ISSN impresa 0717-3644
ISSN online 0718-221X

Maderas. Ciencia y tecnología 2025 (27): 11, 1-11

DOI: 10.22320/s0718221x/2025.11

RADIAL VARIATION OF FIBER MORPHOLOGY AND WOOD DENSITY OF THE COMMERCIAL SPECIES *Drypetes* SP. AND *Myroxylon balsamum*

Leif Armando Portal-Cahuana[1,♠]

https://orcid.org/0000-0002-2717-4348

German Payeza-Tuesta[2]

https://orcid.org/0000-0001-6497-5008

Erick Alberto Grandez-Piña[2]

https://orcid.org/0000-0001-5826-3434

Marcus Vinicius Stenico da Silva[3]

https://orcid.org/0000-0002-2395-7206

Mario Tomazello-Filho[3]

https://orcid.org/0000-0002-9814-0778

ABSTRACT

Studying the radial variation of wood density, an essential biophysical property that reflects the quality of commercial species in tropical forests, is crucial. Understanding how these variations relate to wood anatomy provides valuable insights. In this study, we evaluated fiber morphology and radial density variation using X-ray densitometry in two commercial species from southeastern Peru. Ten trees from each species, *Drypetes* sp. and *Myroxylon balsamum* (Peru balsam), were analyzed. Fiber characteristics were assessed using macerated tissue, and density profiles were obtained via X-ray densitometry. The results indicate that in Drypetes sp., density decreases from the pith to the bark, whereas Myroxylon balsamum shows no significant radial variation. These findings are important for the efficient use and processing of these species.

Keywords: Fiber morphology, radial variation, tropical species, wood anatomy, wood density, X-ray densitometry.

[1]Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas. Escuela Profesional de Ingeniería Forestal. Chachapoyas, Perú.
[2]Gerencia Regional Forestal y de Fauna Silvestre Madre de Dios. Unidad de Gestión Forestal y de Fauna Silvestre. Tahuamanu. Perú.
[3]Universidade de São Paulo. Escola de Agricultura Luiz de Queiroz. Departamento de Recursos Florestais. Piracicaba, Brasil.

♠Corresponding author: leif.portal@untrm.edu.pe
Received: 11.10.2022 Accepted: 03.12.2024

INTRODUCTION

Tropical forests are home to high biodiversity (Edwards *et al*. 2019), where, for example, trees have different growth strategies at the longitudinal and radial levels, growing faster to reach the light (light-demanding species) or growing slow (shade-tolerant species) (Nock *et al*. 2009), where, in addition, the growth of these trees are influenced by the local climate and/or global anomalies such as the El Niño phenomenon, Sea Surface Temperature Mar, among others (Aragão *et al*. 2022, López *et al*. 2022) and these factors will influence the wood density.

Wood density is a biophysical property that is specified as the ratio of the mass of wood divided by the volume of wood (Panshin and De Zeeuw 1980). Wood density in tropical forests varies significantly, ranging from very low to extremely high value, e.g., balsa tree (*Ochroma pyramidale* (Cav. ex Lam.) Urb.) (0,18 $g.cm^{-3}$) (Bhekti *et al*. 2017), to wood with very high densities, e.g., yellow lapacho (*Handroanthus serratifolius* (Vahl) S.O.Grose) (0,90 $g.cm^{-3}$) (Andrade *et al*. 2019) is related to the anatomy of the wood, and the mechanical properties, the capacity and storage of water, vulnerability to cavitation, the successional state of the trees, etc. (Lehnebach *et al*. 2019, Woodcock and Shier 2002). This biophysical property can vary between species, within the same species and even within a tree, in tropical forests they vary longitudinally (along the stem) and/or radially (pith-bark) (Panshin and De Zeeuw 1980, Valente *et al*. 2013). Wood density is directly related to the wood quality and therefore its important in industrial sector (Lobão *et al*. 2012, Woodcock and Shier 2002).

Yet, the anatomy of the wood will directly influence the density of the wood, such as the thickness of the fiber wall, the size of the lumen, inclusions in the vessels, the diameter of the vessels, etc. (Arnič *et al*. 2022, Tomazello *et al*. 2008). One of the ways to evaluate the radial variation of wood density at high resolution and interannual sensitivity is with X-ray densitometry (Gaitan *et al*. 2019, Pagotto *et al*. 2017). Various studies with tropical trees using X-ray densitometry showed radial variations in density explained through the anatomy of the wood (Chavesta *et al*. 2020, Lobão *et al*. 2012, Portal *et al*. 2019).

In this study, we evaluated the fiber morphology and radial density variation of two commercial species from the department of Madre de Dios in southeastern Peru using X-ray densitometry. The study aimed to addess the following questions: . a) What is the radial variation in fibers morphology for the species studied? b) What is the radial variation in wood density for the species studied? c) Can the radial variation in wood density be explained by the fiber morphology of the species studied?

MATERIALS AND METHODS

Study area

The wood samples of the species *Drypetes* sp. and peru balsam (*Myroxylon balsamum* (L.) Harms) come from a tropical humid forest in eastern Peru, specifically within the Amazon región of the Madre de Dios department "MDD" (Figure 1). MDD is considered the biodiversity capital of Peru and is considered a global biodiversity hotspot (Myers *et al*. 2000, Asner *et al*. 2012). Specifically, samples were taken in the province of Tahuamanu in the concession Corporación Forestal Tres Fronteras S. R. L. "CORFOREST S.R.L.". This location geographically situated at a latitude of -11°31'63'' S and a longitude of -69°62'38'' W, with an altitude of 332 m.a.s.l. The MDD climate is characterized by having an average annual rainfall of 2000 mm and an average annual temperature of 25 °C with a dry season from June to August (Portal *et al*. 2021, Sánchez-Cuervo *et al*. 2020).

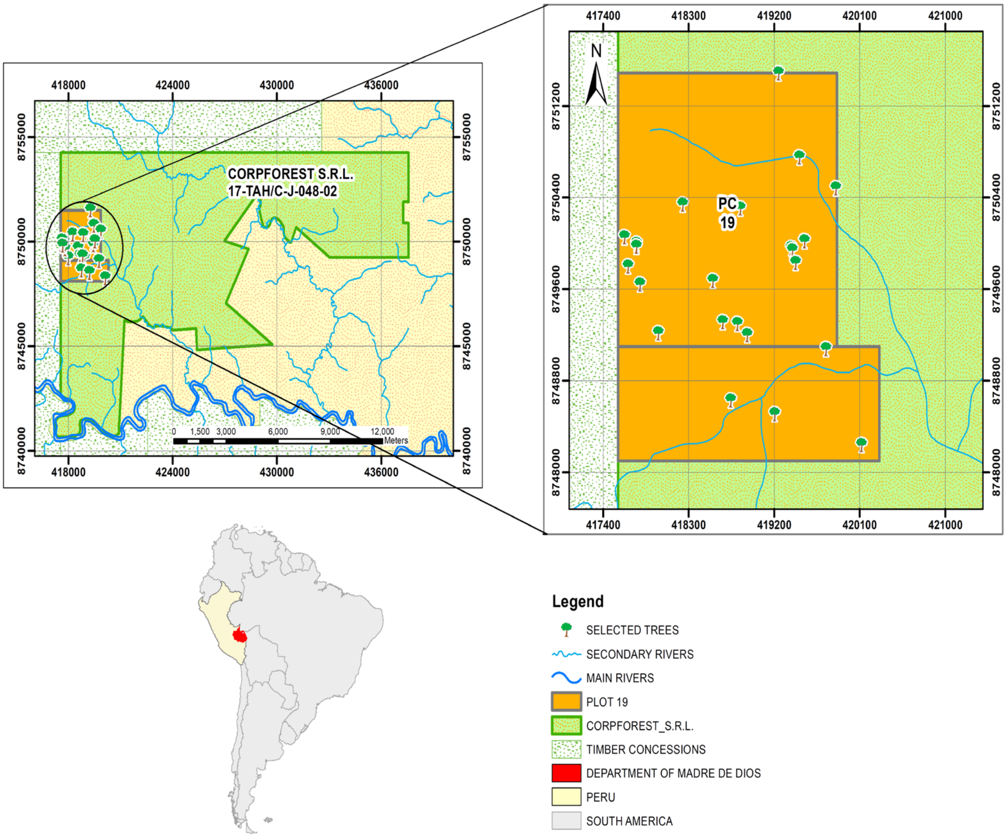

Figure 1: Location of the study area within the tropical humid forest of Madre de Dios and the distribution of the trees studied.

Fiber morphology analysis and X-ray densitometry

We selected two species of commercially used trees: *Drypetes* sp. and peru balsam (*Myroxylon balsamum* (L.) Harms). Wood samples were collected in August 2020 using a simple random design. We selected trees with diameters at breast height (DBH) ≥ 41 cm. from cutting plot No. 19 of CORFOREST S.R.L. In this plot, we found 18 trees of *Drypetes* sp. and 36 inventory-worthy tres of peru balsam (*Myroxylon balsamum* (L.) Harms) in the year 2020. We recorded forestry variables such as tree height and DBH, assessed the phytosanitary status of the trees, and documented their geographic coordinates.

Ten tres of each species were felled, and we colected their terminal branches, which were later herborized. The species were verified at the MOL herbarium of the Universidad Nacional Agraria La Molina.

The logs obtained from the two species were taken to the wood processing plant, where one slice per tree was cut at the end of the log (Granato *et al*. 2019), with a thickness of 5-6 cm per the diameter (Figure 2), the slices were dried in the environment. Subsequently, two sub-samples were obtained from each slice in the pinth to bark direction and they were transported to the Wood Anatomy and Identification Laboratory "LAIM" at the University of São Paulo/Luiz de Queiroz Higher School of Agriculture USP/ESALQ for the corresponding analyses.

Fiber morphology

The analysis of fiber morphology in the two studied species was conducted using macerated tissue to understand variations in the radial density profile of the species. To achive this, wooden cubes were obtained from there radial positions: 30 % (near the pith), 60 % (in the middle) and 90 % (near the bark). Small wood splinters, similar in size and shape to matchsticks, were obtaind from from the cubes.

These splinters were then placed in test tubes containing a macerating solution composed of 120 vol. hydrogen peroxide and acetic acid in in a 1:1 ratio. The containers were covered with aluminum foil and placed in an oven at 60 °C for 24 hours to dissociations the xylem cells. After this period, they were washed four times with water to removė any residues of the macerating solution. Subsequently, the fibers were mounted on slides, dehydrated, stained with safranin, and covered with glycerin using semi-permanent type sheets (Johansen 1940, Sass 1951).

Finally, we captured photographic records of the fibers using an Axio Scope A1-Zeiss optical microscope with 10X and 40X magnifications. These images were used to measure fiber diameter, lumen size, length, and determine fiber wall thickness by subtracting the lumen diameter between two fibers (Figure 2). Fiber measurements were conducted using Image Pro Plus software (Portal *et al*. 2019).

X-ray densitometry

To obtain the radial apparent density profile of the wood in both species, 2 cm-wide 2 cm-thick test specimens were extracted from two sub-samples per tree inthe bark-pith direction. Clarifying that wood's apparent density includes empty spaces, such as pores, when measuring its mass per total volume. Conversely, basic density focuses solely on the mass of the solid part of the wood, excluding pores, making it useful for evaluating its quality and strength. The samples were attached to a wooden support and were cut transversally, with the help of a double circular saw, approximately 1,2 to 1,8 mm thick. Subsequently, the samples were placed in a climate chamber (Memmert) at 20 °C and 60 % relative humidity until the wood samples reached a stable humidity of 12 %. Then, in the X-Ray Faxitron equipment, model MX20-DC12, the samples and the cellulose acetate calibration wedge were scanned with X-rays in the irradiation chamber (Quintilhan *et al*. 2021). The scanned images of the wood cross sections and the calibration wedge were saved in ".tif" format at a resolution of 513 ppi. Using the RStudio software, they were analyzed using the xRing package (Campelo *et al*. 2019), after calibrating the images with the acetate wedge, the apparent density profiles of the wood of the two species were extracted with a resolution of 0,025 mm.

Statistical analysis

Microdensitometry data were analyzed using RStudio software and the xRing package (Campelo *et al*. 2019). This allowed us to determine the microdensity values of the wood for both forest species, with a range of 0,0017 mm. Fiber analysis was also conducted using the statistical software RStudio (R Core Team 2019).

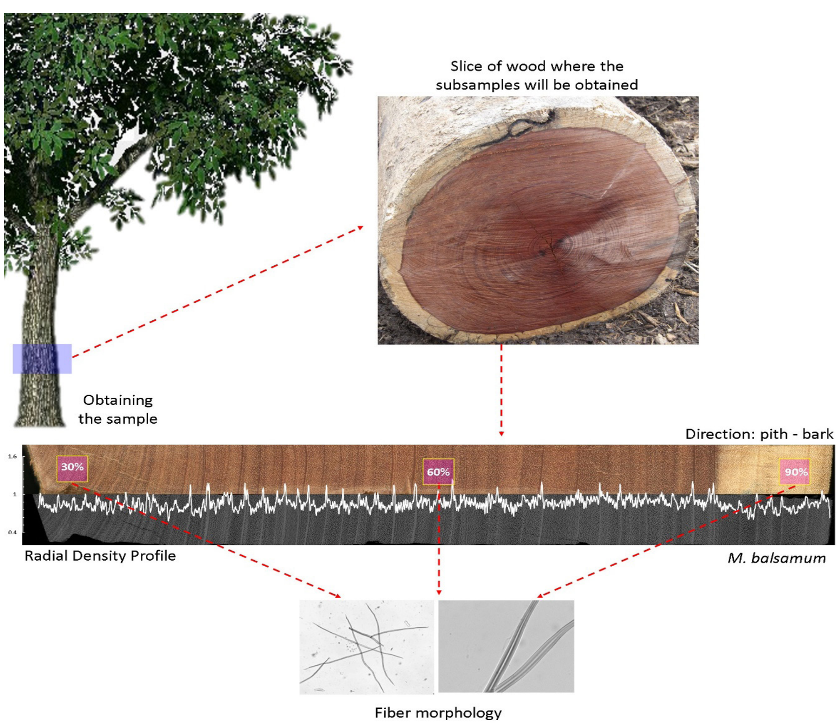

Figure 2: General scheme of the field process and results analysis: obtaining wood discs from the base of the tree, including both wood and radiographed samples, displaying the density profile from the pith to the bark, and identifying the fiber extraction points (30%, 60%, and 90%) for the species *Myroxylon balsamum*.

RESULTS AND DISCUSSION

Fiber morphology

The morphology characteristics of fibers, including diameter, length, lumen size, and thickness, were expressed in microns. The average values for these characteristics were obtained for both *Drypetes* sp. and peru balsam (*Myroxylon balsamum* (L.) Harms) in the three radial positions (30, 60 and 90 %), as shown in Table 1.

Table 1: Morphology of the fibers and their radial variation in three positions.

Average fiber values			
Characterístic	Descriptive Statistics	*Drypetes* sp.	*Myroxylon balsamum*
Fiber diameter (µm)	Average	26,29	15,73
	SD	4,77	3,18
Fiber length (µm)	Average	1318,40	1032,96
	SD	354,00	315,41
Fiber lumen (µm)	Average	15,57	3,66
	SD	3,50	1,24
Wall thickness (µm)	Average	5,36	6,04
	SD	1,70	1,37
Radial variation of the fibers			
Fiber diameter (µm)	Pith	26,10 a	14,91 b
		(4,83)	(2,84)
	Intermediary	26,49 a	15,99 a
		(4,72)	(3,22)
	Bark	26,27 a	16,30 a
		(4,77)	(3,27)
Fiber length (µm)	Pith	1307,16 a	1034,77 ab
		(208,57)	(365,00)
	Intermediary	1308,51 a	999,027 b
		(184,78)	(196,10)
	Bark	1341,87 a	1065,08 a
		(563,83)	(354,06)
Fiber lumen (µm)	Pith	15,41 a	3,65 a
		(3,53)	(1,15)
	Intermediary	15,74 a	3,70 a
		(3,66)	(1,25)
	Bark	15,54 a	3,61 a
		(3,27)	(1,31)
Wall thickness (µm)	Pith	5,34 a	5,62 b
		(1,69)	(1,18)
	Intermediary	5,37 a	6,14 a
		(1,51)	(1,37)
	Bark	5,36 a	6,34 a
		(1,87)	(1,45)

Averages sharing the same letter within the same column do not exhibit statistically significant differences from each other, as determined by the Tukey test (p>0,05). SD = standard deviation.

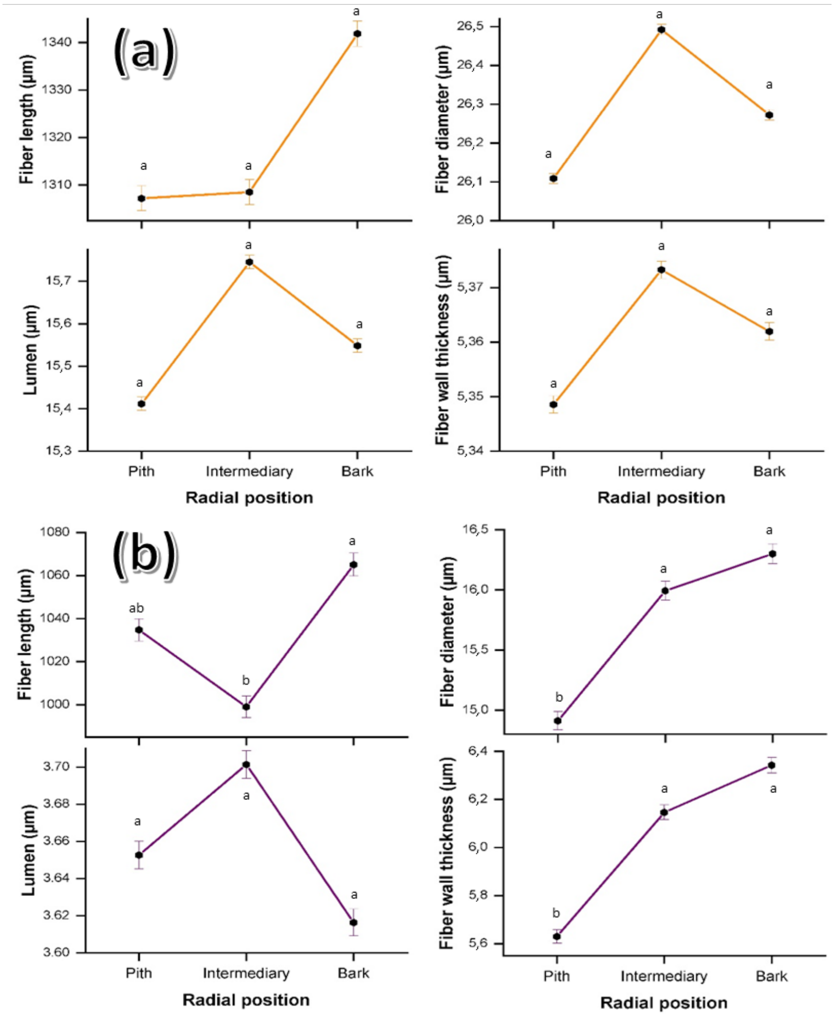

Figure 3: Radial variation of fibers (a) *Drypetes* sp. (b) peru balsam (*Myroxylon balsamum* (L.) Harms), measured at theree positions: pith (30 %), intermediary (60 %) and bark (90 %). The average data were derived from 250 measurements per fiber, representing 10 trees per species, with a 0,5% margin of error.

In general, the morphologies of the fibers of the species and/or species of the same genus agree with the scientific literature (InsideWood 2022). Regarding the radial variation of the morphology of the fibers, the species *Drypetes* sp. did not present significant variations in the radial direction; while the species peru balsam (*Myroxylon balsamum* (L.) Harms) showed significant variation in the radial direction (pith-bark) for the diameter (increase of 9,3 %) and thickness of the fiber wall (increase in 12,81 %) (Figure 3). These variations represent radial changes in fiber morphologies that were found in other tropical species guapuruvú (*Schizolobium parahyba* (Vell.), white bolaina (*Guazuma crinita* Lam.), teak (*Tectona grandis* L.), ambaúrana (*Amburana cearensis* (Allemão) A.C.Sm.) where they increased in the radial pith-bark direction (Chavesta *et al*. 2020, Lima *et al*. 2021, Lobão *et al*. 2012, Portal *et al*. 2019), in addition, the thickness of the fiber wall for peru balsam (*Myroxylon balsamum* (L.) Harms) increased with the age of the trees, as reported in other studies (Tirak and Erdin 2016).

Radial variation of density (pith-bark)

Table 2 shows the average values of bulk and basic density and the radial variation in the three positions for the two species studied.

Table 2: Average values of density and radial variation of density for the two species studied.

Average density values			
Characteristic		*Drypetes* sp.	*Myroxylon balsamum*
Apparent density (kg/m^3)		820	990
		(0,17)	(0,15)
Basic density (kg/m^3)		680	820
		(0,13)	(0,12)
Radial direction of density			
Apparent density (kg/m^3)	Pith	800 b	980 a
		(0,17)	(0,14)
	Intermediary	850 a	990 a
		(0,14)	(0,16)
	Bark	810 b	980 a
		(0,17)	(0,13)
Basic density (kg/m^3)	Pith	660 b	810 a
		(0,14)	(0,11)
	Intermediary	700 a	820 a
		(0,11)	(0,13)
	Bark	670 b	810 a
		(0,13)	(0,10)

Averages sharing the same letter within the same column do not exhibit statistically significant differences from each other, as determined by the Tukey test (p>0,05).
Numbers in parentheses standard deviation.

Based on the average basic density of the two species (Table 2), it agrees with the scientific literature (Zanne *et al*. 2009), classifying them qualitatively as follows: *Drypetes* sp. has a high basic density, while peru balsam (*Myroxylon balsamum* (L.) Harms) has a very high basic density (Sibille 2006).

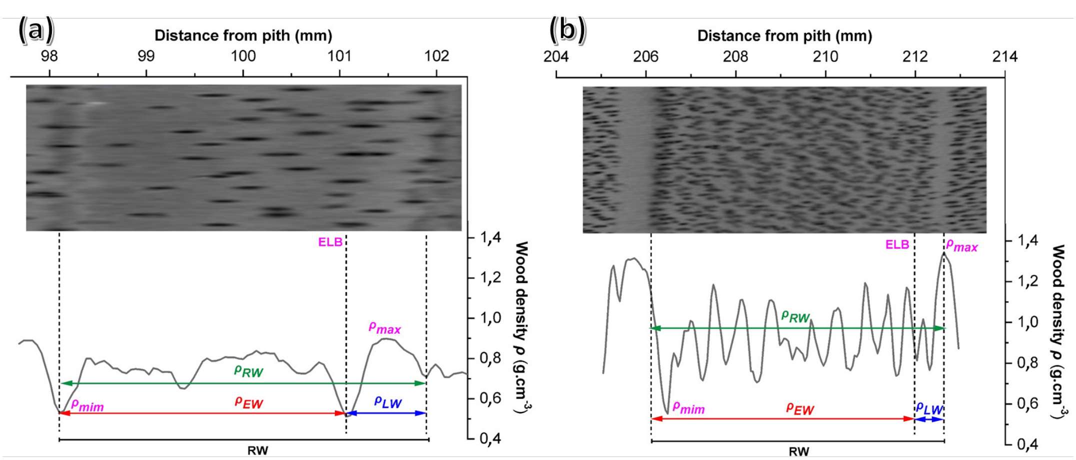

Figure 4: A schematic figure llustrating the parameters of wood density obtained from a growth ring in the species (a) *Drypetes* sp. (b) Peeru balsam (*Myroxylon balsamum* (L.) Harms). RW: growth ring width. ρEW: early wood. ρLW: latewood. ELB: boundary of earlywood and latewood. ρmin: minimum density. ρmax: maximum density. ρRW: average wood density in a growth ring. The X-ray image at the top of the two figure shows the intra-annual density fluctuation in the two species. This figure was adapted from (Gonçalves *et al*. 2021).

In Figure 4, you can observe the detailed apparent wood density of the two studied species at the level of a growth ring. This information was obtained through X-ray densitometry, and it aligns with various studies on tropical species that investigate wood density within a growth ring (intra-annual), its fluctuation, and its gradual variations (Gaitan *et al*. 2019, Gonçalves *et al*. 2021, Pagotto *et al*. 2017).

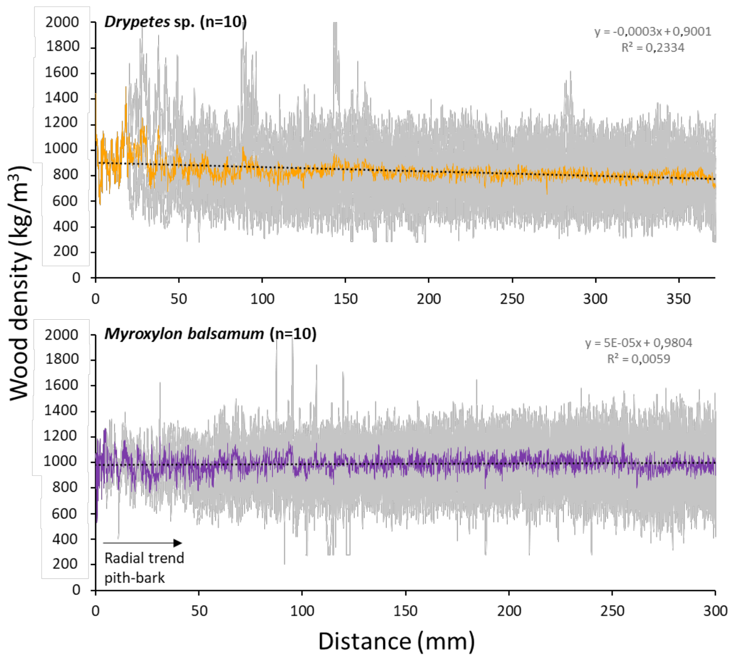

Figure 5: The radial variation in the bulk density. Gay lines represent individual tree, colored lines indicate the average density for each species, and the black dotted line despicts the overall density trend.

Figure 5 shows the radial variation of apparent wood density in the pith-bark direction. It observed that the species *Drypetes* sp. exhibits higher density near the pith, which gradually decreases as it approaches the bark. In contrast, for peru balsam (*Myroxylon balsamum* (L.) Harms), the bulk density remais relatively constant in the radial direction. Woodcock and Shier (2002) mentioned that species with a basic density greater than 0,55 g.cm^{-3} tend to exhibit a radial decrease in density. This characteristic is often associated with species of late succession that is associated with the production of dense wood, which coincides with the species *Drypetes* sp., however, other studies shows the same results of peru balsam (*Myroxylon balsamum* (L.) Harms) where the density does not increase or decrease as jequitibá-branco (*Cariniana legalis* (Mart.) Kuntze) (Lima *et al*. 2011).

As the species peru balsam (*Myroxylon balsamum* (L.) Harms) exhibits minimal radial density variation (from pith-bark), it simplifies the processes of wood transformation and utilization (Plaster *et al*. 2008). Understanding how density varies in the radial direction of tropical species is crucial, as density ranks among the most significant physical properties of wood and influences various other technological wood properties (Panshin and De Zeeuw 1980, Rios *et al*. 2018).

In terms of fiber morphology, there were no statistically significant variations observer at the three positions studied for the species *Drypetes* sp., as determined by the Tukey test. Instead, other anatomical characteristics such as the number of vessels, vessel area vessel diameter, and percentage of parenchyma may provide a better explanation for the radial density variation (Fortunel *et al*. 2014, Fujiw and Sameshima 1991, Ziemińska *et al*. 2015). Fort the species peru balsam (*Myroxylon balsamum* (L.) Harms), there no differences in density observed from the pith to the bark, and the lumen of the fibers remained consistent.

CONCLUSIONS

In conclusion, this study provides valuable insigntsinto the radial variations in wood density and fiber morphology of the commercial species *Drypetes* sp. and Peru balsam (*Myroxylon balsamum* (L.) Harms) in the Madre de Dios region of Peru. The results indicate that *Drypetes* sp. Show a decrease in density from the pith to the bark, while *M. balsamum* demostrates consistent radial density. These findings are crucial for improving the utilization and processing of these native species and significantly advancing our understanding of wood quality in tropical forests. Studies like this area highly beneficial for decision-making in the forestry industry and for promoting the sustainable management of our natural resources.

Authorship contributions

L.A.P-C.: Contributed to the conception, experimental work and interpretation of the analyzed data, writing and reviewing of the manuscript, read and approved the final manuscript. G.P-T.: Contributed to the investigation, methodology, read and approved the final manuscript. E.A.G-P.: Contributed to the software, formal análisis and read and approved the final manuscript. M.V.S-S.: Contributed to the investigation, methodology, read and approved the final manuscript. M.T-F.: Contributed to writing and reviewing of the manuscript, read and approved the final manuscript.

REFERENCES

Andrade, V.; Machado, S.; Figueiredo, A.; Botosso, P.; Miranda, B.; Schöngart, J. 2019. Growth models for two commercial tree species in upland forests of the Southern Brazilian Amazon. *Forest Ecology and Management* 438: 215-223. https://doi.org/10.1016/j.foreco.2019.02.030

Aragão, J.R.V.; Zuidema, P.A.; Groenendijk, P. 2022. Climate-growth relations of congeneric tree species vary across a tropical vegetation gradient in Brazil. *Dendrochronologia* 71. e125913. https://doi.org/10.1016/j.dendro.2021.125913

Arnič, D.; Krajnc, L.; Gričar, J.; Prislan, P. 2022. Relationships Between Wood-Anatomical Features and Resistance Drilling Density in Norway Spruce and European Beech. *Frontiers in Plant Science* 13. e872950. https://doi.org/10.3389/fpls.2022.872950

Asner, G.; Mascaro, J.; Muller, H.; Vieilledent, G.; Vaudry, R.; Rasamoelina, M.; Hall, J.; Breugel, M. 2012. A universal airborne LiDAR approach for tropical forest carbon mapping. *Oecologia* 168(4): 1147-1160. https://doi.org/10.1007/s00442-011-2165-z

Bhekti, Y.; Ishiguri, F.; Aiso, H.; Ohshima, J.; Yokota, S. 2017. Wood properties of 7-year-old balsa (*Ochroma pyramidale*) planted in East Java. *International Wood Products Journal* 8(4): 227-232. https://doi.org/10.1080/20426445.2017.1394560

Campelo, F.; Mayer, K.; Grabner, M. 2019. xRing-An R package to identify and measure tree-ring features using X-ray microdensity profiles. *Dendrochronologia* 53: 17-21. https://doi.org/10.1016/j.dendro.2018.11.002

Chavesta, M.; Tomazello-Filho, M.; Carneiro, M.; Nisgoski, S. 2020. Axial and radial evaluation of the basic density and fiber dimensions of *Guazuma crinita* Martius wood. *Floresta* 50(2). e1143. https://doi.org/10.5380/rf.v50i2.58356

Edwards, D.P.; Socolar, J.B.; Mills, S.C.; Burivalova, Z.; Koh, L.P.; Wilcove, D.S. 2019. Conservation of Tropical Forests in the Anthropocene. *Current Biology* 29(19): R1008-R1020. https://doi.org/10.1016/j.cub.2019.08.026

Fortunel, C.; Ruelle, J.; Beauchêne, J.; Fine, P.V.A.; Baraloto, C. 2014. Wood specific gravity and anatomy of branches and roots in 113 A mazonian rainforest tree species across environmental gradients. *New Phytologist* 202(1): 79-94. https://doi.org/10.1111/nph.12632

Gaitan, J.; Moya, R.; Berrocal, A. 2019. The use of X-ray densitometry to evaluate the wood density profile of *Tectona grandis* trees growing in fast-growth plantations. *Dendrochronologia* 55:71-79. https://doi.org/10.1016/j.dendro.2019.04.004

Gonçalves, J.Q.; Durgante, F.M.; Wittmann, F.; Piedade, M.T.F.; Ortega Rodriguez, D.R.; Tomazello-Filho, M.; Parolin, P.; Schöngart, J. 2021. Minimum temperature and evapotranspiration in Central Amazonian floodplains limit tree growth of *Nectandra amazonum* (Lauraceae). *Trees* 35: 1367-1384. https://doi.org/10.1007/s00468-021-02126-7

Granato, D.; Stahle, D.; Barbosa, A.; Feng, S.; Torbenson, M.; de Assis Pereira, G.; Schöngart, J.; Barbosa, J.; Griffin, D. 2019. Tree rings and rainfall in the equatorial Amazon. *Climate Dynamics* 52(3-4): 1857-1869. https://doi.org/10.1007/s00382-018-4227-y

InsideWood. 2022. Inside Wood. Inside Wood - Search the Inside Wood Database. https://insidewood.lib.ncsu.edu/description?18

Johansen, D.A. 1940. *Plant microtechnique*. McGraw-Hill Book Company. 530p.

Lehnebach, R.; Bossu, J.; Va, S.; Morel, H.; Amusant, N.; Nicolini, E.; Beauchêne, J. 2019. Wood Density Variations of Legume Trees in French Guiana along the Shade Tolerance Continuum: Heartwood Effects on Radial Patterns and Gradients. *Forests* 10(2). e80. https://doi.org/10.3390/f10020080

Lima, I.L.; Ranzini, M.; Longui, E.L.; Barbosa, J.A. 2021. Wood characterization of *Tectona grandis* L. F. cultivated in Brazil: A review of the last 30 years. *Research, Society and Development* 10(14). e162101421549. https://doi.org/10.33448/rsd-v10i14.21549

Lima, I.; Longui, E.; Garcia, M.; Zanatto, A.; Freitas, M.; Florsheim, S. 2011. Variação radial da densidade básica e dimensões celulares da madeira de *Cariniana legalis* (Mart.) O. Kuntze em função da procedência. *Cerne* 17(4): 517-524. http://dx.doi.org/10.1590/s0104-77602011000400010

Lobão, M. S.; Costa, D. P.; Almonacid, M.A.A.; Tomazello-Filho, M. 2012. Qualidade do lenho de árvores de *Schizolobium parahyba* Var. *amazonicum*, Acre, Brasil. *Floresta e Ambiente* 19(3): 374-384. https://doi.org/10.4322/floram.2012.044

López, L.; Villalba, R.; Stahle, D. 2022. High-fidelity representation of climate variations by *Amburana cearensis* tree-ring chronologies across a tropical forest transition in South America. *Dendrochronologia* 72. e125932. https://doi.org/10.1016/j.dendro.2022.125932

Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; da Fonseca, G.A.B.; Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403(6772): 853-858. https://doi.org/10.1038/35002501

Nock, Ch.; Geihofer, D.; Grabner, M.; Baker, P.; Bunyavejchewin, S.; Hietz, P. 2009. Wood density and its radial variation in six canopy tree species differing in shade-tolerance in western Thailand. *Annals of Botany* 104(2): 297-306. https://doi.org/10.1093/aob/mcp118

Pagotto, M.; De Soto, L.; Carvalho, A.; Nabais, C.M.; Tomazello-Filho, M.; Ribeiro, A.; Lisi, C. 2017. Evaluation of X-ray densitometry to identify tree-ring boundaries of two deciduous species from semi-arid forests in Brazil. *Dendrochronologia* 42: 94-103. https://doi.org/10.1016/j.dendro.2017.01.007

Panshin, A.; De Zeeuw, C. 1980. *Textbook of wood technology.* McGraw-Hill Book Company: New York, USA. 4th ed.722p.

Plaster, O.; Oliveira, J.; Abrahão, Ch.; Braz, R. 2008. Comportamento de juntas coladas da madeira serrada de *Eucalyptus* sp. *Cerne* 14(3): 251-258. https://www.redalyc.org/pdf/744/74411656009.pdf

Portal, L.A.; Figueiredo, J.V.; Camargo, J.H.; Vieira, G.; Oliveira, D.; Alves, L. M.; Latorraca, J. 2019. Variabilidad radial física y anatómica del leño de árboles de *Amburana cearensis*. *Colombia Forestal* 22(1): 17-26. https://doi.org/10.14483/2256201X.13083

Portal, L.A.; Huamán, B.A.; Mamani, E.M.; Palermo, P.M.; Latorraca, J.V. 2021. Dendrochronology of two forest species in the urban area of the city of Puerto Maldonado, Peru. *Floresta* 51(3). e10. https://doi.org/10.5380/rf.v51i3.72410

Quintilhan, M.T.; Santini, L.; Ortega Rodriguez, D.R.; Guillemot, J.; Cesilio, G. H.M.; Chambi-Legoas, R.; Nouvellon, Y.; Tomazello-Filho, M. 2021. Growth-ring boundaries of tropical tree species: Aiding delimitation by long histological sections and wood density profiles. *Dendrochronologia* 69. e125878. https://doi.org/10.1016/j.dendro.2021.125878

R Core Team. 2019. R: A language and environment for statistical computing. R Founda- tion for Statistical Computing. Vienna: s.n. ISBN 3-900051-07-0. http://www.R-project.org.

Rios, P.D.; Vieira, H.C.; Pereira, G.F.; Turmina, E.; Nicoletti, M.F. 2018. Variação radial e longitudinal da densidade básica da madeira de *Pinus patula*. *Pesquisa Florestal Brasileira* 38: 1-5. https://doi.org/10.4336/2018.pfb.38e201501016

Sánchez-Cuervo, A.M.; de Lima, L.S.; Dallmeier, F.; Garate, P.; Bravo, A.; Vanthomme, H. 2020. Twenty years of land cover change in the southeastern Peruvian Amazon: Implications for biodiversity conservation. *Regional Environmental Change* 20(1). e8. https://doi.org/10.1007/s10113-020-01603-y

Sass, J.E. 1951. *Botanical microtechnique*. Constable and Company. London, UK. 3th ed. 228p.

Sibille, A. 2006. Guía de Procesamiento Industrial Fabricación de Muebles con Maderas Poco Conocidas-LKS. WWF Perú a través del Proyecto CEDEFOR. 1ra edición. Lima, Perú. 76p.

Tirak, K.; Erdin, N. 2016. Radial Variation of Annual Ring Width and Fiber Dimensions from Natural and Plantation Trees of Alder (*Alnus glutinosa* L. Gaertner) Wood. *Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi* 12(2): 1-12. http://ordergi.duzce.edu.tr/Dokumanlar/arsiv/2016_2_Tam.pdf

Tomazello, M.; Brazolin, S.; Chagas, M.P.; Oliveira, J.T.S.; Ballarin, A.W.; Benjamin, C. A. 2008. Application of X-ray technique in nondestructive evaluation of eucalypt wood. *Maderas. Ciencia y Tecnología* 10(2): 139-149. https://doi.org/10.4067/S0718-221X2008000200006

Valente, B.; Evangelista, W.; Silva, J.; Lucia, R. 2013. Variabilidade radial e longitudinal das propriedades físicas e anatômicas da madeira de angico-vermelho. *Scientia Forestalis* 41(100): 485-496.

Woodcock, D.W.; Shier, A.D. 2002. Wood specific gravity and its radial variations: The many ways to make a tree. *Trees* 16(6): 437-443. https://doi.org/10.1007/s00468-002-0173-7

Zanne, A.E.; Lopez-Gonzalez, G.; Coomes, D.A.; Ilic, J.; Jansen, S.; Lewis, S.L.; Miller, R.B.; Swenson, N.G.; Wiemann, M.C.; Chave, J. 2009. *Global Wood Density Database*. Dryad Digital Repository. https://datadryad.org/stash/dataset/doi:10.5061/dryad.234

Ziemińska, K.; Westoby, M.; Wright, I.J. 2015. Broad Anatomical Variation within a Narrow Wood Density Range-A Study of Twig Wood across 69 Australian Angiosperms. *Plos One* 10(4). e0124892. https://doi.org/10.1371/journal.pone.0124892