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POTENTIALS OF THERMO-OIL TREATMENT PROCESS FOR IMPROVED PROPERTIES OF LESSER UTILIZED WOOD SPECIES IN NIGERIA

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ABSTRACT

The growing demand for timber has resulted in increased exploitation of forest plantations and the use of fast-growing species. In response, technology has been developed to improve the mechanical qualities and durability of wood. This technology has reduced the need for toxic chemicals, instead promoting non-toxic modifications to prevent the decay and increase the mechanical properties of timber. Thermal modification is one such alternative method, which improves wood's dimensional stability and decay resistance while only slightly decreasing its strength qualities. As an eco-friendly approach, thermo-oil modification of wood shows promise as an alternative to traditional chemical treatments. Numerous scientific articles have explored the thermo-oil modification of wood, summarizing its properties and potential applications. This reviewed article also examines the effects of thermo-oil modification on various wood properties, including dimensional stability, chemical properties, and resistance to termites and fungi.

Keywords: Modification, Wood dimensional Stability, Durability, Thermo-oil treatment

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INTRODUCTION

1.0 Wood as a renewable resource

Wood is an excellent building material with several advantages, such as a high strength-to-weight ratio, lower processing energy, and ease of workability compared to other building materials (Asdrubali *et al*., 2017). It is a renewable material and considered environmentally friendly; however, its low dimensional stability and durability limit its structural applications, requiring modification (Lee *et al*., 2018). Dimensional stability is crucial when choosing wood for structural use, as it affects appearance and usability. Wood is susceptible to degradation by fungi, termites, mold, bacteria, algae, and lichens, leading to financial loss and posing health risks (Stirling *et al*., 2017; Lee *et al*., 2018; Gradeci *et al*., 2017). Due to the growing demand for durable wood species, Nigerian forest estates predominantly consist of lesser-used wood species (Adiji *et al*., 2022). Although these species have lower overall strength, they can be used in buildings with limited load requirements and in veneer-based products when laid up properly (Sandberg *et al*., 2023). To improve the resistance to biodeterioration and dimensional stability of lesser-used wood species, treatment strategies are needed to reduce their hygroscopic tendency. Heat treatment using oil as the heating medium is an environmentally friendly method that enhances properties such as color stability, mechanical strength, and durability against termites and fungi, but its effectiveness depends on factors such as the type of oil used and the wood species (Lee *et al*., 2018; He *et al*., 2022; Wehsener *et al*., 2018; Wong *et al*., 2021).

1.1 Importance of Wood

Wood is a sustainable and renewable resource, unlike non-renewable materials such as steel and concrete. Sustainable forestry practices ensure a continuous supply of wood while also promoting forest health. Additionally, wood products have lower embodied energy compared to materials like steel and concrete, resulting in reduced greenhouse gas emissions during production. Wood's natural insulating properties provide better thermal performance compared to materials like steel and concrete (Asdrubali *et al*., 2017). This often leads to wooden structures requiring less energy for heating and cooling, ultimately resulting in lower energy costs. Furthermore, wood is a versatile material that can be easily shaped, cut, and joined to create complex designs, offering architects and designers more flexibility in achieving unique and innovative building shapes and forms (Naboni and Paoletti, 2015). Its adaptability also makes it suitable for adaptive reuse in projects and sustainable building practices.

1.2 Lesser Utilized Wood Species (LUWS)

Nigeria's forested areas are home to around 560 different species of trees, with a density of 30 to 70 species per hectare (Adiji *et al*., 2021). Iroko (*Melicia excelsa*), Obeche (*Triplochiton scleroxylon*), Mansonia (*Mansonia altissima*), Mahogany (*Entandrophragma cylindricum*), Omo (*Cordia millenii*), Aye (*Sterculia rhinopetalia*), Afara (*Terminalia superba*), Ayinre (*Albizia lebbek*), Danta (*Esogordonia papaverifera*), and Abura (*Mitragyna ciliata*) are some of the most well-known tree species in Nigeria (Adiji *et al*., 2021; Adekunle *et al*., 2013). Nigeria is home to a wide variety of tree species, and according to Beak Consultants (1999), only 60 of them have been found to have commercial worth; the other species are either neglected or destroyed during harvest. Many of the desirable timber species that are now available are being over-exploited to the point of extinction because they are not permitted to reach adulthood before being harvested. Adiji *et al*., 2021. Study, however, revealed that, in light of the nation's wood resources, greater focus should be made on the use of under-utilized wood species for sustainable utilization. Although this approach broadens our understanding of these species, it has not been shown to be effective in encouraging their use. Other than that, the primary problem nowadays is not a lack of understanding regarding the characteristics of wood that require theoretical determination. There isn't much knowledge about the use of lesser-known or less-used wood species in Nigeria. Less-used species (LUS) will be effectively promoted and used if industry is given access to and knowledge about the characteristics of Nigeria's less common wood species is made available. This will help ease the pressure on the few primary species in the face of the challenges of meeting the demand for wood-by-wood industries by users. However, in order to utilize the less common wood species effectively, information on their qualities such as their durability and water sorption behavior must be widely disseminated (Gladys, 2009). By effectively using them, less-utilized wood species can assist manage the forest estate sustainably while also helping to meet the demand from wood companies and wood users (Adiji *et al*., 2021; Owoyemi and Oyeleye, 2017).

2.0 Wood Modification

In recent years, there has been a significant increase in the demand for durable, eco-friendly wood products that have been treated to last longer. This trend is driven in part by concerns about the environment and the desire for low-maintenance outdoor wood products (Sandberg *et al*., 2015). Wood is a sustainable, non-toxic, and widely available material that has been used by humans for centuries. While traditionally wood has been minimally processed, there are limitations to its natural form, and modifications are often necessary to achieve the desired results.

Wood modification is utilized to address the weaknesses of wood materials, including changes in moisture content, low dimensional stability, hardness, and wear resistance. Additionally, it aims to improve the limited resistance to bio-deterioration from fungus, termites, marine borers, and UV radiation. This process is commonly used to enhance the physical, mechanical, or aesthetic qualities of sawn timber, veneer, or wood particles used in the creation of wood composites. The end result is a material that can be disposed of without posing any greater environmental risks than unaltered wood. Concerns over the environmental impact of wood treated with certain preservatives have prompted a surge in the wood modification sector. This growth is further driven by the introduction of novel technologies to the market, such as thermal modification, acetylation, furfurylation, and other impregnation techniques, demonstrating the potential of modern innovations.

2.1 Reasons for current development in the wood modification industries

The term "wood modification" is a broad term that encompasses the use of various techniques such as chemical, mechanical, physical, or biological methods to alter the properties of wood. Essentially, it refers to any changes that occur to wood after it has been harvested from the forest. According to Hill (2006), wood modification is defined as "the application of a chemical, biological, or physical agent to the material, resulting in the enhancement of a desired property during the wood's service life." It is important that modified wood does not release harmful compounds during use, at the end of its life, or after it has been disposed of or recycled (Candelier and Dibdiakova, 2021). Additionally, the modified wood should be safe to use and should not pose any harm under normal conditions. If the goal is to increase resistance to biological attack, the method of action should be non-biocidal. It is important to note that the use of potentially hazardous chemicals in the manufacturing process of modified wood is not prohibited, as long as there are no dangerous residues left behind after the transformation process.

The growing fascination with wood modification in recent decades can be ascribed to several factors like progress in research, the demands of the business sector, and the broader societal implications. Changes in forestry techniques and the utilization of wood, especially in construction, can modify the characteristics of the material. There is an increasing recognition of the utilization of rare species that exhibit outstanding characteristics in terms of longevity and visual appeal. Furthermore, there is acknowledgment of the ecological damage created by the utilization of chemicals to augment the longevity and minimize the need for upkeep of wooden goods, which is governed by legislation. The industry is placing a growing emphasis on enhancing the worth of cut timber and its associated goods. The United Nations (UN) largely coordinates these reforms and related efforts, such as the Paris Agreement, within the framework of the United Nations Framework Convention on Climate Change (United Nations, 2015).

2.2 Approaches and Methods of Wood Modification

The practice of modifying wood to enhance its performance, durability, and versatility as a material is increasingly common (Zelinka *et al*., 2022). Changes in wood chemistry through modification often impact its interaction with water, making it crucial to understand these characteristics in order to determine the qualities of the modified material. However, modifications typically result in changes in the mass and/or volume of the dry wood. Sandberg *et al*., 2017 outlined four different methods for wood modification: chemical treatments, thermo-hydro (TH) and thermo-hydro-mechanical (THM) treatments, biological process-based therapies, electromagnetic irradiation treatments, and plasma treatments. Recent examples of commercial wood modifications, along with their original scientific publications, include thermal modification (Tjeerdsma *et al*., 1998; Sailer *et al*., 2000; Iyiola et al., 2019), furfurylation (Schneider 1995; Westin 1996; Lande et al., 2008; Falade et al., 2020), modification with DMDHEU (dimethylol dihydroxy ethylene urea) (Militz 1991), and acetylation (Larsson *et al*., 2000; Emmanuel *et al*., 2022). These known approaches and methods have demonstrated the potential to produce more durable wood or wood products with reduced hygroscopicity by physically altering the wood's components or chemically modifying its structure (Hill, 2006).

2.2.1 *Chemical Modification*

The wood cell wall polymers can undergo various chemical alterations, with hydroxyl groups being the most common sites of reactivity (Rowell 2005). These hydroxyl groups in the wood polymers, such as cellulose, hemicellulose, and lignin, are the most reactive sites in wood, albeit with differences in their relative reactivities. They also contribute to dimensional instability through hydrogen bonding with water (Larsson Brelid, 1998). Increased dimensional stability can be achieved by chemically modifying the wood through reaction with stable, covalently bound, less hydrophilic groups (Larsson Brelid, 1998). Numerous approaches for wood protection have been extensively studied and reported, including the use of metallic salts and creosote for long-term durability, coatings for aesthetic purposes, and methods for moisture and UV protection (Schultz *et al*., 2007). However, chemical alteration is gaining popularity as a way to reduce the water sensitivity of wood, increase durability, and decrease dimensional instability (Chaouch *et al*., 2013). Chemical modification involves a chemical agent reacting with wood chemical components to form covalent bonds, resulting in the alteration of the chemical structures of wood cell wall components, such as lignin, cellulose, and hemicellulose (Herrera *et al*., 2018; Evans *et al*., 2015). This modification can lead to permanent improvements in properties, particularly in terms of durability, dimensional stability, and reduced equilibrium moisture content, opening up new possibilities for the use of wood in previously unexplored areas. Combined modification methods can also introduce additional functionality in wood, such as photoluminescence, electrical conductivity, sensors, and transparency, although this may come at the expense of the original material properties.

2.2.2 *Chemical Impregnation of Wood*

Impregnating wood cell walls with environmentally friendly chemicals is a diverse and continually fascinating area of study. Typically, this process involves treating wood with a solution of monomers that permeate the cell walls, followed by polymerization. The impregnating chemicals enhance wood properties by increasing the size and bonding of the cell wall's polymeric constituents, creating a "non-leachable" impregnate in service. Fixation of the wood by the chemical can occur through two main mechanisms (Hill, 2006): (a) impregnation of monomers (or oligomers) with subsequent polymerization within the cell wall, or (b) diffusion of a soluble material into the cell wall followed by treatment to render the material insoluble (immobile). Impregnating wood is a major concern in wood science due to factors such as ensuring maximum penetration. The maximum diameter of the cell wall micropores is approximately 2–4 nm, meaning that larger molecules are required to penetrate the swollen cell wall. It is important to allow sufficient time for the chemical impregnation to diffuse into the intracellular spaces of the wood to ensure maximum penetration of the wood cells. Using specific methods such as pressure treatment can aid in penetrating larger wood samples, but it will not result in cell wall penetration, which is a process purely controlled by diffusion. Chemicals with a molar volume greater than $100 cm^3/mol^{-1}$, which corresponds to a molecular diameter of approximately 0.68 nm, have limited ability to penetrate the cell wall.

2.2.3 *Acetylation*

A great deal of research has been done on the process of acetylating timber, which is essentially employing acetic anhydride to chemically alter the wood cell walls. The main mode of action is the interaction of acetic anhydride with the hydroxyl groups of the cell wall polymers, which forms ester linkages and adds an acetate moiety to the cell wall. Many characteristics of wood are influenced by the hydroxyl (OH) groups that are attached to the polymeric components of the cell wall (Rowell *et al*., 2005). Since acetylation doesn't require a catalyst, it is a useful technique for wood alteration.

The process of acetylating wood involves applying external pressure to cause the electrophilic reagent typically acetic anhydride to migrate through the vessels in broad-leaved wood species and the pits in coniferous wood. Easy-to-access hydroxyl groups in the wood are reacted with by the reagent. Following that, it penetrates deeper into the cell wall and reacts (Rowell, 1983). As a result, the cell wall thickening and elimination of water-attracting hydroxyl groups lessen wood's capacity to absorb moisture and increase its resistance to swelling and decay. (Hill, 2006; Hill and Jones, 1996). Radiant pine has primarily been utilized in commercial applications thus far because of its low density and porous character. However, compared to solid wood products, the acetylated fibres in fiberboard are more likely to undergo reactions, which could result in a preference for different wood species.

2.2.4 *Furfurylation*

Furfuryl alcohol, a liquid derived from agricultural wastes such as maize cobs and sugar cane, is used in the process of furfurylation. This involves impregnating a material with furfuryl alcohol or its prepolymer, with the presence of a moderate acid catalyst. The subsequent heat-curing phase results in the production of a hard, water resistant product, followed by a drying process that includes chemical recycling. The dark, brownish hue of the product is partly attributed to the resin, while exposure to bright sunlight can cause greying. Kebony AS, established in 2009 in Skien, Norway, was the first company to commercially produce furfurylated wood. Their facility has a production capacity of 20,000 m^3/year, and a second factory has recently been built near Antwerp, Belgium. Additionally, Foreco Dalfsen in the Netherlands utilizes pre-polymerized furfuryl alcohol resin to create furfurylated solid wood products known as Nobelwood.

The polymerization of furfuryl alcohol in wood is a complex chemical reaction, and it remains uncertain whether furfurylation can be classified as a distinct chemical process. Furfuryl alcohol has the capacity to react with both the lignin in cell walls and its own molecules, resulting in the formation of a polymeric structure (Lande *et al*., 2008; Nordstierna *et al*., 2008; Gérardin, 2016; Li *et al*., 2016). Dimethyl ether bridges may be sporadically produced by the self-condensation of furfuryl alcohol, resulting in the formation of water and a condensed furan product. The furan moieties in this molecule are connected by methylene linkages. (Lande *et al*., 2008). Currently, the primary focus of furfurylated wood product production is on using Scots pine and radiata pine. In addition, alternative wood species such as silver birch, European beech, and maple have been studied extensively (Lande *et al*., 2004).

2.2.5 *Impregnation through polymerization*

Since the Impreg and Compreg procedures were developed in the early half of the 20th century, there has been extensive research on using resins to enhance the characteristics of wood (Stamm and Seborg, 1943, 1944; Stamm *et al*., 1946). The primary difference between the two materials lies in the use of compressive forces before and during the curing process of Compreg, as indicated by their names. Impreg can be based on phenol, melamine, or urea and is cured in mildly acidic or alkaline conditions, while Compreg is typically based on phenol-formaldehyde resins. In addition, Impreg includes a monomer, such as methyl methacrylate or styrene, which facilitates hardening through a stepwise polymerization mechanism. Stefanowski *et al*. (2018) provided a review on the resin modification of wood.

2.2.6 *Thermal modification*

The use of heat in wood processing has been important for ensuring its suitability for use over a long time. There are different processes involving the heating of wood: Wood drying; Thermal modification can be inform of heating in the absence of air, i.e. pyrolysis and thermolysis, heating in the presence of air, i.e. combustion; Complete combustion with full access to oxygen or incomplete combustion when the availability of oxygen access is limited.

At temperatures exceeding 300°C, the main components of wood undergo severe degradation, with some exceptions. Elevated temperatures are crucial when transforming wood with water or moisture. Different wood components degrade at different temperatures, with extractives being the most sensitive, followed by hemicelluloses, cellulose, and lignin (Jones *et al*., 2019). The goal is to change the wood's internal chemical composition without adding chemicals that could interact with reactive sites. Heat modification effects on wood are well-documented, with species-specific variations in cross-linking, polymerization, softening, lignin redistribution, and loss of acid groups. The specific chemistry is influenced by process parameters, with hydrolysis and catalysis occurring more frequently in closed-system processes. Treating materials at temperatures between 160 °C and 220 °C (European Committee for Standardization, 2008) aims to enhance biological durability, improve dimensional stability, and control color changes.

2.2.7 *Thermo-oil Treatment*

On a large scale, wood thermal modification is a well-established commercial technology for improving the dimensional stability and durability of timber. The treatments of wood that involve the use of air or nitrogen demand accurate control of high temperatures for the planned process time to improve the properties of wood (Wang, 2007). The inclusion of hot oil in wood modification will provide fast and equal heat transfer to the wood and the same conditions all over the whole vessel, and the oil will also serve as a perfect separation of oxygen from wood (Rapp and Sailer, 2001). It was found that the improved dimensional stability and resistance against biological attack of oil-heat treated wood not only benefit from the heat treatment but also from the shell formed by water-repellent oil during the process (Wang, 2007).

When hot-treating wood, using crude vegetable oils as a heating medium such as linseed, sunflower, or rapeseed oil can have several benefits. First and foremost, due to their ability to distribute heat more evenly and quickly to wood, vegetable oils make excellent heating media. Additionally, the oil may separate oxygen from wood as it is being treated, preventing an oxidation process that would otherwise weaken the treated samples (Dubey *et al.*, 2011). Oil heat treatment of wood is a process used to improve the properties of wood by subjecting it to high temperatures in the presence of different types of oils. This treatment alters the wood's structure and enhances its durability, stability, and resistance to decay and insects. The oil choice can affect the final properties of the treated wood. Different types of oil can be used in this process, such as vegetable oils, mineral oils, and modified natural oils.

Advantages of Wood Modification

Wood modification refers to the process of chemically, physically, or biologically altering the characteristics of wood in order to enhance its sustainability, durability, and overall performance (Sandberg, 2017). One of the key benefits of wood modification is the reduction of the wood's susceptibility to dimensional changes caused by fluctuations in moisture, such as twisting, warping, and swelling. This results in a more stable wood, making it well-suited for applications where dimensional stability is crucial, such as exterior decking and cladding (Olaniran *et al*., 2022). Additionally, modified wood exhibits enhanced durability and resistance to rot, fungi, insects, and other biological factors that contribute to its deterioration (Reinprecht, 2016). As a result, modified wood products have a longer lifespan and require less maintenance and replacement over time, particularly in high-moisture or outdoor environments. Certain wood modification methods can also improve the strength, stiffness, and toughness of the wood, making it more suitable for structural applications and demanding load-bearing situations. In engineering and construction settings, modified wood products provide improved performance and safety due to their ability to withstand larger loads and pressures (Sandberg *et al*., 2021).

Wood modification creates new opportunities for the use of wood in situations where conventional untreated wood would not be possible or appropriate. Because modified wood can be utilised in outdoor settings, ground contact applications, coastal situations, and high humidity conditions, its range of applications in construction, landscaping, and infrastructure is expanded (Khademibami *et al*., 2022). It modifies the colour, texture, and grain pattern of the wood to improve its look. Environmentally friendly materials and treatments are used in several wood modification procedures, which minimises the use of hazardous chemicals and their negative effects on the environment. Because modified wood products increase the utilisation of wood resources and decrease waste, they may also support sustainable forestry practices. All things considered, wood modification has several benefits that enhance the wood's performance, sustainability, and adaptability as a building material and encourage creativity and innovation across a range of industries. THT alters the mechanical properties of wood, which limits the material's potential uses, but it also improves the wood's natural durability and aesthetics (Olarescu *et al*., 2014). This is due to structural and colour changes primarily caused by hemicellulose degradation (Salca, 2016), which enhances the wood's appearance and makes it more suitable for use in engineering, construction, and architectural projects, among other applications.

2.4. Effect of oil heat treatment on the properties of wood

2.4.1 *Colour Changes*

The color of natural wood is determined by the chromophores found in the lignin and extractives. When wood is heated, hemicellulose degradation adds extra chromophores to the wood, causing color alterations (Nemeth *et al*., 2016). It's commonly observed that wood darkens after being heated, and the degree of darkening increases with temperature. The amount of oil absorption also impacts the color change of the wood; wood that absorbs more oil generally has a deeper color (Sailer *et al*., 2000). The treatment of Radiata pine wood with linseed oil at 180°C for three hours resulted in a noticeable difference in colour between the treated and untreated wood. The treated wood exhibited significantly less lightness and more reddish and yellow tones (Dubey *et al*., 2011). The wood was treated using a bi-geothermal technique involving 160°C for 0.5 hours, followed by 0.5 hours at ambient temperature, which caused the wood to turn practically black and develop visible char on the surface (Tomak *et al*., 2011). According to Nemeth *et al*. (2016), the degree of darkening is heavily influenced by the wood's extractive content, with wood containing higher extractive content showing a more noticeable additional darkening effect from the oxidation process. It was also observed that the level of colour changes between sapwood and heartwood differed (Razak *et al*., 2011). Sapwood of Acacia hybrid treated in hot palm oil exhibited a significant decrease in lightness compared to heartwood, primarily due to its brighter colour.

2.4.2 *Dimensional Stability*

The treatment of wood, including factors such as temperature and duration, has a significant impact on its characteristics. The type of oil used for heating also plays a role in the outcome. According to Wang and Cooper (2005), palm oil is more effective than soybean oil at improving the dimensional stability of white spruce when used for heating. Additionally, Lyon *et al*., (2007) found that the drying characteristics of vegetable oils are essential for enhancing the resistance of treated wood to decay. They reported that out of the three vegetable oils studied, linseed oil is the best for creating long-lasting samples, followed by soybean and rapeseed oil. This is because linseed oil contains a high quantity of polyunsaturated and monounsaturated fatty acids, making it a drying oil. As a result of its high unsaturation level, linseed oil effectively prevented water from seeping into the wood samples, thereby enhancing the dimensional stability of the wood. Oil heat treatment decreased the equilibrium moisture content (EMC) in the treated samples, leading to reduced water absorption and improved dimensional stability. This decrease in EMC can be attributed to various heat-induced factors, including a decrease in the water affinity hydroxyl groups, reduced accessibility of hydroxyl groups to water molecules due to an increase in cellulose crystallinity, and further crosslinking. In a study by Dubey *et al*., (2011), linseed oil was applied to Pinus radiata wood at temperatures of 160°C, 180°C, and 210°C for 1 hour, 3 hours, and 6 hours, respectively. The comparison between treated and untreated wood showed that the treated wood exhibited improved volumetric swelling percentage (S) and anti-swelling efficiency (ASE).

2.4.3 *Mechanical Properties*

After being heated with oil, the strength characteristics of the wood are affected because of heat-induced changes in the chemical composition of the cell wall components. Each of the three primary cell wall constituents namely: hemicellulose, cellulose, and lignin contribute differently to the strength properties of the wood. Homan and Jorissen (2004) likened these components of the cell wall to concrete, where lignin functions as small stones or sand to help with compression forces, cellulose serves as reinforcement to help with tension strains, and hemicellulose acts as the cement that acts as the bonding agent. As a result, changing any of these components will affect the strength attributes to varied degrees. Wood with oil heat treatment has mechanical properties that are quite excellent even in the absence of oxygen. In contrast, compared to other heat treatment methods, significant oil uptake also adds to the wood's increased mechanical strength. The compressive strength perpendicular to the grain (CSPG) of Scots pine and beech wood treated with oil heat did not considerably decrease, according to Tomak *et al*., (2011). Because the treated wood retained more oil, resulting in higher density values, several of the treated samples even showed higher CSPG when compared to the control samples. It is believed that oil fills the lumen, fortifies the cell wall, and improves the lateral stability of the wood. Typically, relatively thin cell walls buckle and lead to compression failure in wood. Cheng *et al*., (2014) also reported similar results, that the high oil uptake that thickened the fibres and enhanced their longitudinal strength was the primary reason for the increase in CSPG for poplar wood following oil heat treatment.

2.4.4. *Durability Properties*

Spear *et al*., (2006) investigated how resistant Corsican pine and Norway spruce were to *Coniophora puteana* and *Postia placenta*, the fungus that causes brown rot, when the trees were submerged in hot linseed oil, rapeseed oil, and a special resin made from linseed oil at temperatures of 180 and 200 degrees Celsius. The wood treated in non-drying rapeseed oil showed a greater mass loss in resistance when compared to the wood treated in drying linseed oil, according to the data from Tomak *et al*., (2011) found that the type of oil used as the heating medium has a significant impact on the extent to which wood protects against fungal infections. The researchers concluded that when compared to other vegetable oils such as nut, soybean, canola, and corn oil, waste, and sunflower oil provided the strongest defense against fungal deterioration. The efficiency of the vegetable oils might be related to the chemical composition of oils, their drying properties, and the barrier properties of the dry film. Apart from wood, oil heat treatment also proved to have enhanced the durability of bamboo against *Coriolus versicolor* when subjected to heat treatment in palm oil at various temperature levels (Kamarudin and Sugiyanto, 2010).

This assumption, however, does not fully consider termite resistance. Several studies have indicated that heat-treated wood is more susceptible to termite attacks than untreated wood (Oliver-Villanueva *et al*., 2013; Surini *et al*., 2012). Toxic components produced during the heat treatment of wood were found to cause termite death, but the toxicity was initially ineffective, allowing termites to still consume the treated wood. There is limited information on termite resistance in woody materials treated with oil heat. Research has shown that termite resistance did not improve with rapeseed oil treatment in Scots pine and Norway spruce, and the weight loss from termite attacks was greater in the oil-heat-treated samples compared to the control samples (Smith *et al*., 2003). However, termite resistance significantly improved when bamboo (Dendrocalamus asper) was treated with hot coconut oil, although the weight loss caused by termites was higher in the oil heat-treated samples than in the control samples (Manola and Garcia, 2012).

CONCLUSION

Thermo-oil treatment of wood has led to the improvement of heat treatment with natural oils. This improvement imparts positively on the treated wood species extended service life compared to the untreated wood as it is also environmentally friendly. The Oil serves as a good heating medium for transfering heat steadily and evenly without causing serious damage to the wood cells.

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