acetylation, which involves esterifying wood hydroxyl groups with acetic anhydride, has been shown to significantly enhance dimensional stability and decay resistance by bulking the cell wall and reducing hygroscopicity (Rowell, 2006; Adebawo *et al*., 2020). Previous work in the Nigerian context byFabiyi and Ogunleye (2015); Adebawo *et. al*., (2016); Adebawo *et al*., (2019); Adegoke *et al*., (2021), demonstrated the successful application of acetylation to improve the properties of *Triplochiton scleroxylon*. However, many such methods involve complex processes, costly reagents, or specialized equipment, presenting barriers to widespread adoption, particularly in developing economies.

Alkaline treatment has emerged as a simpler, more cost-effective, and environmentally benign alternative for wood modification. Primarily utilizing sodium hydroxide (NaOH), this process works by solubilizing hemicellulose and lignin, the most hygroscopic components of the cell wall (Baruah *et al*., 2018). The addition of sodium sulfite (Na_2SO_4) enhances this effect by sulfonating lignin, increasing its solubility and facilitating a more extensive removal (Ying*et al*., 2021). While the effectiveness of alkaline treatment on natural fibres for composite materials is well-documented (Aziz and Ansell, 2004; Chen *et al*., 2018; Perremans *et al*, 2018; Bekele *et al*., 2023), its application to solid wood, particularly for enhancing the dimensional stability of permeable species like Obeche, remains underexplored. Crucially, the relationship between treatment duration and the resulting balance of beneficial hydrophobicity and potential structural degradation has not been systematically established.

Therefore, this study aims to bridge this knowledge gap by systematically investigating the effects of NaOH-Na2SO3 treatment duration on the dimensional stability of wood. The broad objective is to analyze how the duration of the chemical treatment affects the wood's physical properties, specifically to assess changes in mass, density, and water-related stability, and thereby determine the optimal treatment time that achieves the greatest dimensional stability while maintaining structural integrity.

Materials and Methods

Study Area

The experimental work for this study was conducted in the Wood and Paper Technology Laboratory at the Federal College of Forestry, Ibadan, Nigeria. This lies between latitudes7° 40'and 7° 38' N, and longitudes 3° 86' and 3° 85'E.

Material Procurement and Preparation

Heartwood samples of *Triplochiton scleroxylon* (Obeche) were procured from a certified timber merchant in Ibadan, Oyo State, Nigeria. The wood was confirmed to be air-dried and free of visible defects, including knots, cracks, and fungal infestations. The samples were then further conditioned in a laboratory environment at a temperature of 20 ± 2°C and a relative humidity of 65 ± 5% until they reached equilibrium moisture content.

From this stock, defect-free specimens were prepared in accordance with the relevant standards for each test. For the determination of density, weight and volume loss, 20 mm × 20 mm × 60 mm specimens were prepared, while for water absorption and volumetric swelling, specimens with dimensions of 20 mm × 20 mm × 20 mm were prepared. The initial oven-dry mass and volume of each specimen were recorded before any treatment to serve as a baseline.

Preparation of Alkaline Sulfite Treatment Solution

A mixed alkaline sulfite solution was prepared for the wood treatment. A 1 Molar (M) solution of Sodium Hydroxide (NaOH) was prepared by dissolving 40 grams of laboratory-grade NaOH pellets (Sigma-Aldrich, =97% purity) in 1 litre of distilled water. Subsequently, a 0.5 M solution of Sodium Sulfite (Na_2SO_4) was prepared by dissolving 63 grams of anhydrous Na2SO3 powder (Sigma-Aldrich, =98% purity) in 1 litre of distilled water. The two solutions were then mixed in a 1:1 volume ratio to create the final treatment solution of 1M NaOH + 0.5M Na2SO3.

Alkaline Sulfite Treatment Process

The wood specimens were fully immersed in the prepared alkaline sulfite solution within a reflux condensation setup to prevent evaporation losses. The ratio of solution volume to wood sample mass was maintained at a minimum of 10:1 to ensure consistent and sufficient chemical availability for all specimens. The samples were first soaked at room temperature (28 ± 2°C) for 30 minutes to allow initial penetration. Following this, the container was transferred to a thermostatically controlled water bath and heated at 100°C for the designated treatment durations: 1 hour, 3 hours, and 5 hours. A separate set of specimens was left untreated to serve as the control group.

Upon completion of the cooking duration, the specimens were removed from the solution and thoroughly rinsed with distilled water until the rinse water attained a neutral pH (~7), ensuring the removal of any residual chemicals. The treated samples were then oven-dried at 103 ± 2°C for 48 hours to achieve a constant weight. The final oven-dry mass and dimensions of each treated specimen were measured.

Determination of Physical Hygroscopic Properties

Density, Mass Loss and Volume Loss:

The density of alkaline-treated and untreated wood of Obeche was calculated in accordance with ASTM-D2395 (1998) as the ratio of oven-dry mass to volume, with volume determined by direct measurement of the dimensions using equation 1.

$$D = \frac{M}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, D (g/cm^3) = density; M (g) = Mass of the wood, and

V= volume of the wood is calculated using:

V(cm^3) = L x W x H (L= length; W = width; H = height (or thickness)

The percentage mass loss and]volume loss due to alkaline treatment were calculated using equations 2 and 3, respectively:

$$Mass\ Loss\ (\%) = \frac{M_0 - M_1}{M_0} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$Volume\ Loss\ (\%) = \frac{V_0 - V_1}{V_0} X\ 100 \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where M0 is the initial oven-dry weight before treatment,

M1 is the final oven-dry weight after treatment and drying;

V0 is the initial oven-dry volume before treatment, and V1 is the final oven-dry volume after treatment and drying.

Determination of Hygroscopic Properties

Water Absorption and Volumetric Swelling: The oven-dried specimens (both treated and untreated) were immersed in distilled water at room temperature for 168 hours (7 days) to achieve saturation. The weight and dimensions of each specimen were measured before and after 2 hours and 7 days of immersion.

$$WA\ (\%) = \frac{W_2 - W_1}{W_1} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where, WA = water absorption; W_2 = specimen after water soaking and W_1 = weight of specimen before water soaking.

$$VS\ (\%) = \frac{V_2 - V_1}{V_1} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where, VS= volumetric swelling; V_1 = volumeof wood before soaking, V_2 = volume of wood after soaking

Anti-Swell Efficiency (ASE) and Water Repellent Efficiency (WRE): These indices were calculated to quantify the effectiveness of the treatments and were measured according to ASTM -1037 (1999).

Anti-swell efficiency was calculated according to Eqn. (5) and (6)

$$ASE\ (\%) = \frac{S_u - S_t}{S_t} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where, ASE = anti-swell efficiency; S_u = volumetric swelling coefficient of untreated wood samples and S_t = volumetric swelling coefficient of treated wood samples

Water repellent efficiency was calculated according to Eqn. (4) and (7)

$$WRE\ (\%) = \frac{W_u - W_m}{W_u} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where, WRE = Water repellent efficiency; W_u = water absorption of untreated samples and W_m = water absorption of treated samples.

Statistical Analysis

All experiments were conducted using a completely randomised design with at least four replicates (n = 4) per treatment group (1 h, 3 h, 5 h, and control). The data obtained were subjected to a one-way Analysis of Variance (ANOVA) using SPSS Statistics software. Treatment duration was the fixed factor. The significance of differences between group means was determined using Duncan Multiple Range post-hoc test at a 95% confidence level ($p < 0.05$). Data are presented as mean ± standard error.

Results and Discussion

The effects of alkaline sulfite treatment duration on the physical properties and dimensional stability of *Triplochiton scleroxylon* wood were profound and

statistically significant. The results are presented and discussed below, integrating empirical findings with their mechanistic explanations and industrial implications.

Treatment-induced Compositional and Structural Changes

Density of treated and untreated Obeche (Triplochiton scleroxylon) wood

The results of untreated and treated *Triplochiton scleroxylon* wood samples are presented in Figure 1. The result of the density test revealed that the untreated (control) sample of *Triplochiton scleroxylon* had the highest density, with an average value of 0.39 g/cm³. This value served as a benchmark for assessing the effect of the chemical treatment on the wood. After treatment with sodium hydroxide (NaOH) and sodium sulfite (Na2 SO3), a noticeable reduction in density was observed in the wood samples, and this reduction became more pronounced with increasing cooking duration (1hour, 3 hours, and 5 hours).



Figure 1: Density of alkaline-treated and untreated *Triplochyton scleroxylon* wood

The initial density of the samples varied significantly between groups ($p<0.05$). However, after treatment, the density of all treated groups was statistically similar clustering between 0.34–0.38 g/cm³, and was significantly lower than the untreated control (0.48 g/cm³). This indicates that the treatment effectively homogenized the wood's density, creating a consistently less dense material regardless of the initial minor variations in the samples, primarily through the extraction of cell wall components.

The decrease in density is attributed to the chemical breakdown of some structural components in the wood, especially hemicellulose and lignin, which are known to be sensitive to alkaline treatment. These components are partially removed during the cooking process, leading to a reduction in overall wood mass. According to recent studies, NaOH facilitates the swelling of cellulose fibres and the dissolution of hemicellulose, while Na2 SO3 enhances delignification by sulfonating lignin, making it more soluble in the solution (Augustina *et al.*, 2022; Zhang *et al.*, 2022). The observed increase in density loss with longer cooking time reflects intensified chemical components. The control sample's higher density treatment degrades key structural components in leading to measurable declines in density.

Journal of Forestry Research and Management. Vol. 22 (2). 70-79; 2025, ISSN 0189-8418
www.jfrm.org.ng

Mass Loss and Volume Loss

The alkaline sulfite treatment successfully modified the chemical composition and physical structure of the wood. A one-way ANOVA revealed that treatment duration had a highly significant effect ($p < 0.05$) on both mass loss and volume loss (Table 1), confirming that the chemical alteration was directly controllable by processing time.

Table 1: Mass Loss and Volume Loss of Alkaline-Treated Obeche Wood

Treatment duration	% Mass Loss	% Volume Loss
Control	0.00±0.00	0.00±0.00
1 hour	1.65±1.40[a]	4.63±0.59[b]
3 hours	5.15±1.03[b]	5.50±2.67[b]
5 hours	10.06±1.48[c]	6.59±2.29[b]

Values are mean ± SE. Different superscript letters within a column indicate significant differences ($p < 0.05$)

Mass loss increased progressively and significantly with treatment duration, from 1.65% (1h) to 10.06% (5h). This is a direct metric of the dissolution and extraction of wood constituents, primarily hemicellulose and lignin (Zhang *et al*., 2017). Sodium hydroxide swells the cellulose microfibrils and solubilizes hemicellulose, while sodium sulfite sulfonates lignin, enhancing its solubility and removal (Chen *et al.,* 2018). The statistically distinct groupings (a, b, c) demonstrate that each longer duration removed a significantly greater amount of material. The volume loss followed a different pattern; while significant compared to the control, the values for the 1-hour and 3-hour treatments were statistically similar, with only the 5-hour treatment showing a higher, though not statistically unique, mean value. This suggests that initial treatment causes a contraction of the wood matrix (likely from the dissolution of polymers supporting the cell wall structure), but extended treatment may lead to a point where the remaining cellulose framework begins to dictate volume stability, despite continued mass loss (Hill, 2006).

Enhancement of Hygroscopic Properties and Dimensional Stability

Water Absorption (WA) and Volumetric Swelling (VS)*:* The primary objective of the treatment—to enhance dimensional stability—was successfully achieved. The chemical modifications induced a drastic improvement in the wood's resistance to water, as detailed in Table 2. The most striking result is the reduction in long-term (7-day) water absorption. The untreated control exhibited extreme hygroscopicity, absorbing 390.29% of its dry weight in water. In contrast, all treated samples absorbed significantly less water. The 3-hour treatment was optimal, reducing absorption by nearly 60% to 160.97%. This remarkable improvement is a direct result of the removal of hygroscopic hemicellulose, which contains the majority of accessible hydroxyl groups in the cell wall that bind with water molecules (Rowell, 2012).

Table 2: Water Absorption and Volumetric Swelling of Treated and Untreated Obeche Wood

Treatment Duration	Water Absorption		Volumetric Swelling	
	2hrs	7days	2hrs	7days
Control	36.78±6.46[a]	390.29±30.68[c]	28.42±12.89[b]	49.66±12.59[b]

Journal of Forestry Research and Management. Vol. 22 (2). 70-79; 2025, ISSN 0189-8418
www.jfrm.org.ng

1 hr	32.03±13.56[a]	249.164±4.62[ab]	11.44±0.51[a]	16.78±0.78[a]
3 hours	38.01±15.46[a]	160.97±45.66[a]	8.23±0.65[a]	9.94±5.77[a]
5 hours	45.62±4.75[a]	301.59±26.06b[c]	13.29±4.12[a]	16.41±3.33[a]

Values are mean ± SE. Different superscript letters within a column indicate significant differences ($p < 0.05$, Tukey's HSD test).

The extraction of lignin further diminished the wood's ability to retain water, yet the sharp rise in absorption at 5 hours (301.59%) is a critical observation. This outcome indicates that overtreatment leads to excessive microstructural breakdown, forming a porous network that encourages capillary water uptake and negates the advantages gained from hemicellulose removal (Pandey and Pitman, 2003). In parallel, significant improvements were recorded in volumetric swelling. While untreated control samples swelled by nearly 50% over seven days, all treated samples exhibited swelling values below 17%. This substantial reduction aligns with the findings of Nawawi *et al.* (2023), who demonstrated that alkaline treatments with NaOH can partially degrade hemicellulose, cellulose, and lignin. The removal of these amorphous regions decreases the wood's capacity to absorb and retain moisture, thereby enhancing its dimensional stability

Anti-Swell Efficiency (ASE) and Water Repellent Efficiency (WRE)

The Anti-Swell Efficiency (ASE) and Water Repellent Efficiency (WRE) metrics were calculated from the data of WA and VS, to quantify this enhancement (Figure 2).



Figure 2: Anti-Swell Efficiency (ASE) and Water Repellent Efficiency (WRE)

The consistently high ASE values confirm that alkaline sulfite treatment effectively restricts dimensional changes in *Triplochiton scleroxylon*. This improvement can be attributed to the selective removal of the amorphous, swellable components of hemicellulose and lignin, leaving behind a cellulose-rich framework that is more rigid and less prone to expansion (Hill, 2006). In contrast, the WRE values reveal a more complex response. Water repellency peaked at 3 hours, reaching nearly 59%, but then declined sharply to 23% at 5 hours. This trend highlights a dual mechanism: while hemicellulose removal reduces water uptake, excessive delignification generates micropores that promote capillary absorption, undermining the treatment's effectiveness. The 3-hour exposure thus represents the optimum balance between these opposing processes. Interestingly, even at 5 hours, ASE remained high despite the marked drop in WRE. This suggests that although greater volumes of water penetrate through the porous structure, the cell wall matrix—now depleted of its elastic

hemicellulose–lignin components—swells less and remains dimensionally rigid (Berglund and Burgert, 2018).

Correlation between Compositional Changes and Stability Enhancement

The study highlights a clear correlation between the chemical changes induced by alkaline sulfite treatment and the resulting stability of *Triplochiton scleroxylon*. Progressive removal of hemicellulose and partial lignin breakdown reduced the wood's hygroscopicity, directly improving its resistance to water absorption and swelling. However, the relationship proved non-linear: while moderate treatment (3 hours) produced exceptional stability, extended exposure (5 hours) caused excessive degradation, creating pores that undermined water repellency. The peak performance at 3 hours thus represents a critical balance between beneficial compositional alteration and preservation of structural integrity. Remarkably, the stability achieved at this point is comparable to that of more established treatments such as acetylation (Rowell, 2006) and thermal modification (Esteves and Pereira, 2009), underscoring alkaline sulfite treatment as a cost-effective and efficient method for enhancing Obeche wood's dimensional stability.

Conclusion

This study confirmed that alkaline sulfite treatment can significantly improve the dimensional stability of *Triplochiton scleroxylon* (Obeche) wood. The process works by modifying the wood's chemical composition, reducing the presence of hygroscopic components such as hemicellulose, which are largely responsible for moisture uptake and swelling. Among the different treatment durations tested, the 3-hour exposure proved to be the most effective. At this stage, the wood gained strong resistance to water absorption and swelling while still retaining its structural integrity. Shorter treatment times were less effective, while prolonged treatment (5 hours) led to excessive degradation of the wood structure.

In practical terms, the findings highlight the importance of optimizing treatment duration rather than assuming that longer exposure always produces better results. A 3-hour alkaline sulfite treatment offers the best balance between enhancing durability and preserving strength, making it suitable for applications where Obeche is exposed to fluctuating humidity. This optimized approach not only improves performance but also ensures more efficient use of chemicals and energy in wood modification processes.

References

Adebawo, F. G., Ogunsanwo, O. Y., and Olajuyigbe, S. O. (2020): Decay resistance of the acetylated tropical hardwood species. *Journal of Forest and Environmental Science*, 36(3): 225-232.

Adebawo, F. G., Sadeghifar, H., Tilotta, D., Jameel, H., Liu, Y., and Lucia, L. (2019): Spectroscopic interrogation of the acetylation selectivity of hardwood biopolymers. *Starch - Stärke* 71(11-12),1900086.

Adebawo, F.G., Naithani, V. Sadeghifar, H., Tilotta, D., Lucia, L.A., Jameela, H., Ogunsanwo, O.Y. (2016): Morphological and interfacial properties of chemically modified tropical hardwood. *RSC Adv*. DOI: 10.1039/c5ra19409a

Adegoke, O. A., Adebawo, F. G., Ajala, O. O., Adelusi, E. A. Oloketuyi, A. J. (2021): Improving Hydrophobicity of Tropical Hardwood along Axial Positions. *J. Appl. Sci. Environ. Manage.* 25(8):1339-1343.

ASTM D-1037(1999): Standard Test Methods for evaluating properties of Wood-base fiber and Particle panel

materials." American Society for Testing and Materials, West Conshohocken, PA.

ASTM D2395 (1998): Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials

Augustina, S., Wahyudi, I., Dwianto, W., and Darmawan, T. (2022): Effect of sodium hydroxide, succinic acid and their combination on densified wood properties. *Forests* 13(2): 293.

Aziz S.H. and Ansell M.P. (2004):The Effect of Alkalization and Fibre Alignment onThe Mechanical andThermal Properties ofKenaf and Hemp Bast Fibre Composites: Part 1—Polyester Resin Matrix. *Compos. Sci. Technol*.;64:1219–1230. doi: 10.1016/j.compscitech.2003.10.001

Baruah J., Nath B.K., Sharma R., Kumar S., Deka R. C., Baruah D. C. and Kalita E. (2018): Recent Trends in the Pretreatment of Lignocellulosic Biomass for Value-Added Products.*Frontiers in Energy Research*, 141 (6) : 1-19. doi: 10.3389/fenrg.2018.00141

Bekele, A. E., Lemu, H. G., and Jiru, M. G. (2023): Study of the Effects of Alkali Treatment and Fiber Orientation on Mechanical Properties of Enset/Sisal Polymer Hybrid Composite. *Journal of Composites Science*, *7*(1), 37. https://doi.org/10.3390/jcs7010037

Berglund, L., and Burgert, I. (2018): Bioinspired wood nanotechnology for functional materials. *Advanced Materials*, 30(19), 1704285.

Chen, Y.; Su, N.; Zhang, K.; Zhu, S.; Zhu, Z.; Qin, W.; Yang, Y.; Shi, Y.; Fan, S.; Wang, Z.; et al. (2018):Effect of fiber surface treatment on structure, moisture absorption and mechanical properties of luffa sponge fiber bundles. *Ind. Crop. Prod*. 2018, 123, 341–352.

Esteves, B., and Pereira, H. (2009): Wood modification by heat treatment: A review. *BioResources*, 4(1), 370–404.

Fabiyi J. S. and Ogunleye B. M. (2015): Mid-Infrared Spectroscopy and Dynamic Mechanical Analysis of Heat-treated Obeche (Triplochiton scleroxylon) Wood. *Maderas. Ciencia y tecnología* 17(1): 5 – 16. DOI:10.4067/S0718-221X2015005000001

Hill, C.A.S. (2006): Wood Modification: Chemical,Thermal and Other Processes; John Wiley &Sons, Ltd.: Chichester, UK, 357p

Militz, H., and Lande, S. (2009): Challenges in wood modification technology on the way to practical applications.*Wood Material Science & Engineering*, 4(1–2), 23–29. https://doi.org/10.1080/17480270903275578

Nawawi, D. S., Maria, A., Firdaus, R. D., Rahayu1 I. S., Fatrawana A., Pramatana F., S. Sinaga P., and Fatriasari W. (2023): Improvement of dimensional stability of tropical light-wood *Ceiba pentandra* (L) by combined alkali treatment and densification. *Journal of the Korean Wood Science and Technology*, 51(2): 133-144. https://doi.org/10.5658/WOOD.2023.51.2.133

Ogunsanwo, O.Y. and Onilude, M. A. (2000): Specific gravity and shrinkage variation in plantation grown obeche (*Triplochiton scleroxylon* K. Schum). *J Trop For Res* 16: 39-45.

Pandey, K. K., and Pitman, A. J. (2003): FTIR studies of the changes in wood chemistry following decay by brown-rot and white-rot fungi. International Biodeterioration & Biodegradation, 52(3), 151–160.

Perremans, D., Hendrickx, K., Verpoest, I., and Van Vuure, A.W.(2018): Effect of chemical treatments on the mechanical properties of technical flax fibres with emphasis on stiffness improvement. Compos. Sci. Technol. 160, 216–223.

Rowell, R. M. (2006): Acetylation of wood—A review. *Forest Products Journal*, 56(9), 4-12.

Rowell, R. M. (2012): Handbook of wood chemistry and wood composites. CRC press.

Sandberg, D., Kutnar, A. and Mantanis, G. (2017): Wood modification technologies: A review. "iForest - Biogeosciences and Forestry, 10"(6), 895–908.

Sathre, R. and Gustavsson, L. (2009): Using wood products to mitigate climate change: External costs and structural change. *Appl. Energy*, 86, 251–257.

Ying, W., Shi, Z., and Yang, H. *et al*. (2018): Effect of alkaline lignin modification on cellulase–lignin interactions and enzymatic saccharification yield. *Biotechnol Biofuels* 11:214 https://doi.org/10.1186/s13068-018-1217-6

Zhang, X., Chen, S., Ramaswamy, S., Kim, Y.S., and Xu, F. (2017): Obtaining pure spectra of hemicellulose and cellulose from poplar cell wall Raman imaging data. Cellulose, 24, 4671–4682.

Zhang, X., Li, L.,and Xu, F. (2022): Chemical Characteristics of Wood Cell Wall with an Emphasis on Ultrastructure: A Mini-Review. Forests, 13, 439. https://doi.org/10.3390/f13030439