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# Radial variation of wood density and fiber morphology of two commercial species in a tropical humid forest in Southeastern Peru

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TECHNOLOGY OF FOREST PRODUCTS

## ABSTRACT

**Background:** Knowledge of the anatomy and properties of wood help to understand the quality of wood and plan its ideal technological use, therefore, it is necessary to understand the variations in wood characteristics and properties. Here we evaluate the radial variation of wood density and fiber morphology of two commercial forest species in a tropical humid forest of the department of Madre de Dios in Peru: *Jacaranda copaia* and *Hura crepitans* collected in a management area.

**Results:** Forestry collecting 10 usable trees by species. We provide general values of the densities and fibers of the two species studied.

**Conclusions:** Regarding the variation of the radial density, *J. copaia* presented a density growth in the pith-bark direction, while for *H. crepitans* its variation was not significant, these variations are clearly explained by the morphology of its fibers.

## HIGHLIGHTS

The *Jacaranda copaia* species presented an increase in density in the bark-pith direction, while for the *Hura crepitans* species there was no significant variation, these variations are explained by the fiber morphology of its fibers.
The biomass of wood and the biomechanics of these species since density and fibers are directly related.

**Key words:** Tropical wood; wood anatomy; wood quality; X-ray densitometry.

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## INTRODUCTION

The various ecosystem services provided by tropical forests are very important for humanity, the largest tropical forests in the world with great biodiversity are found in South America (Aguirre et al., 2021; Qin et al., 2017). However, human activities have made intensive use of natural resources causing degradation, deforestation, and change in land use, with expansive agriculture contributing to the increase in global $CO_2$ (Exbrayat et al., 2017; Nasi et al., 2011; Nobre et al., 2016). For this reason, different initiatives have been carried out to sustainably manage tropical forests, such as forest certification, which is a little over 20 years old, with forest management being a strategy and a current priority issue to conserve natural resources (Ehrenberg and Peña, 2020; Marengo et al., 2018; Nebel et al., 2001).

For this reason, wood density (WD) is a physical property considered one of the most important when analyze the quality, as it's related to the other technological properties of the wood. WD is defined as the ratio between the dry mass of wood and it's saturated volume (Cremonez et al., 2019; Lehnebach et al., 2019; Cahuana et al., 2019). The wood is widely used worldwide because there is a very favorable relationship between strength and basic density, compared to other building materials, wood achieves greater strength with less density which makes it more efficiently used in structures that support much more than its own weight (Ramage et al., 2017). In tropical trees, WD is a key variable to understand life history strategies (Nock et al., 2009).

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It is important to point out that the characteristics of trees vary considerably, such as the anatomy, physical, chemical and mechanical properties of their different parts such as the roots, main stem and branches; constantly reflecting the adaptation of the tree to its environment (Lachenbruch et al., 2011; Lehnebach et al., 2019). Knowing these variations in the trees, it is necessary to study them, for example, the density of the wood and its variation (inside the tree) in the longitudinal direction (base-crown) and radial direction (pith to bark), to understand the quality of the wood. Wood is essential and its technological use is better (Cruz et al., 2019; Valente et al., 2013). For example, the radial variation of the WD is affected by the age of the tree and changes in conductivity and storage, in addition, the biomechanics of the trees is of great importance to understand this radial variation of the WD and that the tree is standing supporting various external factors (Nock et al., 2009; Salvo et al., 2017).

To determine the radial variation of the wood in the pith-bark direction, among other methodologies, there is X-ray densitometry, which allows determining the radial variation of the density of the wood through the profiles of the density of the wood, making it possible to find variations between and within the growth rings, being a more important technique taking density readings in short intervals of up to microns (Gaitan et al., 2019; Tomazello et al., 2008). In addition, this technique can be applied to determine the proportions of sapwood and heartwood, help in the identification of the limit of the growth rings and build chronologies of the WD (Jacquin et al., 2017; Pagotto et al., 2017; Cahuana et al., 2019; Schöngart et al., 2017).

Here we present an evaluation of the radial variation of wood density and fiber morphology of two commercial forest species in a tropical moist forest in the department of Madre de Dios in Peru. Specifically, we address the following questions: (i) How does the density of the wood of the two species studied vary in the radial direction? How does the morphology of the fibers of the two species studied vary in the radial direction? Can the morphology of the fibers of the two species be studied to explain the variation in density? We address these questions using two native commercial forest species (*Jacaranda copaia* and *Hura crepitans*) from different botanical families with different ecological growth strategies.

## MATERIAL AND METHODS

### Study area

The trees were sampled at the site located in the tropical humid forest in southeastern Peru, in the department of Madre de Dios (Figure 1), which geographically has an area of ~85,000 km$^2$ (Sánchez-Cuervo et al., 2020), which forms the global biodiversity hotspot (Myers et al., 2000; Asner et al., 2012). The site specifically was the concession Corporación Forestal Tres Fronteras S. R. L. "CORFOREST S.R.L.", granted by the Peruvian state in the province of Tahuamanu. The climate of the department is of a warm and humid seasonal tropical type, with a rainy season from November to May with an average annual rainfall of 2000 mm/year and a dry season from June to August with an average annual temperature of 25°C (Cahuana et al., 2021; Sánchez-Cuervo et al., 2020).

### Selected species

Two species of native tropical commercial trees were selected for this research: *Jacaranda copaia* (Aubl.) D. Don. and *Hura crepitans* L., the important criteria for their selection were the availability of wood, the wide geographical distribution, in addition, the two species have ecological and economic importance for the department (Portal et al., 2020), making these species be an interesting case study to understand the morphology of the fibers and the radial variation of the density in the tropical humid forest of Madre de Dios.

### Field phase

The collection of the samples was carried out in a simple random design, in which individuals with diameters at breast height (DBH) ≥ 41 cm, were randomly selected from the cutting plot No. 19 of CORFOREST S.R.L.", the species *J. copaia* had 34 trees and *H. crepitans* with 48 inventoried and usable trees. From these two species, information was collected such as tree height, DBH, geographic coordinates and phytosanitary

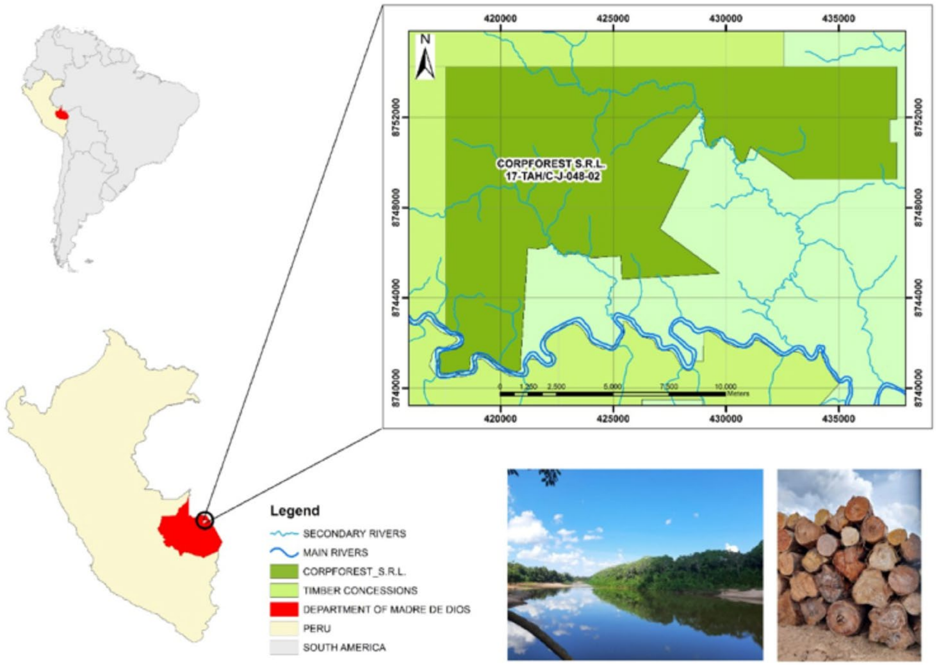


**Figure 1.** Location of the study site within the tropical humid forest of Madre de Dios. An image of the access to the study area by the Tahuamanu River and another image of the log yard are also provided.

status of the individuals, among others. Ten trees per species were felled and botanical samples were collected from the terminal branches, which were herborized and sent to the MOL herbarium of the Universidad Nacional Agraria La Molina to confirm the species. Next, the logs were transported from the field to the concession's processing plant where a slice was removed from each tree from the end of the first log (Granato-Souza et al., 2019), with a thickness of 5 to 6 cm by diameter. of each log (Figure 2) and finally said slices were dried in the environment with separators stacked horizontally.

## Density analysis by X-ray densitometry

For the determination of the radial profile of the microdensity of the woods, the methodology described by (Quintilhan et al., 2021), was used, four radial sub-samples were obtained from the slices (3.0 cm wide x 5.0 cm thick, bark-pith); From these radial sub-samples, after a visual analysis, only two samples per tree were selected, 2.0 cm wide x 2.0 cm thick, pith bark; said sample was glued on a wooden support and cut crosswise, with a double circular saw with a thickness of approximately 1.2 - 1.8 mm; subsequently, the samples of the two species were conditioned in an air conditioning chamber (24 h, 20 °C, 50% RH; 12% humidity); After proceeding to the irradiation chamber (Faxitron X-Ray Equipment, model LX-60, 5.9 kV, 33 sec), a cellulose acetate calibration wedge was placed (Figure 2). The X-ray scanned images of the cross sections of the wood samples and the calibration wedge (high resolution, TIF, 513ppi) were analyzed using the RStudio software, with the help of the xRing package (Campelo et al., 2019), with which it was possible to determine the microdensity values of the wood of the two forest species (range, 0.017 mm). The data was transferred to a spreadsheet in Excel software and the radial profiles of the microdensity of the two species were constructed.

## Analysis of the morphology of the fibers

To investigate potential variations in the radial microdensity profile of two forest species, an anatomical analysis was conducted. This involved analyzing fiber morphology and dimensions. Small wood blocks were obtained from three radial positions: near the pith (30%), in the middle (60%), and near the bark (90%). From these blocks, fine wood pieces were extracted and placed in test tubes with a macerating solution of acetic acid and hydrogen peroxide (120 vol, 1:1). The test tubes were covered with aluminum foil and placed in an oven at 60 °C for 24 hours to dissociate the cells. Afterwards, the fibers were washed with distilled water and separated on a slide for dehydration, staining, and assembly of semi-permanent sheets with glycerin (Johansen, 1940; Sass, 1951). The fibers were then photographed using an Axio Scope A1-Zeiss optical microscope at 10 and 40X magnifications to measure length, diameter, lumen, and estimate fiber wall thickness using Image Pro Plus software (Chavesta et al., 2020; Cahuana et al., 2019). These measurements were taken from three different samples. Two examples of the measurements can be seen in (Figure 3). To analyze potential differences in the mean values of fiber density and morphology across the three radial positions, an ANOVA test was conducted. Subsequently, a Tukey analysis was performed to determine if statistically significant differences exist between these positions. The statistical analyses were carried out using Rstudio software (RStudio Team, 2015).

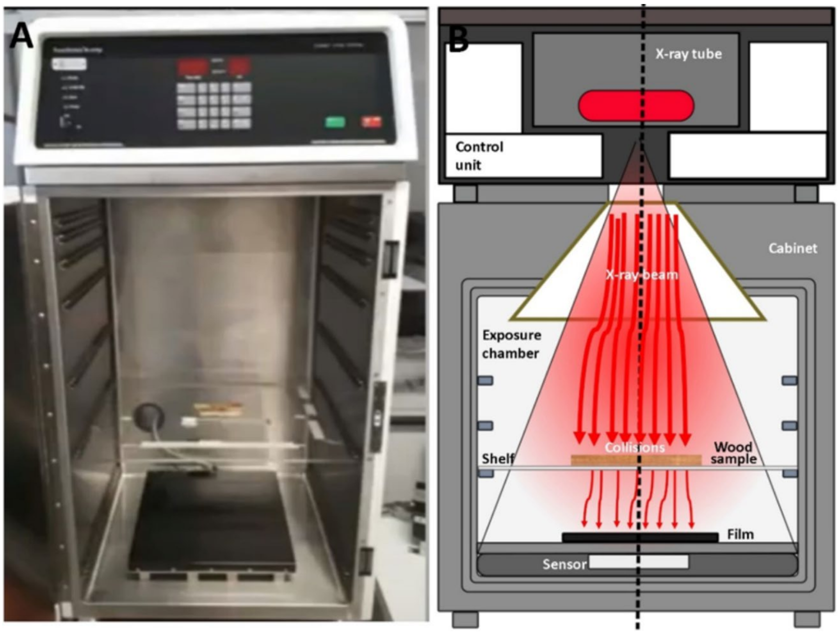


**Figure 2.** A) Faxitron X-ray equipment, model LX-60. B) Design of the parts and X-ray process in the Faxitron equipment.

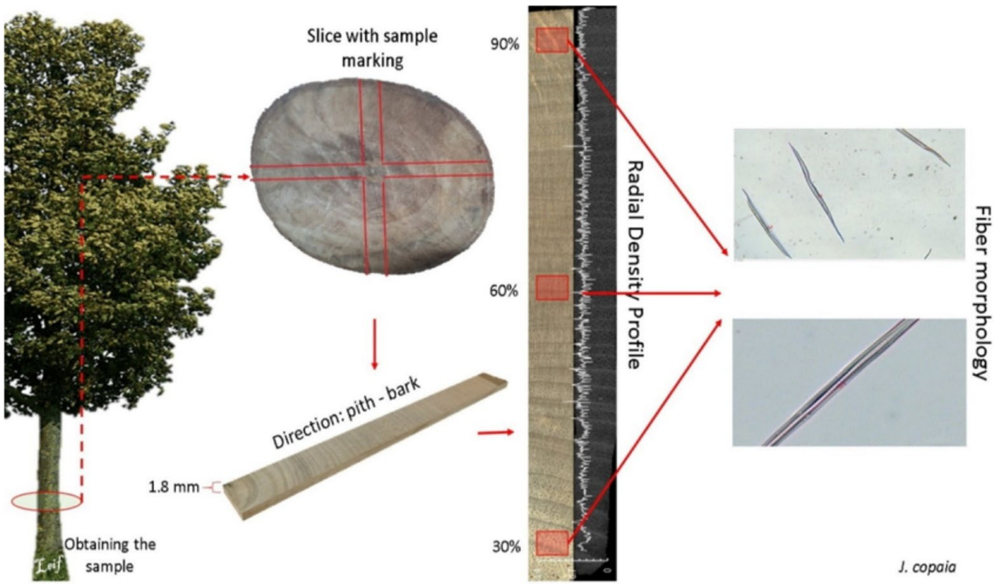


**Figure 3.** Scheme of the field process and obtaining results.

## RESULTS

### Density and radial profile in the pith-bark direction

The average values of apparent density and basic density, generated from X-ray densitometry, are shown in Table 1, as well as the radial variation of the density of the two forest species (Table 1) in the three positions.

Based on the basic density of the two species, we can affirm that *J. copaia* is classified as low density and *H. crepitans* is classified as medium density (Acevedo and Chavesta, 1991; Sibille, 2006). Next, (Figure 4) shows the radial profile (pith-bark direction) of the bulk density of the two species studied by X-ray densitometry of the 10 trees studied by species, where the variations in density and trends in the radial direction, where *J. copaia* showed a growing increase in the radial direction while *H. crepitans* did not show significant variation.

In (Figure 5), it can be seen that the apparent density profiles can help identify the limits of the growth rings of the two species studied, where the species: *J. copaia* and *H. crepitans* present the delimitation of the growth rings due to a change in the thickness of the fiber wall and therefore it presents a higher density and this is expressed in higher peaks in the density profile. Furthermore, in Figure 5, it can be observed that the density of the *H. crepitans* species decreases near the cambium due to the functional activity of this tissue.

## Fiber morphology and radial variation in three positions

The average values for the two species studied on the morphology of the fibers and the radial variation in the three positions are presented in Table 2. Fiber dimensions: length, diameter, lumen and thickness (μm).

On the radial variation of the dimensions of the fibers, with respect to the length of the fibers, the species *J. copaia* showed significant variation, while *H. crepitans* did not show significant variation. Regarding the diameter of the fibers, the species that showed significant variation was *J. copaia*, on the lumen of the fibers, neither of the two species showed significant variations. Finally, regarding the thickness of the fiber wall, the two species showed significant variations in the three radial positions.

Regarding the variations of the dimensions of the fibers in the radial direction in the three positions (pith, intermediate and bark), in the case of *J. copaia*, we can observe that the intermediate position (60%) presents higher values in all dimensions of the fibers falling values both in the pith and in the bark; for the case of *H. crepitans* on the lengths of the fibers, it is also observed that the intermediate position shows the greater length of fibers (Figure 6), on the other hand, they present an increase in the diameter and lumen of the fibers in the radial direction, while that thickness shows a decrease from pith to the bark.

**Table 1.** Average values of the density and the variation of the density in the three positions studied.

| Density | | Apparent density (g/cm3) | | Basic density (g/cm3) | |
|---|---|---|---|---|---|
| Species | | ***Jacaranda copaia*** | ***Hura crepitans*** | ***Jacaranda copaia*** | ***Hura crepitans*** |
| Radial direction | Pith | 0.47 a (0.12) | 0.68 a (0.15) | 0.38 a (0.09) | 0.54 a (0.12) |
| | Intermediary | 0.49 a (0.12) | 0.68 a (0.12) | 0.39 a (0.10) | 0.54 a (0.09) |
| | Bark | 0.42 b (0.15) | 0.67 a (0.14) | 0.33 b (0.12) | 0.53 a (0.11) |
| Average values | | 0.46 | 0.62 | 0.38 | 0.51 |

The values in parentheses correspond to the standard deviation. If the average is followed by the same letter within the same column, there is no statistical difference between them, according to Tukey's test (p > 0.05).

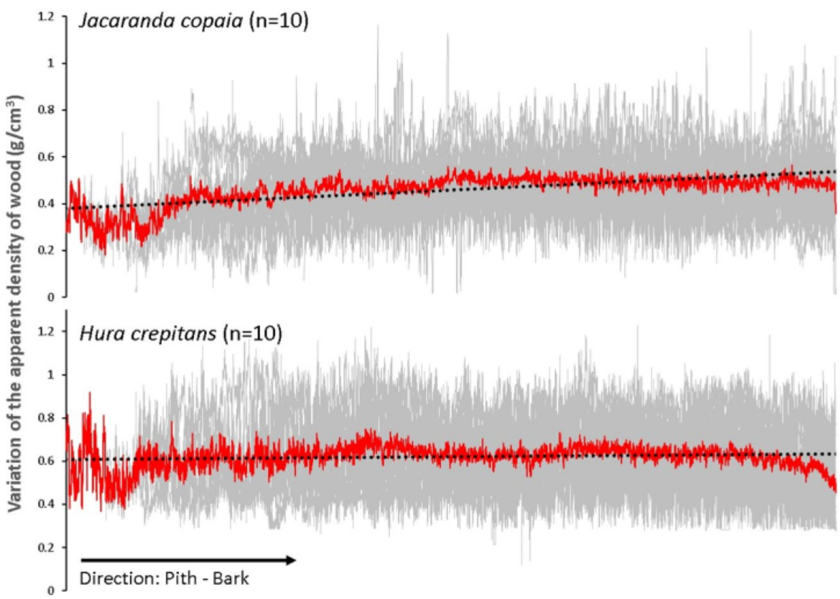


**Figure 4.** Radial profile of apparent density by means of X-ray densitometry. The gray lines show the graphs of each sample per tree, the red line shows the average for each species and finally the black dotted line shows the apparent density trend for each tree. Each species.

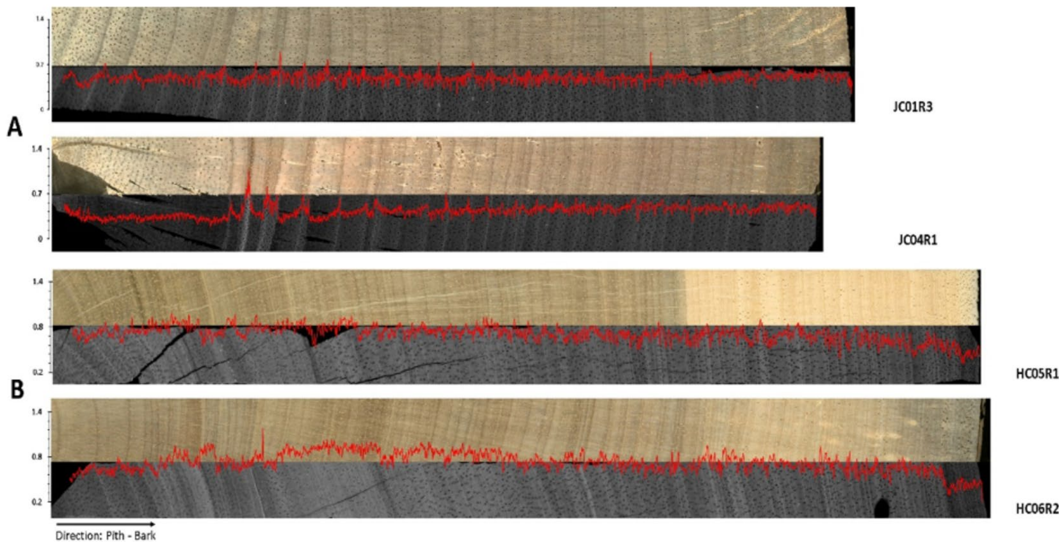


**Figure 5.** Radial profile of two samples per species. A) *Jacaranda copaia*. B) *Hura crepitans*. Scanned images and X-ray images, red line bulk density profile that helps delineate growth rings.

**Table 2.** Average values of the morphology of the fibers and the radial variation in the three positions of the two species studied.

| Morphology of the fibers | | Fiber length (µm) | | Fiber diameter (µm) | | Fiber lumen (µm) | | Wall thickness (µm) | |
|---|---|---|---|---|---|---|---|---|---|
| Species | | J. copaia | H. crepitans | J. copaia | H. crepitans | J. copaia | H. crepitans | J. copaia | H. crepitans |
| Radial direction | Pith | 1135.76 $^{b}$ | 1326.59 $^{a}$ | 25.17 $^{b}$ | 26.56 $^{a}$ | 16.24 $^{a}$ | 17.62 $^{b}$ | 4.46 $^{b}$ | 4.46 $^{a}$ |
| | | (201.98) | (237.5) | (5.58) | (6.57) | (5.34) | (4.89) | (1.41) | (1.76) |
| | Intermediary | 1180.82 $^{a}$ | 1349.17 $^{a}$ | 26.6 $^{a}$ | 26.64 $^{a}$ | 16.88 $^{a}$ | 18.37 $^{ab}$ | 4.88 $^{a}$ | 4.13 $^{b}$ |
| | | (189.92) | (252.71) | (5.47) | (6.92) | (5.71) | (5.36) | (1.46) | (1.41) |
| | Bark | 1152.99 $^{ab}$ | 1337.06 $^{a}$ | 25.91 $^{ab}$ | 26.81 $^{a}$ | 16.29 $^{a}$ | 19.61 $^{a}$ | 4.80 $^{a}$ | 3.99 $^{b}$ |
| | | (168.96) | (249.98) | (5.48) | (6.94) | (5.23) | (9.57) | (1.57) | (1.2) |
| Average values | | 1156.53 | 1337.63 | 25.91 | 26.67 | 16.47 | 18.5 | 4.72 | 4.21 |

The values in parentheses correspond to the standard deviation. If the average is followed by the same letter within the same column, there is no statistical difference between them, according to Tukey's test ($p > 0.05$).

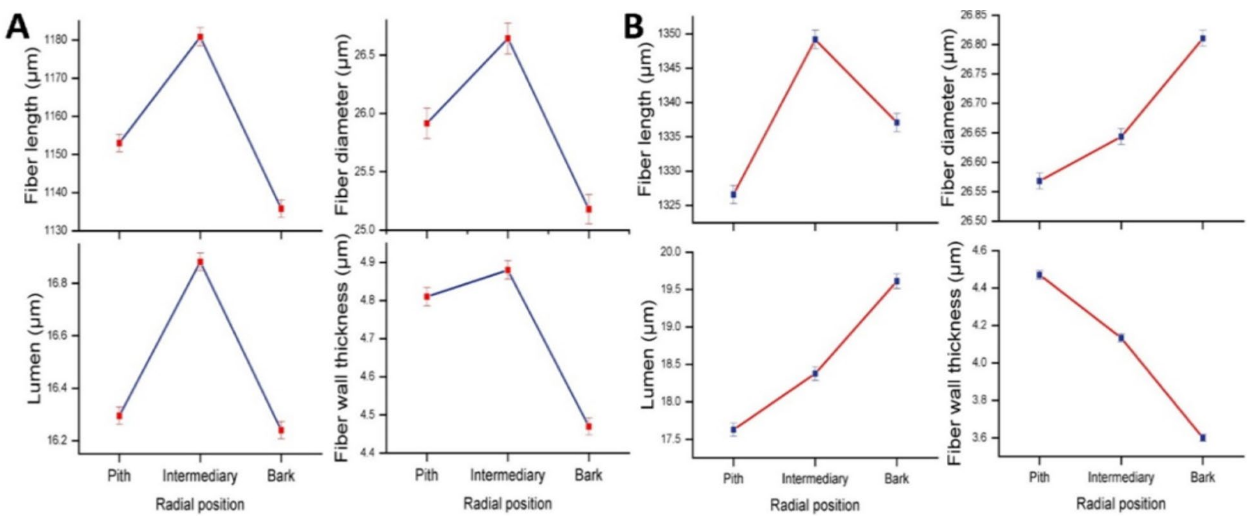


**Figure 6.** Variation of the dimensions of the fibers in the radial positions: bark (90%), intermediary (60%) and pith (30%). A) *J. copaia*. B) *H. crepitans*.

As we can see in Table 2, the species *H. crepitans* did not show statistically significant radial variation in its apparent density, whereas for *H. crepitans* the length and diameter of the fibers show the same trend. Regarding the species *J. copaia*, the dimensions of the fibers respond directly to the radial variations of the density, the length, diameter, lumen and thickness of the fibers present the same pattern as the density in the three radial positions. In general, the morphology of the fibers explains the density of the wood that the two forest species studied presently. For example, in the case of the species *J. copaia* it presents a low density where the lumen of the species is greater and the thickness of the wall is smaller, something similar occurs for the species *H. crepitans* of medium density.

## DISCUSSION

The species *J. copaia* and *H. crepitans* from the tropical humid forest in the department of Madre de Dios in southeastern Peru showed an increase in density in the pith-bark direction and this radial variation is explained by the morphology of their fibers. The values of the basic density of the species agree with the scientific literature, for example, *J. copaia* presents 0.37 g/cm$^3$, *H. crepitans* 0.42 g/cm$^3$ (Baker et al., 2004; Fearnside, 1997), only for the In the case of *H. crepitans*, the values found are slightly higher. This may be due to various factors such as habitat, relief and age of the trees, among others (Louzada, 2003; Morel et al., 2018).

Radial variation with a tendency to increase in the pith-bark direction is associated with species with densities up to 0.55 g/cm$^3$ and is a characteristic of early succession (Rungwattana and Hietz, 2018; Woodcock and Shier, 2002), as in the case of *J. copaia*, which will produce low-density wood at the beginning, maximizing growth in height and diameter mainly due to light, when they reach the canopy, accelerated growth is no longer important and they will invest in higher-density wood, mainly due to biomechanical aspects that contribute to withstand wind pressure (Rungwattana and Hietz 2018). However, in the case of *H. crepitans*, the density increase trend in the pith-bark direction does not occur, possibly because it is close to the limit between species with late successional characteristics and species with early successional characteristics (Woodcock and Shier, 2002). This technological information for the species *H. crepitans* is important for its industrial use. In addition, the species *H. crepitans* may be well adapted to its environment, guaranteeing its basic functions (Rungwattana and Hietz 2018).

Tropical species such as *Anadenanthera peregrina*, *Ochroma pyramidale*, and *Schizolobium parahyba* Var *amazonicum* showed the same type of increasing radial variation from pith to bark as *J. copaia* (Rueda and Williamson, 1992; Valente et al., 2013; Lobão et al., 2012) and the same behavior was found in tropical forest plantation species such as *Guazuma crinita*, *Schizolobium parahyba*, *Tectona grandis*, *Toona ciliata*, (Chavesta et al., 2020; Lima et al., 2021; Melo et al., 2018; Ribeiro et al., 2011). On the other hand, the tropical species *Cariniana legalis* also did not present any significant trend of radial variation in the pith-bark direction, the same as the species *H. crepitans* (Lima et al., 2011; Ribeiro et al., 2011), which does not exist a significant difference in the radial variation of wood in the species *H. crepitans* is favorable for industrial transformation processes (Plaster et al., 2008; Rios et al., 2018).

The use of X-ray densitometry to help in the process of delimitation of the limits of growth rings has been reported for tropical species (*Amburana cearensis*, *Aspidosperma pyrifolium*, *Poincianella pyramidalis*, *Nectandra amazonum*, *Tectona grandis*), being a tool that helps in this process and is an additional technique for studies of growth rings in tropical forests (Gaitan et al., 2019; Gonçalves et al., 2021; Pagotto et al., 2017; Cahuana et al., 2019).

The dimensions of the fibers of the two species studied are similar to other research in tropical forests in Peru, for *J. copaia* they found a fiber diameter of 28 µm and a length that varies from 912 to 1497 µm and for *H. crepitans* a diameter of 29 µm and a length that varies from 1208 to 1762 µm, for the diameter of the fibers of both species our results are slightly lower and for the length of the fibers of both species our results are in the range of variation (Acevedo and Kikata, 1994).

The tropical species: *Guazuma crinita*, *Schizolobium parahyba*, *Amburana cearensis*, *Anadenanthera peregrina* and *Tectona grandis*, their fibers and how they vary radially were also studied, comparing them in three positions, to understand the influence of the fibers on the physical properties of wood such as density basic in tropical forests (Chavesta et al., 2020; Chuquicaja et al., 2020; Lobão et al., 2012; Melo et al., 2018; Cahuana et al., 2019). The forest species *Cariniana legalis*, *Tectona grandis*, *Casuarina equisetifolia* and *Schizolobium parahyba* Var *amazonicum* found differences in the length, and thickness of the fibers, and presented an increase in the pith-bark direction similar to *J. copaia* (Chuquicaja et al., 2020; Lima et al., 2011; Lobão et al., 2012; Qumruzzaman et al., 2012).

## CONCLUSION

We report for the first time the radial variation of fiber density and morphology of two tropical species native to the Amazon of Madre de Dios in Peru. The species present different radial behavior in their density, where the *J. copaia* species presented an increase in density in the bark-pith direction, while for the *H. crepitans* species there was no significant variation, these variations are explained by the fiber morphology of its fibers. We suggest that future research can use vascular elements and percentages of parenchymatic tissue or other anatomical values that help to better explain these variations in density in the radial direction. Additionally, relate the biomass of wood and the biomechanics of these species since density and fibers are directly related.

## AUTHORSHIP CONTRIBUTION

Project Idea: LAPC, EAGP, GPT, MTF

Funding: LAPC, EAGP, GPT, MTF

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Processing: LAPC, EAGP, GPT, MTF

Analysis: LAPC, EAGP, GPT, MTF

Writing: LAPC, EAGP, GPT, MTF

Review: LAPC, EAGP, GPT, MTF

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