Plant Archives Vol. 25, Supplement 1, 2025 pp.2929-2933 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.404

EFFECTS OF CONVECTIVE VACUUM DRYING ON MOISTURE DYNAMICS AND PHYSICAL PROPERTIES IN *MELIA DUBIA CAV.*

Nishant[1]*, Ashutosh Pathak[2] and N.K. Upreti[1]

[1]Forest Research Institute, Forest Products Division, Uttarakhand, 248001, India.

[2]Forest Research Institute, Forest Botany Division, Uttarakhand, 248001, India.

*Corresponding author E-mail: nishantuchiha1@gmail.com

ORCID - https://orcid.org/0009-0006-5162-6451

(Date of Receiving : 23-11-2024; Date of Acceptance : 11-01-2025)

ABSTRACT

This study investigates the effects of Convective Vacuum Drying (CVD) on the moisture dynamics and physical properties of *Melia dubia* Cav., a fast-growing timber species of commercial importance. CVD, characterized by reduced pressure and controlled low-temperature conditions, enabled efficient moisture removal while preserving the wood's structural integrity and aesthetic quality. The drying process significantly enhanced basic density and reduced volumetric shrinkage, demonstrating improved dimensional stability and mechanical performance. These results highlight the efficacy of CVD as a scientifically advanced and energy-efficient drying method for timber, offering substantial improvements over conventional techniques. The findings underscore the potential for broader application of CVD across timber species and provide a basis for further optimization of drying parameters to meet industrial quality standards.

***Keywords* :** Convective Vacuum Drying, *Melia dubia,* Moisture dynamics.

Introduction

Drying, a cornerstone process in preserving and processing agricultural products, including timber, focuses on removing moisture to enhance stability, shelf life, and overall quality (Bonazzi & Dumoulin, 2014). This process is particularly critical for timber, as excess moisture can lead to various issues such as warping, cracking, and susceptibility to fungal attacks, significantly impacting its structural integrity and aesthetic appeal.

Traditional drying methods, such as air drying, often involve prolonged drying times and can result in uneven moisture distribution within the timber, leading to quality inconsistencies (Akonor, 2012). Furthermore, these methods may not always be suitable for all timber species, especially those with high moisture content or sensitivity to drying conditions.

In light of these challenges, convective vacuum drying has emerged as a promising alternative, offering several advantages over conventional techniques. Convective vacuum drying (CVD) operates on the principle of reducing the boiling point of water under reduced pressure, allowing for lower drying temperatures (Mousa & Farid, 2002). This characteristic is particularly beneficial for preserving the integrity of heat-sensitive materials, such as timber, as it minimizes the risk of thermal degradation and maintains the desired color and strength properties.

The application of vacuum in CVD accelerates the drying process by increasing the moisture gradient between the timber's core and its surface, facilitating faster moisture removal (Drying Characteristics of *Dracocephalum moldavica* Leaves: Drying Kinetics and Physicochemical Properties, 2023). This accelerated drying not only reduces processing time but also contributes to energy savings, making it an environmentally friendly option. Moreover, the controlled environment within a vacuum chamber minimizes the risk of contamination and oxidation, ensuring the production of high-quality timber.

Melia dubia Cav., a fast-growing timber species native to the Indian subcontinent, has garnered significant attention in recent years due to its remarkable growth rate and desirable wood characteristics. Its lightweight yet strong timber, coupled with its aesthetic grain patterns, makes it suitable for various applications, including furniture making, plywood production, and construction. However, like many other timber species, *M. dubia* requires careful drying to prevent defects and ensure optimal quality.

Given the advantages of CVD and the increasing demand for high-quality *M. dubia* timber, understanding the impact of CVD on critical physical properties of *M. dubia* timber, including color stability, dimensional stability (shrinkage), and mechanical strength is must to meet the stringent requirements of various industries.

Present study aims to investigate the effects of CVD on the moisture dynamics and physical properties of this valuable species with respect to various factors such as temperature, pressure, and drying time on the moisture removal rate.

Materials and Methods

Material

The material investigated was *M. dubia* logs and were procured from the Seema dawar, plantation of Genetics and Tree Improvement Division, FRI, Dehradun. Seven logs of 5ft length were utilized for this study. Planks of dimensions 76.2cm × 7.62cm × 2.54cm were made from the logs. The end coating of bituminous paint was immediately applied to prevent moisture loss. Two kiln samples were prepared from the wettest, defect-free planks, and from their sides, moisture strips were removed and weighted using a Putex electronic weighing machine. These strips were oven-dried in an I-therm AI-7982 hot air oven at 103 ± 2°C for 24 hours to calculate initial moisture content (Bureau of Indian Standards, 1991). The subsequent equation was used for the calculations:

$$\text{Initial Moisture Content } \% = \frac{\text{Initial weight } \ \text{ Oven dry weight}}{\text{Oven dry weight}} \times 100$$

Kiln drying and drying properties

The study was carried out using a convective vacuum drying chamber which is established at the Wood Seasoning Discipline, Forest Products Division, FRI, Dehradun. A convective vacuum drying chamber is a vacuum cylinder with a 12 mm thick tested low-carbon steel (MS) plate with an inner diameter of 121.92 cm (4 feet) and a length of 152.40 cm (5 feet) (Upreti, 2020). Twelve layers of seven planks each were stacked and put inside the kiln. The samples were stacked on 2 cm by 2 cm stickers and the stack was restrained by placing a weight on top to minimize warping. Drying was controlled by wood moisture content. The vacuum drying process was initiated with cyclic vacuum drying. The kiln was kept at 45°C temperature using heaters and a reversible fan having airflow of 1 meter/sec, with the fan direction changed every 30 minutes. Once the temperature got stabilized heaters were turned off. Then absolute vacuum pressure of 200 mm of Hg was applied and sustained for 30 minutes using a water ring-type vacuum pump, followed by the release of the vacuum. This completes one Cycle of drying. Following each cycle, the moisture content of the stack was determined using a kiln sample and a measurement of the condensed water quantity was also made (Upreti *et al.*, 2013). To ascertain the rate of drying, loss of moisture in percentage per hour was recorded.

$$\text{Drying rate} = \frac{\text{Percent moisture change}}{\text{Drying duration (Hour)}}$$

Physical Characterization

The physical tests were conducted on 20 samples for each test, prepared from randomly selected planks from the stack both without vacuum drying and with vacuum drying according to IS: 1708 (1986) Methods of testing of small clear specimens of timber (Bureau of Indian Standards, 1986). From each drying condition (Without vacuum drying, with vacuum drying) 20 samples were randomly taken and two physical properties were measured: basic density and volumetric shrinkage.

Data Analysis

The collected data from the various tests were subjected to an independent sample t-test for equality of means to ascertain the impact of vacuum drying on the properties of *M. dubia* wood. The results were used to assess the effectiveness of the drying method in enhancing the wood quality and performance characteristics. The analysis of the data was done with SPSS Statistics v26.

Results

Drying Behaviour

The vacuum drying process effectively reduced the moisture content of the Melia wood from 75.21 % to 12-8% over 30 hours 30 minutes as shown in Figure 1 This corresponds to a drying rate of 2.12% per hour. Notably, the wood exhibited no visual defects it might be associated with the weight placed on the stack while drying and low drying temperature, and there was no observed discoloration throughout the drying process, indicating the effectiveness of vacuum drying in preserving the appearance and structural integrity.

The drying curve of *M. dubia* indicates a typical drying behaviour observed in wood species. The initial phase of drying shows a rapid decrease in moisture content due to the removal of free water from the wood. This is followed by a more gradual decrease as the bound water is removed, and the drying process enters the stabilization phase. Vacuum drying achieved a drying rate of 2.12% per hour without any visible defects and discolouration.

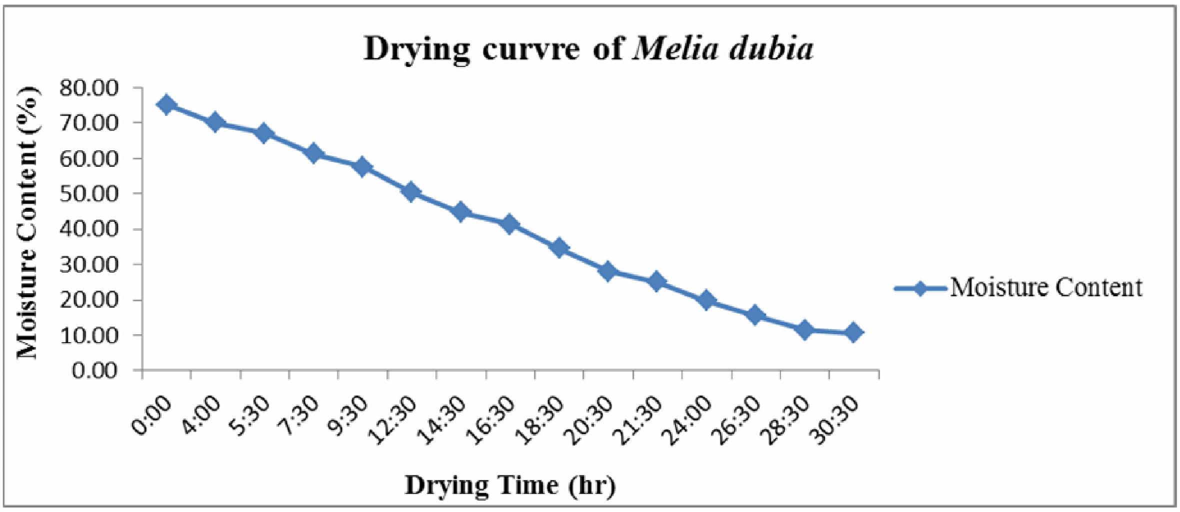

Fig. 1 : Moisture reduction during drying of *M. dubia* wood

Initial Rapid Drying Phase: During the first 5 hours, the moisture content drops from approximately 75% to 55%, indicating a high rate of moisture loss. This rapid phase is primarily due to the evaporation of free water from the wood surface and the outer layers.

Intermediate Drying Phase: From 5 to 20 hours, the drying rate slowed down. The moisture content decreased from 55% to 30%. This phase is characterized by the diffusion of bound water from the interior of the wood to the surface, which is a slower process compared to the evaporation of free water.

Final Stabilization Phase: In the last phase, from 20 to 30h 30 minutes, the moisture content continued to decrease but at a much slower rate, eventually reaching around 10%. This phase represented the removal of the remaining bound water and the equilibrium moisture content being approached.

The drying behaviour of *M. dubia* wood observed in the Figure 1 is consistent with the general drying characteristics of hardwood species. The initial rapid loss of moisture can be attributed to the high permeability of the wood, allowing free water to evaporate quickly. As the drying progresses, the removal of bound water becomes the dominant process, which is slower due to the lower diffusion rates of water within the wood cells.

The final stabilization phase indicates that the wood is approaching its equilibrium moisture content, where the rate of moisture loss significantly decreased. This phase is crucial for ensuring the dimensional stability and preventing defects such as warping or checking.

Drying time for *M. dubia* was significantly reduced when compared to previous study (Karimanisha *et al.*, 2021) where it took six days to reach from an initial moisture content of about 65% to final moisture content of 12% due to vacuum drying. Hence vacuum drying provided faster drying rate even with lower temperature used which may lead to lower energy consumption. This renders vacuum drying as suitable and preferable drying method.

The t-test result for basic density shows a t-value of -5.498 with a p-value (Sig. 2-tailed) of 0.000. Since the p-value is significantly less than 0.05, we reject the null hypothesis, concluding that there is a statistically significant difference in basic density between the two groups. Mean basic density before CVD was 0.42± 0.48 and after CVD it was found to be 0.48± 0.18. The negative mean difference (-0.0634959) indicates that the group subjected to convective vacuum drying (CVD) has a higher basic density than the group without CVD as shown in Table:1. This supports the idea that CVD positively impacts the wood's density, possibly due to the preservation of the cellular structure at lower drying temperatures.

For volumetric shrinkage, the t-value is 13.616 with a p-value of 0.000. This again is well below 0.05, leading to the rejection of the null hypothesis and confirming a statistically significant difference in volumetric shrinkage between the two groups. Mean volumetric shrinkage before CVD was 19.9 % ± 3 and after CVD it was found to be 10.6 % ± 0.65. The positive mean difference (9.3603355) suggests that the group treated with CVD experienced less volumetric shrinkage than the group without CVD as shown in Table:1. This result indicates that CVD enhances the dimensional stability of the timber, making it more suitable for applications where minimal shrinkage is critical.

Table 1: Independent samples T- test of physical properties before and after vacuum drying

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Basic Density	46.687	.000	-5.498	38	.000*	-.0634959	.0115482
Volumetric Shrinkage	19.664	.000	13.616	38	.000*	9.3603355	.6874359

The results from the independent samples t-test strongly support the hypothesis that convective vacuum drying has significant effects on the basic density and volumetric shrinkage of *M. dubia* timber. Specifically, CVD increases basic density and decreases volumetric shrinkage compared to conventional drying methods, making it a superior technique for improving the physical properties of this wood species. These findings have important practical implications, especially for industries where wood strength, hardness, and dimensional stability are critical.

Discussion

The CVD (convective vacuum) drying significantly affected both the basic density and volumetric shrinkage of the wood in *M. dubia*. Specifically, CVD led to a significant increase in basic density and a significant decrease in volumetric shrinkage compared to conventional drying methods. This aligns with findings that indicate the drying method can substantially influence wood properties, particularly in terms of density and dimensional stability (Honorato-Salazar *et al.*, 2023, Almeida *et al.*, 2015).

The observed increase in basic density following CVD can be attributed to the combined effects of vacuum pressure and convective heat transfer. The application of vacuum pressure during drying reduces the boiling point of water, allowing for moisture removal at lower temperatures. This is particularly beneficial for timber species like *M. dubia*, which are known to be susceptible to degradation and cellular collapse at high temperatures (Duong & Matsumura, 2018). By lowering the drying temperature, CVD helps preserve the cellular structure of the wood, preventing excessive cell wall collapse and maintaining a higher density (Schulgasser & Witztum, 2015). Furthermore, the convective heat transfer mechanism employed in CVD promotes a more uniform temperature distribution within the timber compared to conventional drying methods, which reduces the risk of internal stresses and defects such as checking and splitting (Rosner, 2017).

The significant decrease in volumetric shrinkage observed in the CVD-treated *M. dubia* can be explained by the process's ability to modify the wood's cell wall structure. During CVD, the application of vacuum pressure creates a pressure gradient that drives water out of the wood's cellular structure. As water is removed from the cell walls, they come closer together, leading to a reduction in overall volume (Yang *et al.*, 2020). This phenomenon is further enhanced by the lower drying temperatures used in CVD, which minimize the wood's natural tendency to shrink as it dries (Gonçalves *et al.*, 2014). The relationship between moisture loss and shrinkage is well-documented, indicating that higher density woods tend to exhibit greater volumetric shrinkage (Quequeto *et al.*, 2018).

The findings of present study have important implications for the use of *M. dubia* timber. The increased basic density achieved through CVD suggests that this drying method can enhance the wood's strength and hardness, which is particularly relevant for structural applications where high strength-to-weight ratios are desirable (Honorato-Salazar *et al.*, 2023, Almeida *et al.*, 2015). Additionally, the reduced volumetric shrinkage observed in CVD-treated *M. dubia* indicates improved dimensional stability, making it more suitable for applications where dimensional accuracy is crucial, such as furniture making and flooring (Schulgasser & Witztum, 2015). Further research is needed to investigate the applicability of CVD to other timber species and optimize the drying parameters for specific applications and improve the supply of quality timber (Ekundayo *et al*., 2022).

Acknowledgements: This work was conducted at the Forest Products Division and the Forest Botany Division, Forest Research Institute, Dehradun. Author

Contributions

Nishant-Writing-Review and Editing, Visualization, Conceptualization; Ashutosh Pathak Conceptualization and Editing; N.K. Upreti–Conceptualization and Editing.

Data availability: The raw data can be obtained on request from the corresponding author.

Competing interests: The authors declare no competing interests

References

Akonor, P.T., & Amankwah, E.A. (2012). *Thin layer drying kinetics of solar-dried Amaranthus hybridus and Xanthosoma sagittifolium leaves*. http://csirspace.food researchgh. org/handle/123456789/1064

Almeida, T. de, Almeida, D. H., Marcolin, L.A., Gonçalves, D., Christoforo, A.L., & Lahr, F.A.R. (2015). Correlation between dry density and volumetric shrinkage coefficient of three Brazilian tropical wood species. *International Journal of Materials Engineering*, ***5***(1), 1–4.

Bureau of Indian Standards (with Public.Resource.Org). (1986). *IS 1708-1 to 18: Methods of testing of small clear specimens of timber*.

Bureau of Indian Standards (with Public.Resource.Org). (1991). *IS 11215: Moisture content of timber and timber products- Methods for determination*. http://archive.org/details/gov.in.is.11215.1991

Ekundayo, O. O., Arum, C., & Owoyemi, J. M. (2022). Evaluation of Physical and Mechanical Properties of Selected Wood Species obtained from Saw Mills in Akure, Nigeria. *Journal of Applied Sciences and Environmental Management*, ***26***(6), 999–1005.

Gonçalves, D. N., Resende, O., Costa, L.M., & Prado, M. C. (2014). Determination of physical properties of crambe fruits during drying. *Engenharia Agrícola*, ***34***, 972–979.

Honorato, A., & Monsalvo, V. (2023). Variability of some wood physical properties of ten Cedrela odorata L. clones. *Journal of Agricultural Sciences Research (2764-0973)*, *3*.

Iwansyah, A. C., Manh, T. D., Andriana, Y., Aiman bin Hessan, M., Kormin, F., Cuong, D. X., Xuan Hoan, N., Thai Ha, H., Thi Yen, D., & Thinh, P. V. (2020). Effects of various drying methods on selected physical and antioxidant properties of extracts from Moringa oliefera leaf waste. *Sustainability*, ***12***(20), 8586.

Karimanisha, K., Divya, M., Ravi, R., & Sekar, I. (2021). *Standardization of the seasoning schedule for Melia Dubia Cav*. https://www.thepharmajournal.com/archives/2021/vol10issue11/PartK/10-10-397-383.pdf

Mousa, N., & Farid, M. (2002). Microwave vacuum drying of banana slices. *Drying Technology*, ***20***(10), 2055–2066.

Quequeto, W. D., Siqueira, V. C., Schoeninger, V., Martins, E. A., Isquierdo, E. P., & Silva, F. P. da. (2018). Physical properties of buckwheat (Fagopyrum esculentum Moench) grains during convective drying. *Revista Brasileira de Engenharia Agrícola e Ambiental*, ***22***(11), 793–798.

Rosner, S. (2017). Wood density as a proxy for vulnerability to cavitation: Size matters. *Journal of Plant Hydraulics*, *4*, e001.

Rudy, S., Dziki, D., Biernacka, B., Krzykowski, A., Rudy, M., Gawlik-Dziki, U., & Kachel, M. (2020). Drying characteristics of Dracocephalum moldavica leaves: Drying kinetics and physicochemical properties. *Processes*, ***8***(5), 509.

Schulgasser, K., & Witztum, A. (2015). How the relationship between density and shrinkage of wood depends on its microstructure. *Wood Science and Technology*, ***49***(2), 389–401.

Standardization of the seasoning schedule for Melia Dubia Cav. - Google Search. (n.d.). Retrieved August 26, 2024, from https://www.google.com/search?q=Standardization+of+the+seasoning+schedule+for+Melia+Dubia+Cav.&rlz=1C1CHBD_enIN816IN816&oq=Standardization+of+the+seasoning+schedule+for+Melia+Dubia+Cav.+&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIGCAEQRRhAMgYIAhBFGDzSAQkyNjk0ajBqMTWoAgiwAgE&sourceid=chrome&ie=UTF-8

Tsotsas, E., & Mujumdar, A. S. (Eds.). (2011). *Modern Drying Technology: Volume 3: Product Quality and Formulation* (1st ed.). Wiley.

Upreti, N. K. (2020). *Vacuum kiln*. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=SShiHAkAAAAJ&citation_for_view=SShiHAkAAAAJ:_FxGoFyzp5QC

Upreti, N. K., Kukreti, M. C., Kandpal, R. P., & Chetan Swaroop, C. S. (2013). *Convection heating based vacuum kiln for timber drying and its performance*. https://www.cabidigitallibrary.org/doi/full/10.5555/20133145899

Van Duong, D., & Matsumura, J. (2018). Transverse shrinkage variations within tree stems of Melia azedarach planted in northern Vietnam. *Journal of Wood Science*, ***64***(6), 720–729.

Yang, R., Liang, Y., Hong, S., Zuo, S., Wu, Y., Shi, J., Cai, L., Li, J., Mao, H., & Ge, S. (2020). Novel low-temperature chemical vapor deposition of hydrothermal delignified wood for hydrophobic property. *Polymers*, ***12***(8), 1757.