MadrasAgric.J.,2024; https://doi.org/10.29321/MAJ.10.600003

RESEARCH ARTICLE

Improvement in the Decay Resistance of *Melia Dubia* Wood against White Rot Fungi and Changes in Properties due to Thermo-Hydro-Mechanical Modification

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Received: 16 Oct 2024

Revised: 23 Oct 2024

Accepted: 11 Nov 2024

ABSTRACT

Despite extensive studies on thermal modification, limited research has focused on fast-growing, short-rotation species like *Melia dubia*. While *Melia dubia* holds significant industrial importance due to its rapid growth and high demand in the pulpwood, plywood, and timber sectors, the juvenile wood produced in short-rotation plantations is often less durable. Thermo hydro mechanical (THM) modification combines thermal and mechanical treatment under controlled conditions, offers a sustainable, eco-friendly alternative to chemical preservative treatments. In the current study, specimens from *Melia dubia* wood were used to obtain wood material with improved decay resistance by using THM treatment, performed at four temperatures: 160 °C, 170 °C, 180 °C, and 190 °C. Fungal resistance was tested under laboratory conditions through a soil block bioassay against white rot fungi *Trametes versicolor*, which indicated that decay resistance increased with increasing temperature. The highest weight loss was recorded in the untreated control samples, whereas the samples treated at 190 °C showed the lowest weight loss percentage, indicating enhanced decay resistance. At the same time, noticeable changes in color, weight loss, and thickness were observed post-treatment. Correlation analysis derived from a scatterplot matrix revealed a positive correlation between temperature and density (r = 0.51), a significant negative correlation between temperature and weight (r = -0.45), and a weak, non-significant negative trend between weight and density (r = -0.14). These findings highlight that higher temperatures increase density while reducing weight and thickness, improving wood durability.

Keywords: Thermo-hydro-mechanical modification, density, color, *Melia dubia*, *Trametes versicolor*, Soil block Bioassay.

INTRODUCTION

Wood has been used as a construction material for thousands of years worldwide to meet anthropogenic needs. With the increasing population and its wide range of applications, the demand for wood has also risen (Ramage *et al.*, 2017). However, the gradual decline in the availability of high-quality raw materials necessitates the more efficient use of existing resources (Domaracka *et al.,* 2022). *Melia dubia*, recognized as one of the fastest-growing trees globally, is particularly valuable as a short-rotation species due to its high demand (Goswami *et al.,* 2020). Although *Melia dubia* can be harvested industrially after just 3-4 years, these short-rotation plantations often produce juvenile wood, which can have inferior properties (Prakash *et al.,* 2018). Therefore, implementing thermo-hydro-mechanical (THM) modification presents a promising alternative to enhance the properties of *Melia dubia* wood. THM treatment is an innovative and eco-friendly approach that improves the intrinsic

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properties of wood, resulting in a modified material that meets functional requirements without compromising the environmental benefits associated with wood (Navi and Sandberg, 2012). Densification makes it possible for low-density wood to substitute the harder species so that low-density species can be modified into effective and high-value material (Kumar *et al.,* 2021). Thermal modification under saturated steam can be performed at lower temperatures with shorter duration to obtain similar or better mechanical properties than modification under superheated steam (Skyba *et al*., 2008). The color characteristics in Pinewood due to thermal modification at a temperature of 120℃ to 150℃ and hot pressing at a press pressure of 5 to 7 MPa for 60 minutes caused color changes in the wood, with increasing pressure at high temperatures (Atik *et al.,* 2013). Combining hygrothermal treatment and densification of poplar wood improved dimensional stability, mechanical properties, and water-repellency (Hajihassani *et. al*., 2018). The density of the Norway spruce *(Picea abies)* and Beech wood *(Fagus sylvatica)* specimens increased after THM and densification also removed the compression set recovery (Skyba *et al*., 2008). Despite the advances in wood modification, limited research specifically focused on improving the properties of fast-growing, short-rotation species like *Melia dubia* through eco-friendly processes such as THM treatment. Most studies on wood modification have targeted slower-growing hardwoods, such as spruce, pine, and beech, with little application to tropical species or fast-growing trees.

MATERIALS AND METHODS

Procurement of material

Melia dubia wood logs were collected from the Silviculture and Forest Management Division, Forest Research Institute, Dehradun (30°19'N, 78°04'E).

The culture of white rot fungi (*Trametes versicolor)* was obtained from Pathology Discipline, Forest Protection Division, Forest Research Institute, Dehradun.

Preparation of samples

Wood logs procured were cut into samples of dimensions 14.6cm x 9.8cm x 3.7cm. The samples were planed and sanded. The initial dimensions and weight of the samples were taken using a vernier caliper and weighing balance.

Treatment of wood

Several successive steps were taken during the wood sample treatment process to guarantee uniformity in the outcome. To minimize the risk of cracking or warping during the steaming phase, the wooden samples were first completely saturated with water for two to three days. The wood samples were steamed once thoroughly wet in an autoclave for 45 minutes at various temperatures (160, 170, 180, and 190 °C). The steam pressure inside the autoclave was then gradually decreased. To prevent exposure to the air, the wood samples were carefully taken out of the autoclave and promptly packed in plastic bags.

The samples were then wrapped and cold pressed for eighteen hours at a regulated pressure between 0.5 and 2 MPa. The cold pressing process further compressed the wood, which lowers its moisture content and improves its structural stability.

The wood samples were left to stable for a day at room temperature following the cold pressing procedure.The samples were oven-dried and then spent 14 days in a solar kiln. The wood could dry slowly and carefully since the solar kiln kept the temperature at 45°C and the relative humidity at 72% RH throughout this time. To ensure full drying the wood samples were kept in the kiln for 14 days to adequately dry to their equilibrium moisture content for further examination and analysis.

Color Variation

Changes in color were made according to visual observation by directly inspecting the wood samples to assess any noticeable differences in color before and after treatment. Color changes were categorized as follows:

Density of Thermo-Hygro-Mechanical Modified Wood Samples

Density is a fundamental property of wood that significantly influences its performance in various applications, such as construction and furniture manufacturing. It is defined as the mass per unit volume of the material, measured at a consistent moisture content. In this study, the density of the wood samples was determined following the Thermo-Hygro-Mechanical (THM) modification process.

The density (ρ) of each sample was calculated using the formula:

$$\text{Density} = \frac{Wo}{Vg}$$

Table 1. Categorization according to changes in color

S.No	Change Pattern	Characteristics
1	No Change	If there was no perceptible difference in the color before and after treatment.
2	Slight Change	A minor shift in color, such as lightening or darkening that, was noticeable but not extreme.
3	Moderate Change	There was a more significant change in color, where the treated wood visibly differed from the untreated samples.
4	Severe Change	A dramatic color shift from the typical color before treatment

Where Wo represents the oven-dry weight of the sample, and Vg is the volume of the sample after THM modification. This method ensures consistency in measurements and enables comparison of the density changes induced by the THM process.

Decay test of Thermo-Hygro-Mechanically treated wood

The decay resistance of wood is an important factor for determining its suitability in various outdoor and industrial applications where exposure to fungal attacks is common. The decay test evaluates the effectiveness of the treatment in enhancing the wood's natural durability.

The THM-treated wood samples were cut into small blocks with dimensions (1.9 × 1.9 × 1.9 cm)³. These samples were small enough to expose all surfaces to fungal attack while also being large enough to represent the characteristics of the material.

The decay test was conducted using the Soil Block Bioassay method, a standard procedure for assessing wood durability (as per IS 4873:2008). Samples were exposed to fungi by placing them in test bottles, which actively grow mycelia of *T. versicolor* on feeder strips. These feeder strips provide the nutrients for fungal growth, which then spreads onto the wood samples. Then, the test bottles were placed in a a Biological Oxygen Demand (BOD) incubator at 25 °C ± 2 °C and 75 % ± 5 % RH for the growth of fungi on samples. The wood blocks were weighed before (W_1) and after 4 weeks of exposure to fungi (W_2) in test bottles. The efficacy of treatment was categorized based on weight loss percentage. Weight loss was calculated as follows.

$$\text{Weight Loss \%} = \frac{W1 - W2}{W1} X\ 100$$

Where W1 is the weight of wood blocks before exposure to fungi (gm), and W2 is the weight of wood blocks after 4 weeks of exposure to fungi (gm).

Statistical Analysis

ONE WAY ANOVA and Post-hoc test (Tukey's HSD) was done with the help of R studio to find the compare mean weight loss across the different temperature groups.Where the Hypothesis was: The means of the groups, i.e., weight loss at different temperatures, were unequal. The probability that the observed data would occur if the null hypothesis (no effect of temperature) were accurate. A p-value less than 0.05 indicate statistical significance. For the Post hoc tests, Tukey's test was used to determine which groups differed from each other. In order to visualize the relationships between the experimental variables, a scatterplot matrix was constructed to explore the pairwise correlations among Temperature, Thickness, Weight, and Density. This matrix allowed us to observe the linear relationships and potential patterns between each pair of variables, providing an intuitive way to assess how these factors interact with each other in the context of the thermo-hygro-mechanical (THM) treatment on *Melia dubia* wood.

RESULTS AND DISCUSSION

Color variation after Thermo-Hygro-Mechanical modification

Color changes in wood samples subjected to thermo-hydro-mechanical (THM) treatment were pronounced, with treated samples exhibiting a darker hue than control, which intensified with increasing temperatures (Fig 1, Table 2).

This darkening is attributed to chemical transformations within the wood matrix under thermal processing conditions. Sundqvist and Moren (2002) found that extractives, along with hemicelluloses and lignin, are integral to color formation during hydrothermal treatment.

Similarly, Wiberg (1996) demonstrated in studies on Scots pine (*Pinus sylvestris*) and Norway spruce

Table 2: Color variations among the wooden blocks

S,No	Temperature (°C)	Category	Observation for Blocks
1.	Control	No Change	All blocks show a natural wood color, with no visible darkening or change; they are uniform in appearance.
2.	160	Slight Change	Some blocks show minor darkening, while others appear closer to the control; slight unevenness in effect.
3.	170	Moderate Change	Darkening is more pronounced across most blocks, but a few exhibit lighter tones, indicating minor variation.
4.	180	Severe Change	Most blocks are significantly darker, but a few exhibit slightly lighter hues, showing variation in treatment intensity.
5.	190	Severe Change	Nearly all blocks are uniformly dark, with a few showing extreme blackening, suggesting slight over-treatment or higher intensity in spots.

Fig 1: Change in color of the test blocks after treatment

Control **160 ^{0}C** **170^{0}C** **180 ^{0}C** **190^{0}C**

(*Picea abies*) that extractives migrate towards the wood surface during drying, imparting a reddish tone to the outer layers while yellow-colored compounds remain within. These observations indicate that the redistribution and transformation of extractives and other wood constituents under heat contribute significantly to the darker appearance observed in THM-treated wood.

Density

There is an increase in the average wood density of the wooden samples from 0.542 g/cm^3 at 160°C to 0.591 g/cm^3 at 190°C that can be attributed to a series of complex physicochemical transformations induced by higher thermo-hydro-mechanical (THM) treatment temperatures. Elevated temperatures initiate molecular rearrangements within the wood matrix, primarily affecting hemicelluloses and partially lignin, which are more susceptible to thermal degradation. This molecular reconfiguration enhances the wood's rigidity, as heat and pressure facilitate the breakdown of hemicelluloses, releasing bound moisture and volatile organic compounds (Hill *et al.,* 2021). The moisture reduction leads to the collapse of cell lumens, thereby compressing the wood structure and decreasing porosity (Thybring and Fredriksson, 2021).

Decay test

The durability of *Melia dubia* wood treated at different temperatures was tested against the decay fungus *Trametes versicolor* by measuring the mass loss percentage after a soil block bioassay. Results showed that as the treatment temperature increased, the wood's resistance to decay improved: samples treated at 160°C, 170°C, 180°C, and 190°C had average weight losses of 1.26%, 1.25%, 0.79%, and 0.49%, respectively. In comparison, control samples showed a higher weight loss of 1.33%. Based on 4 weeks of observation maximum weight loss was observed in control samples and minimum in samples treated at 190°C. This suggests that wood treated at this temperature had the highest resistance to fungal decay. This improvement is likely due to changes in the wood structure at higher temperatures, which reduce the wood's moisture absorption and make it less prone to the fungus to break down the wood.

In an experimental study combined hydro-thermo-mechanically modified poplar wood was tested for bio resistance. The treatment was carried out at 120°C, 150°C, and 180°C, and then the patient was exposed to brown rot and soft rot. The wood possessed an

Fig 2: Average Density after THM treatment

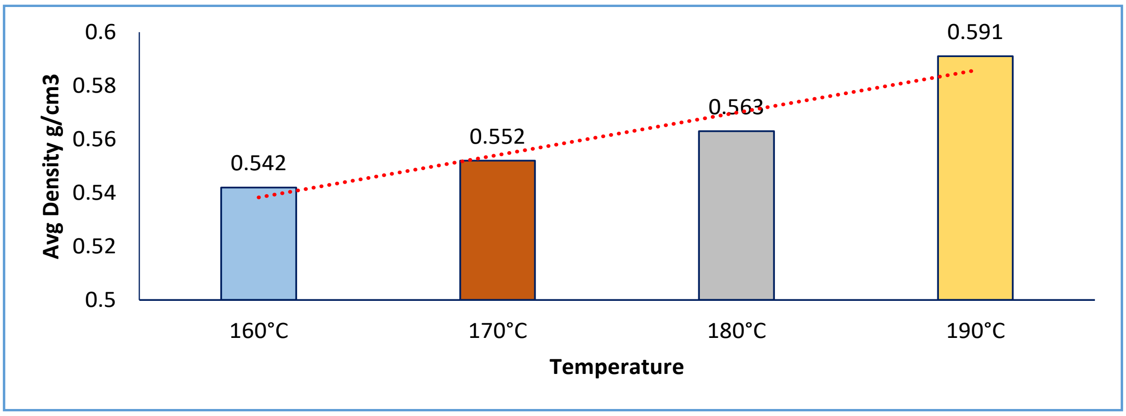
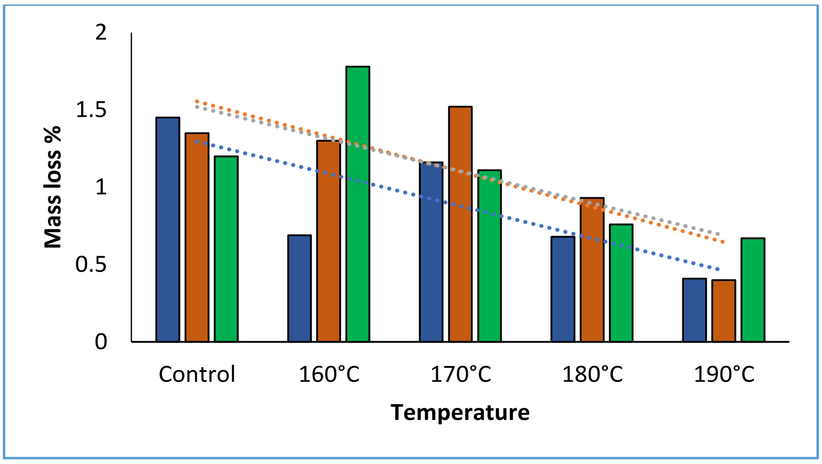


Fig 3: Weight loss percentage of the THM-treated samples



increase in fungal resistance post-treatment (Bami and Mohebby, 2011). Biological resistance of mechanically densified pine sapwood after exposure against *T. versicolor* and *Coniophora puteana* for 12 weeks was found that the highest mass loss occurred in control samples compared to treated samples, highest decay resistance was obtained in samples treated at 212°C (Pelit and Yalem, 2017). Decay resistance against brown rot (*Gleophyllum trabeum*) and white rot (*Trametes versicolor*) study in hybrid poplar (*Populus deltoids* × *Populus trichocarpa*) and Douglas fir (*Pseudotsuga menziesii*) treated by THM showed that resistance of densified hybrid poplar wood was less than Douglas fir heartwood (Lesar *et. al.*, 2013).

Statistical Analysis

One Way Anova:

Table 3 indicates a statistically significant effect of treatment temperature on the weight loss of wood due to fungal decay. The overall F-value of 5.044 ($p = 0.0174$) reveals that temperature significantly influences the decay resistance of the wood, as reflected by the weight loss percentages. This means that the variation in weight loss between the temperature groups is not due to random chance but rather an effect of the temperature treatment.

Post-hoc analysis(Tukey's HSD test)

Table 4 presents the results of Tukey's Honest Significant Difference (HSD) post-hoc test for pairwise comparisons of weight loss percentages across different THM treatment temperatures. The table summarizes the differences in weight loss between each pair of treatment groups, including the adjusted p-values (p adj) and the corresponding confidence intervals for each comparison. The p-values are adjusted for multiple comparisons to control for Type I error.

Significant differences are indicated by the adjusted p-values less than 0.05, with 190°C showing a significant improvement in durability compared to 170°C ($p = 0.0480$) and the Control group ($p = 0.0300$),

Table 3: Results for the one-way Anova

Source of Variation	Degrees of Freedom (Df)	The sum of Squares (Sum Sq)	Mean Square (Mean Sq)	F-Value	p-value (Pr(>F))
Temperature	*4*	*1.6302*	*0.4076*	*5.044*	*0.0174 **
Residuals	*10*	*0.8081*	*0.0808*		

Table 4: Results of Turkey's test

Comparison	Difference (diff)	Lower Bound (lwr)	Upper Bound (upr)	Adjusted p-value (p adj)	Significance
170°C - 160°C	0.0067	-0.7572	0.7705	0.9999	Not significant
180°C - 160°C	-0.4667	-1.2305	0.2972	0.3271	Not significant
190°C - 160°C	-0.7633	-1.5272	0.0005	0.0502	Marginally significant
Control - 160°C	0.0767	-0.6872	0.8405	0.9970	Not significant
180°C - 170°C	-0.4733	-1.2372	0.2905	0.3152	Not significant
190°C - 170°C	-0.7700	-1.5339	-0.0061	0.0480	Significant
Control- 170°C	0.0700	-0.6939	0.8339	0.9979	Not significant
190°C - 180°C	-0.2967	-1.0605	0.4672	0.7094	Not significant
Control- 180°C	0.5433	-0.2205	1.3072	0.2092	Not significant
Control- 190°C	0.8400	0.0761	1.6039	0.0300	Significant

as highlighted in the table. These results suggest that higher temperature treatments, particularly at 190°C, significantly reduce weight loss and improve the decay resistance of *Melia dubia* wood. Comparisons between other temperatures, such as 160°C, 170°C, and 180°C, did not yield significant differences in durability, indicating that the temperature effect on decay resistance becomes pronounced only at higher treatment temperatures.

Correlation Analysis

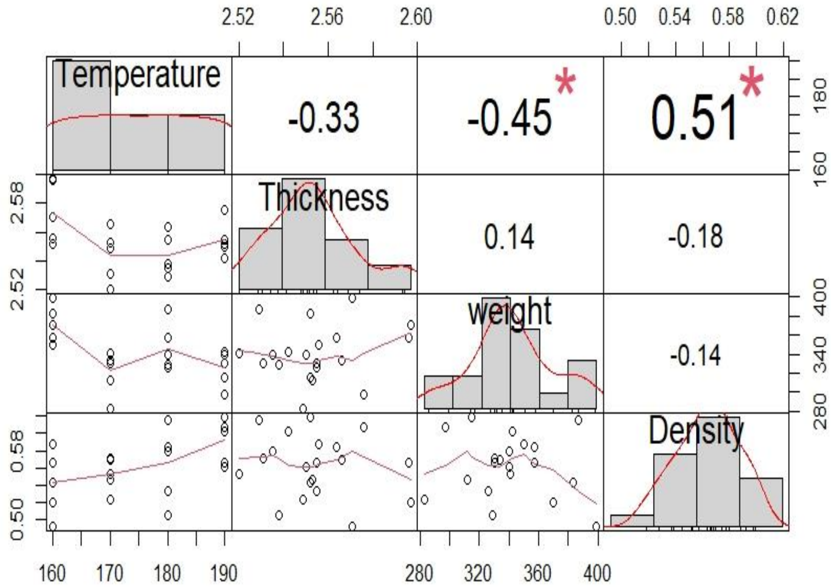
The correlation between temperature, thickness, weight, and density shows how the variables interact with each other. Temperature shows a relatively uniform distribution, while thickness shows a concentrated distribution with a slide skew to the right. The density curb indicates that most values are around the central range and have fewer observations at the extremes. For weight, the distribution appears relatively symmetrical with some variations. The moderate correlation between temperature and density could imply that temperature changes impact density, possibly due to expansion or contraction effects.

The inverse correlation between temperature and weight indicates that as temperature increases, weight tends to reduce due to factors like loss of mass or changes in measurement and different temperatures. The weight and thickness loss of the wood after heat treatment depends on wood species, heating medium, temperature, and treatment medium (Esteves *et al*., 2008).

CONCLUSION

Through this study, it can be concluded that the durability and properties of THM modified wood were increased compared to control samples. The highest decay resistance and improved density were observed in samples treated at 190°C. It was also observed that the density of the wood increased and mass loss % reduced with an increase in temperature. The color parameters also showed a pronounced effect in the THM treatment. Wood's darkening kept increasing with an increase in temperature due to condensation of lignin and pyrolysis of major chemical constituents of wood (Cellulose, Hemicellulose, and Lignin). The research experiment suggests that the THM treatment in wood can potentially improve the properties viz. color, density and durability. Since the THM process is an eco-friendly approach and can improve the natural decay resistance, more studies can be conducted to explore further and improve the properties of wood.

Fig 4: Scatterplot matrix of the temperature (°C), thickness (cm), weight (gm), and density (gm/cm³) after THM.



THM treatment in *Melia dubia* wood is an approach which is intended to be used in various applications; its durability is of great importance. Such THM-modified wood can become a suitable substitute that can maximize wood potential. Further, there is more scope for studies that should focus on treatments that could enhance the mechanical and other useful properties on a pilot basis in-ground application.

ACKNOWLEDGMENT

The authors would like to acknowledge Forest Research Institute, Dehradun, and Forest Research Institute

Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

This is original research work, and any work and/or words of others have been appropriately cited.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflicts of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required.

REFERENCES

Atik, C., Candan, Z.,Unsal, O. 2013. Color characteristics of pine wood affected by thermal compressing. *Ciênc. Florist.* Vol 23 (3), 475-479. https://doi.org/10.5902/198050989291

Bami, L.K., Mohebby, B. 2011. Bioresistance of poplar wood compressed by combined hydro-thermo-mechanical wood modification (CHTM): Soft and brown rot. *Int. Biodeterior. Biodegrad.*65:866-870. https://doi.org/10.1016/j.ibiod.2011.03.011

Domaracka, L., Matuskova, S., Tausova, M., Senova, A., & Kowal, B. (2022). Efficient use of critical raw materials for optimal resource management in EU countries. *Sustainability*, *14*(11), 6554. https://doi.org/10.3390/su14116554

Esteves, B., Velez Marques, A., Domingos, I., Pereira, H. 2008. Heat-induced colour changes of pine (Pinus pinaster) and eucalypt (Eucalyptus globulus) wood. *Wood Sci. Technol. 42*, 369-384.https://doi.org/10.1007/s00226-007-0157-2

Goswami, M., Bhagta, S., & Sharma, D. (2020). Melia dubia and its Importance: A Review. *International Journal of Economic Plants*, 7(Feb, 1), 029-033. https://doi.org/10.23910/2/2020.0351

Hajihassani, R., Mohebby, B., Najafi, S. K., Navi, P. 2018. Influence of combined hygro-thermo-mechanical treatment on technical characteristics of poplar wood. *Maderas, Cienc. tecnol. 20*(1), 117-128.http://dx.doi.org/10.4067/S0718-221X2018005011001

Hill, C., Altgen, M., &Rautkari, L. (2021). Thermal modification of wood—A review: Chemical changes and hygroscopicity. *Journal of Materials Science*, *56*, 6581-6614. https://doi.org/10.1007/s10853-020-05722-z

Kumar, A., Jyske, T., & Petrič, M. (2021). Delignified wood from understanding the hierarchically aligned cellulosic structures to creating novel functional materials: a review. Advanced Sustainable Systems, 5(5), 2000251.https://doi.org/10.1002/adsu.202000251

Lesar, B., Humar, M., Kamke, F. A., &Kutnar, A. (2013). Influence of the thermo-hydro-mechanical treatments of wood on the performance against wood-degrading fungi. *Wood science and technology*, *47*, 977-992. https://doi.org/10.1007/s00226-013-0553-8

Navi, P., Sandberg, D. 2012. *Thermo-hydro-mechanical wood processing*. Crc Press,Lausanne, Switzerland. https://doi.org/10.1201/b10143

Pelit, H.,Yalcin, M. 2017. Resistance of mechanically densified and thermally post treated pine sapwood to wood decay fungi. *J. Wood Sci.* 63:514-522.https://doi.org/10.1007/s10086-017-1641-4

Prakash, V., Uday, D. N., Sujatha, D., Kiran, M.C.,& Narasimhamurthy. 2018.LaminatedVeneer Lumber(LVL)from FastGrowing PlantationTimberSpeciesMeliadubia. *International Journal of Science and Research*. *8*:1721-1723.http://dx.doi.org/10.21275/ART20197006

Ramage, M. H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D. U., & Scherman, O. (2017). The wood from the trees: The use of timber in construction. *Renewable and sustainable energy reviews*, *68*, 333-359. https://doi.org/10.1016/j.rser.2016.09.107

Skyba, O., Niemz, P., Schwarze, F.W. 2008. Degradation of thermo-hygro-mechanically (THM) densified wood by soft-rot fungi. *Holzforschung*, 62 (3), 277-283.https://doi.org/10.1515/HF.2008.029

Thybring, E. E., & Fredriksson, M. (2021). Wood modification as a tool to understand moisture in wood. *Forests*, *12*(3), 372. https://doi.org/10.3390/f12030372

Wiberg, P., 1996: Color changes of Scots pine and Norway spruce. *Holz als Roh- und Werkst,* 54: 349-354. https://doi.org/10.5552/drvind.2022.0005