Rev. Inst. Flor. v. 33 n. 1 p. 7-16 jun. 2021
http://dx.doi.org/10.24278/2178-5031.202133101
ISSN impresso 0103-2674/*on-line* 2178-5031

ANATOMICAL RADIAL VARIATION AND DENSITY IN WOOD OF RUBBER TREE [*Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg.] CLONES[1]

VARIAÇÃO RADIAL DA ANATOMIA E DENSIDADE DA MADEIRA EM CLONES DE SERINGUEIRA [*Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg.]

Erick Phelipe AMORIM[2,8]; Rubens Francisco Pereira de FARIA[3]; Miguel Luiz Menezes FREITAS[4]; Marcela Aparecida de MORAES[5]; José CAMBUIM[6]; Mario Luiz Teixeira de MORAES[6]; Paulo de Souza GONÇALVES[7]; Eduardo Luiz LONGUI[4,8]

ABSTRACT - The anatomical structure and physical properties of wood change significantly among trees of the same species and even among different parts of the same tree. However, studies that characterize radial variation of anatomical characteristics and wood density among clones are scarce, specifically for the rubber tree [*Hevea brasiliensis* (Will. ex Adr. De Juss.) Muell]. Thus, the objective of the research was evaluating the anatomical radial variation and density in wood of *Hevea brasiliensis* clones. For this study, 30 trees, three of each progeny from 10 clones were used. For most clones, we noticed an increase in fiber length and vessel diameter towards the bark. For vessel frequency, ray height, width and frequency, we observed a decrease towards the bark. Fiber wall thickness was the most distinctive anatomical characteristic, compared to the others, presenting a trend of thicker walls in the middle position, consequently influencing basic density clones.

Keywords: Anatomical elements; Wood anatomy; Wood quality.

RESUMO - A estrutura anatômica e as propriedades físicas da madeira variam significativamente entre árvores da mesma espécie e até mesmo entre diferentes partes da mesma árvore. Entretanto, estudos que caracterizam as características anatômicas e a variação radial da densidade da madeira entre os clones são escassos, especificamente para a seringueira [*Hevea brasiliensis* (Will. ex Adr. De Juss.) Muell]. Assim, o objetivo da pesquisa foi avaliar a variação anatômica radial e densidade em madeira de clones de *Hevea brasiliensis*. Para este estudo, foram utilizadas 30 árvores, três de cada progênie de 10 clones. Para a maioria dos clones, notamos um aumento no comprimento da fibra e diâmetro do vaso em direção à casca. Para maioria dos clones notou-se aumento do comprimento de fibra e diâmetro do vaso em direção a casca. Para frequência de vaso, altura, largura e frequência de raios foi notado diminuição da medula para casca. A espessura da parede da fibra foi a característica anatômica mais distinta das demais apresentando padrão tendência de maiores espessuras na região intermediária consequentemente influenciando na densidade básica dos clones.

Palavras-chave: Elementos anatômicos; Anatomia da madeira; Qualidade da madeira.

______

[1]Recebido para análise em 25.05.2020. Aceito para publicação em 29.12.2020.
[2]Programa de Pós-Graduação em Planejamento e Uso de Recursos Renováveis – Departamento de Ciências Ambientais, Universidade Federal de São Carlos, Rod. João Leme dos Santos, 18052-780, Sorocaba, SP, Brazil.
[3]Bacharelando em Engenharia Florestal, Universidade Federal de São Carlos, Rod. João Leme dos Santos, SP-264, 18052-780, Sorocaba, SP, Brazil.
[4]Instituto Florestal, Rua do Horto 931, 02377-000, São Paulo, SP, Brazil.
[5]Faculdade de Ciências Agronômicas, Universidade Estadual Paulista – UNESP, Avenida Universitária, 3780, 18610-034, Botucatu, SP, Brazil.
[6]Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista – UNESP, Campus de Ilha Solteira, SP, Brazil.
[7]Instituto Agronômico de Campinas - IAC, Av. Barão de Itapura, 1481, 13075-630, Campinas, SP, Brazil.
[8]Corresponding authors: Erick Phelipe Amorim- erick.amorim95@hotmail.com; Eduardo Luiz Longui- edulongui@gmail.com

1 INTRODUCTION

Wood anatomical characteristics provide a structural basis for other wood properties, which are often used to assess wood quality. Wood anatomy is closely related to internal and external factors that affect tree growth, such as genetic material, cambium age and silvicultural practices (Zhang et al., 2020).

Accordingly, studies confirm that vessel diameter, vessel density, fiber length, fiber diameter, and cell wall thickness, all these characteristics change in radial and longitudinal directions (Zhao, 2015). In the radial direction, xylem growth is produced by cambium and can be divided into juvenile and adult wood (Zhang et al., 2020).

Studies report that the age of transition from juvenile to adult wood varies considerably among trees of different genetic materials and can be strongly influenced by seed origin, local environmental conditions, and external genetic factors, consequently interfering with anatomical structure (Liu et al., 2020). Understanding anatomical characteristics and basic density in the radial direction is important to assess wood quality and its potential uses (Détienne and Vernay, 2011). In addition, knowledge of wood variation is necessary to improving traits of interest in the trees (Nirsatmanto et al., 2017). Finally, wood arrangement, such as vessel diameter, fiber thickness, and length, defines wood density, and these features are also functionally interrelated (Traore et al., 2018).

The rubber tree [*Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg (Euphorbiaceae)] occurs naturally in the Brazilian Amazon and in neighboring countries. It has been grown in tropical areas with the aim of extracting latex for rubber manufacture. Recently, clones have been developed, aiming at the production of latex and wood (Parra-Serrano et al., 2018).

Hevea brasiliensis is an important forest species because its main output is latex, enabling the fabrication of several synthetic products for industrial use. However, when rubber trees no longer reach acceptable levels of latex production, which varies between 25 and 30 years of age (Lima et al., 2020), their exploitation for latex becomes economically unfeasible.

However, the availability of rubber trees after the latex exploration cycle has driven the success of the timber industry in Malaysia and Thailand in recent years (Ratnasingam et al., 2012). The species has established itself as one of the main woods for furniture production and internal building components in Asia (Eufrade-Junior et al., 2015). Wood can also be used in the manufacture of wood panels, particleboards, fiber cement panels, and Medium Density Fiberboards - MDF (Teoh et al., 2011).

Analyzing wood potential from 10 clones of *H. brasiliensis* for bioenergy in comparison with *Eucalyptus pellita* and *Eucalyptus tereticornis*, Menucelli et al. (2019) demonstrated the superior technological characteristics of *H. brasiliensis* clones to be used for this purpose.

Since 1995, the Brazilian State of São Paulo has established itself as the main rubber producer, representing half of the country's production (Gonçalves et al., 2001). The planted area in Brazil has been increasing significantly, from 159,500 ha to 218,307 ha in 2018 alone (Indústria Brasileira de Árvore – IBÁ, 2019).

Some studies report the anatomy, density, and other properties of rubber tree wood (Menucelli et al., 2019). However, further studies are needed to assess the industrial use of the wood, and in these cases, it is essential to know the anatomical structure from pith to bark, as well as how this potential variation influences wood mechanical resistance, drying, adhesion and workability. Thus, the objective of the research was evaluating the anatomical radial variation and density in wood of *Hevea brasiliensis* clones.

2 MATERIAL AND METHODS

2.1 Location and sampling

Wood samples (discs) of rubber tree were collected from 30 trees, three of each progeny from 10 clones (Table1). The trial was established in the experimental area of the University of São Paulo (UNESP), municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W and 350 m of sea level). The studied clones were as follows: IAC 40, IAC 41, IAC 326, IAC 311, IAC 301, IAN 873, GT1, PB 330, Fx 2261, and RRIM 725. The soil in the experimental area was classified as Red Latosol, a clayey texture (Santos et al., 2018). The origin of the genetic material of the studied clones is reported in Table 1.

Table 1. Parental clones of the 10 clones used for the study of wood anatomy and density.

Tabela 1. Clones parentais dos 10 clones utilizados para o estudo de anatomia e densidade da madeira.

Progenies	**Material genetics**	**Source**
IAC 40 ill.	[RRIM 608 (AVROS 33 x Tjir 1) x AVROS 1279 (AVROS 256 x AVROS 374)]ill.	Brazil
IAC 41 ill.	[RRIM 608 (AVROS 33 x Tjir 1) x AVROS 1279 (AVROS 256 x AVROS 374)]ill.	Brazil
IAC 326 ill.	[RRIM 623(PB 49 x Pil B 84) x Fx 25(F 351 x AVROS 49)]ill.	Brazil
IAC 311 ill.	[AVROS 509 (Pil A 44x Lun N) x Fx 25(F 351 x AVROS 49)]ill.	Brazil
IAC 301 ill.	[RRIM 605 (Tjir 1x PB 49) x AVROS 1518 (AVROS 214 x AVROS 256) ill.	Brazil
IAN 873 ill.	PB 86 x FB 1717	Brazil
GT1 ill.	Primary clone	Indonesia
PB 330 ill.	[PB 5151 (PB 56 x PB 24) x PB 32/36(PB 49x PB 186)] ill.	Malaysia
Fx 2261 ill.	(F 1619 x AVROS 183) ill.	Brazil
RRIM 725ill.	Fx 25 (F351 x AVROS 49) ill.	Brazil

IAC = Institute Agronomic of Campinas (Brazil); IAN = Institute Agronomic of North (Brazil); GT = Gondang Tapen (Indonesia); PB = Prang Besar (Malaysia); Fx = Ford Company (Brazil); RRIM = Rubber Research Institute (Malaysia); ill = illegitimate.

IAC = Instituto Agronômico de Campinas (Brasil); IAN = Instituto Agronômico do Norte (Brasil); GT = Gondang Tapen (Indonésia); PB = Prang Besar (Malásia); Fx = Companhia Ford (Brasil); RRIM = Instituto de Pesquisa da Borracha (Malásia); ill = ilegítimo.

The discs were removed at a height of 1.30 m from the tree, and their dimensions were adjusted up to 20 cm in thickness. With a graduated ruler in mm, disc total length was measured, and then each region was marked as pith, middle and bark (wood near the bark). Figure 1 represents tree demarcation for the study of radial variation.

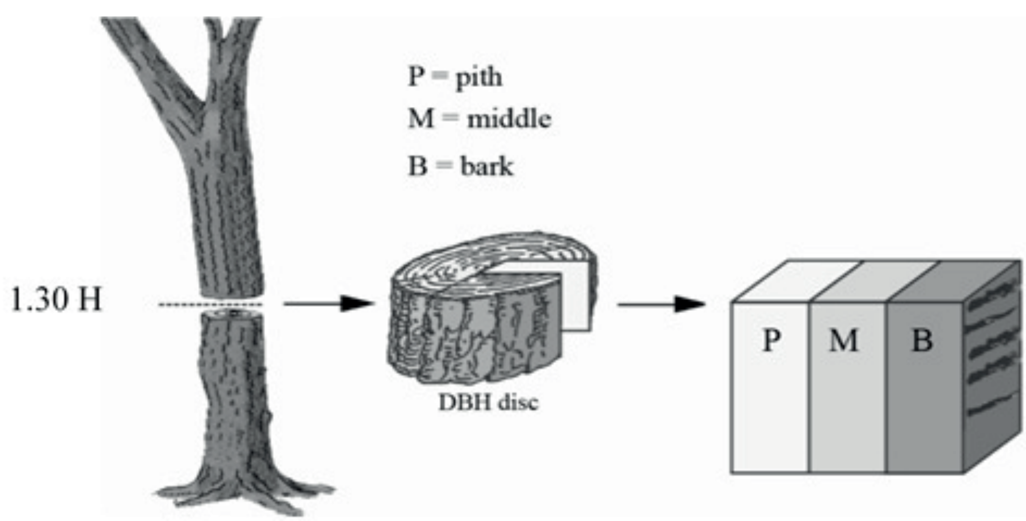

Figure 1. Schematic representation of wood sample collection.

Figura 1. Representação esquemática da coleta de amostras de madeira.

2.2 Radial variation of wood anatomy

One part of wooden discs was transformed into small samples of 1x1x1 cm and were macerated according to the methodology described by Franklin (1945). Macerated samples were stained with aqueous safranin and temporarily mounted in water and glycerin solution (1:1). Other samples (1.0 cm3) were softened in boiling water and glycerin (4:1) for 1-2 hours. From these samples, cuts 20-25 µm thick were obtained with a sliding microtome in the transverse and tangential longitudinal directions. Sections were bleached with sodium hypochlorite (60%), washed thoroughly in water, and stained with 1% safranin (Johansen, 1940). The blades were assembled according to the International Association of Wood Anatomists – IAWA Committee (IAWA, 1989).

Quantitative data were based on at least 25 measurements for each characteristic from each tree, thus fulfilling statistical requirements for the minimum number of measurements. The quantitative anatomical characters studied were Fiber Length – FL; Fiber Wall Thickness – FWT; Vessel Diameter – VD; Vessel Frequency – VF; Ray Height – RH; Ray Width – RW and Ray Frequency – RF.

2.3 Radial variation of basic density

The density of the wood was determined by the relationship between dry mass and saturated volume. The samples (5 x 3 x 2 cm) were immersed in water and were considered saturated when they presented constant mass for 5 days. Subsequently, the specimens were dried in an oven at 103 ± 2°C to obtain the dry mass for 3 days.

The saturated volume was obtained by the hydrostatic balance method. This technique consists of weighing the saturated samples by means of scales. Wood density was calculated by determining the relationship between dry mass and saturated volume in accordance with the Brazilian standard - NBR 11941, Brazilian Association of Technical Standards - ABNT (2003).

For data statistical analysis, was performed a parametric analysis of variance (One-way Analysis of Variance). When a normal distribution of data was not observed, data were transformed (i.e., square root). In the case of a significant difference, Tukey's test was applied to identify pairwise determinants of differences. Only results with $p < 0.01$ were considered significant.

3 RESULTS

In the radial direction, different behaviors of anatomy and wood density among *Hevea brasiliensis* clones were observed. However, it was not possible to define a clear pattern of radial variation among clones, as can be seen in Table 2.

Table 2. Radial variation of wood anatomical characteristics and wood density of ten 12-year-old rubber tree clones from a trial planted in Selvíria, Brazil.

Tabela 2. Variação radial das características anatômicas e da densidade da madeira de 10 clones de seringueira, de 12 anos de idade de um ensaio implantado em Selvíria, Brasil.

Radial position	FL µm	FWT µm	VD µm	VF (nºmm-2)	RH µm	RW µm	RF (nºmm-1)	BD (g.cm-3)
Clone IAC 40 ill.								
Pith	873b	3.9a	82b	1.8a	314a	37a	6.8b	0.393b
Middle	1005a	3.0b	92a	1.4 a	306a	41a	7.8a	0.394b
Bark	1025a	3.0b	99a	1.3a	307a	40a	7.0ab	0.415a
Mean	967CD	3.3C	91DE	1.5BCD	309DE	39D	7.2BCD	0.414B
Clone IAC 41 ill.								
Pith	821b	3.6a	104b	1.6a	425a	52a	7.7b	0.425a
Middle	939 a	4.2a	118a	1.1b	326b	42b	7.1b	0.409a
Bark	981 a	3.5a	130a	1.2ab	346b	53a	8.9a	0.407a
Mean	914D	3.7a	117 A	1.37BCD	366B	49BC	7.9AB	0.413B

to be continued
continua

continuation - Table 2
continuação - Tabela 2

Radial position	FL µm	FWT µm	VD µm	VF (nºmm-2)	RH µm	RW µm	RF (nºmm-1)	BD (g.cm-3)
Clone IAC 326 ill.								
Pith	993b	3.0a	99 a	1.4a	351a	50a	6.7a	0.460ab
Middle	1111a	3.3a	134b	1.0a	372a	52a	7.0a	0.472a
Bark	1024b	3.0a	102a	1.2a	374a	49a	7.0a	0.437b
Mean	1043AB	3.1C	112AB	1.24CDE	366B	49B	6.9DE	0.456AB
Clone IAC 311 ill.								
Pith	969b	3.0b	98a	1.4a	376b	51b	7.8a	0.447b
Middle	1003ab	2.5b	104a	0.9a	456a	59a	7.7a	0.465a
Bark	1077 a	3.7a	105a	0.9a	416ab	61a	7.3a	0.443b
Mean	1017BC	3.0C	102BC	1.08A	416A	57A	7.6BC	0.451B
Clone IAC 301 ill.								
Pith	929a	3.0a	70c	1.3b	338b	35b	10.1a	0.435b
Middle	951a	2.3b	91a	1.6b	305b	38b	8.5b	0.461a
Bark	992a	2.7ab	79b	2.3a	407a	48a	6.6c	0.408b
Mean	957D	2.6D	80EF	1.77AB	350BC	40D	8.4A	0.435B
Clone IAN 873 ill.								
Pith	1179 a	4.2a	109a	2.2a	393a	52a	5.0a	0.451a
Middle	961b	3.8a	82b	2.1a	341b	44b	4.8a	0.404a
Bark	1165a	4.3a	92b	1.9a	361ab	48ab	4.6a	0.419a
Mean	1102A	4.1AB	94CD	2.13A	365B	48BC	4.8H	0.426B
Clone GT1 ill.								
Pith	844b	3.9a	64c	2.5a	302b	38b	6.4a	0.459a
Middle	915b	2.7b	81b	1.4b	320b	37b	5.3b	0.414b
Bark	1139a	3.7a	99 a	1.0b	454a	50a	6.0a	0.433a
Mean	966CD	3.4C	82DEF	1.66BC	358B	41D	5.9FGH	0.433B
Clone PB 330 ill.								
Pith	934b	3.5a	111b	1.2a	343a	44b	7.8b	0.336c
Middle	936b	3.6a	100b	1.1a	285b	43b	7.2a	0.432b
Bark	1115a	3.2a	127 a	0.8a	333a	52a	4.8a	0.447a
Mean	995BC	3.4C	113 A	1.10E	320CDE	46C	6.4EF	0.405B
Clone Fx 2261 ill.								
Pith	1024a	3.8a	85b	0.8b	335a	42a	8.1a	0.433b
Middle	1045a	3.3ab	97ab	1.2ab	361a	41a	7.2b	0.493a
Bark	1051a	3.2b	101 a	1.4a	370a	44a	6.3c	0.426b
Mean	1040AB	3.4C	95CD	1.15DE	342BCD	42D	7.2CD	0.471B

to be continued
continua

continuation - Table 2
continuação - Tabela 2

Clone RRIM 725 ill.								
Radial position	**FL µm**	**FWT µm**	**VD µm**	**VF (nºmm-2)**	**RH µm**	**RW µm**	**RF (nºmm-1)**	**BD (g.cm-3)**
Pith	925b	3.7a	97b	2.2a	336a	51a	6.5a	0.487b
Middle	874b	3.3a	83c	1.3b	265b	49a	6.3a	0.451b
Bark	1069a	3.8a	112 a	1.4b	294ab	49a	5.2b	0.531a
Mean	956CD	3.6BC	98CD	1.67BC	300E	50BC	6.0G	0.491A
General Mean	**995**	**3.4**	**98**	**1.43**	**350**	**46**	**6.9**	**0.436**

FL= Fiber Length; FWT = Fiber Wall Thickness; VD = Vessel Diameter; VF = Vessel Frequency; RH = Ray Height; RW = Ray Width; RF = Ray Frequency; BD = Basic Density and ill = illegitimate. Distinct letters in columns differ statistically ($p<0.01$) by Tukey's test. Difference among radial positions is represented by lowercase letters, while the comparison among clones is represented by uppercase letters.

FL = Comprimento da Fibra; FWT = Espessura da Parede da Fibra; VD = Diâmetro do Vaso; VF = Frequência do Vaso; RH = Altura do Raio; RW = Largura do Raio; RF = Frequência do Raio; BD = Densidade Básica. ill = ilegítimo. Letras distintas nas colunas diferem estatisticamente ($p <0,01$) pelo teste de Tukey. A diferença entre as posições radiais é representada por letras minúsculas, enquanto a comparação entre os clones é representada por letras maiúsculas.

Hevea brasiliensis has axial parenchyma in marginal bands forming a reticulate pattern with rays. Also in fine bands, apotracheal parenchyma diffuse-in-aggregates.

For multiseriate rays, no contrast was observed (Fig. 2A). They are thin (<100 µm) with low frequency of 4-12 cells.mm^{-1}. Rays are composed of two or more cell types (heterocellular) with square and upright cells in marginal rows. Storied structure is absent (Fig. 2B). Figure 2C, shows the detail of a fiber with medium wall thickness.

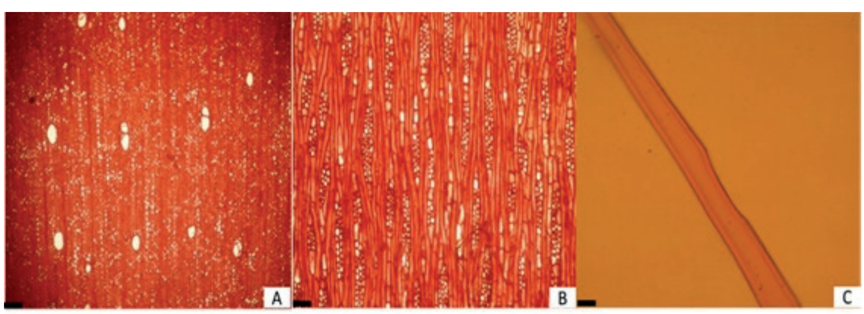

Figure 2. Wood sections of rubber tree from clone IAC 40. A: Transverse section. Scale bar = 250 µm. B: Tangential section. Scale bar = 50 µm. C: Detail of a fiber, which can be seen on medium-thickness walls. Scale bar = 50 µm.

Figura 2. Secções da madeira de seringueira do clone IAC 40. A: Secção transversal. Barra de escala = 250 µm. B: Secção tangencial. Barra de escala = 50 µm. C: Detalhe de uma fibra, na qual pode ser vista paredes de espessura média. Barra de escala = 50 µm.

4 DISCUSSION

An increase in fiber length was observed radially, except for clone IAC 326, in which the middle position had longer fibers and was different from the other positions. Rungwattana and Hietz (2017) mention for some species a transition from juvenile to adult wood may be abrupt, while in others, it may be gradual, or not present a distinct pattern of anatomical characteristics, as noted for the clones in this study.

In the present study, fiber wall thickness showed different radial patterns. Progenies from clones IAC 40, IAC 41, IAC 301, PB 330, and Fx 2261 showed a decrease in the pith-bark direction.

In contrast, progenies of clones GT1, IAC 311, and RRIM 725 showed an increase. Clones IAC 326 and IAN 873 showed no differences in radial positions.

Salvo et al. (2017) observed an increase in fiber wall thickness for *Eucalyptus* species. However, they reported an increase in fiber wall thickness towards the bark in some forest species, and they also reported that such increase occurs from 8 to 15 years of age. The trees we studied are 12 years old. Thus, according to Salvo et al. (2017), these clones would be in this transition phase. So maybe we found this variation among rubber trees clones.

In 25-year-old *Hevea brasiliensis* cultivated in Malaysia, Teoh et al. (2011) reported *Hevea brasiliensis* fiber wall thickness of 5 to 7 µm. These values are higher than in this study, which ranged from 2.3 µm in the intermediate position of clone IAC 301 to 4.3 µm in the bark position of clone IAN 873.

Vessel diameter followed a typical pattern, i.e., an increase in diameter towards the bark (Longui et al., 2014). In the present study, this pattern occurred in most rubber tree clone progenies. Although the pattern is quite common, vessel diameter can change among progenies.

In a study with Malaysian clones of RRIM 2020 and RRIM 2025, at nine years of age, Naji et al. (2012) reported values from 127 to 208 µm from pith to bark. This same pattern was observed by Florsheim et al. (2009) in *Eucalyptus dunii* Miaden and in two native Brazilian species, *Luehea divaricata* Mart. & Zucc. (Longui et al., 2009) and *Cariniana legalis* Mart. Kuntze. (Lima et al., 2011). According to Norul and Hamami (2008), a decrease in vessel frequency towards to the bark is expected. However, we noted another radial variation pattern.

A decrease towards the bark was noted for the progenies of clones IAC 41, GT1, PB330 and RRIM 725. However, clones IAC 301 and Fx 2261 showed an increase in pith for the bark. The progenies of clones IAC 40, IAC 311, IAN 873, IAC 326 and RRIM 725 presented less frequency in bark position, but without statistical differences from the intermediate position.

A possible explanation for different patterns in vessel frequency may be related to the growth rate of trees based on genetic material from different origins (Downes and Drew, 2008). Based on this knowledge, it is possible to estimate variations in wood density and, consequently, in technological behavior, e.g., the drying rate of the wood (Zanuncio et al., 2016).

When we analyzed the mean values of each clone for diameter and frequency of vessels, we observed some differences, which may be linked to genetics, since they are different clones. This phenomenon could also be explained by the polar movement of Auxinic hormones (Indolatic Acid – AIA) produced in young leaves. Since AIA flows into the wood, higher hormonal concentrations increase cell expansion, while low levels stimulate cell differentiation, allowing more time for cell development until the deposition of the secondary wall, resulting in wider vessels, and, possibly, less frequency in a specific region of the trunk (Aloni, 2007).

Radial variation of ray is less studied for commercial purposes, and the patterns are not evident compared to those of vessels and fibers. According to Florsheim et al. (2000), in a study with *E. saligna*, rays tend to become taller and wider with lower frequencies towards the bark. Melo et al. (2016) also observed a decrease in ray value in the pith-bark direction in *Corymbia citriodora*. In the present study, ray frequency increased from pith to bark in most clones, except PB 330, IAC 41, and IAC 326. The ray width also increased towards the bark.

Differences in radial patterns in height, width and frequency of rays are related to their functions. These anatomical elements are responsible for storage and lateral transport of nutritive substances, and they can be modulated by environmental conditions (Melo-Junior et al., 2016). Alternately, variation in the size of initial ray cells can change as the tree grows older. These initial cells can directly interfere with ray cell size and, consequently, with the height and width of rays (Urbinati et al., 2003). For most forest species, Bhat and Priya (2004) state that bulkier rays in lesser quantities are expected close to the bark.

In this study was observed radial variation of basic density in most clones, except for IAC 41 and IAN 873. In some progenies, we noticed a higher density in the middle position, an uncommon result for most forest species. Zaque et al. (2018) observed an increase in wood basic density from pith to the bark. The authors reported that this is the expected behavior for most species in view of the fact that layers closer to the bark have more rigid walls and, consequently, higher densities. Naji et al. (2011), analyzing the radial variation of the basic density of clones of *Hevea brasiliensis*, reported the same pattern as that observed in the present study for most clones, i.e., increasing from pith to bark.

To *Cariniana legalis*, Lima et al. (2011) reported a decrease in density from pith to bark. This indicates a different pattern in native trees or that the results we found in rubber trees may be related to the young age of trees, suggestive of a pattern that would change over time. To two species of African mahogany, França et al. (2015) stated it is expected that wood present a positive relationship between basic density and fiber length and fiber wall thickness, which was not observed for most of the clones in this study.

In progeny RRIM 725, we observed higher wood density and shorter fiber compared to other clones. However, we observed that progenies with lower wood density have higher ray frequency, which can contribute to a decrease in density since ray cells have a thinner wall compared with fibers and should, therefore, contribute less to wood mass and, consequently, density.

5 CONCLUSIONS

In general, wood of rubber tree clones was characterized radially (pith-bark), and we found increased fiber length and decreased fiber wall thickness. Most clones presented an increase in vessel diameter and a decrease in vessel frequency.

Ray dimensions and frequency showed different behaviors, however, for most clones there is an increase in height and width and decrease in frequency. It was possible to observe ray stabilization close to the bark, seemed to be a characteristic of young wood. Basic density presented different patterns among clones, with increase towards to the bark or higher density in the middle position.

6 ACKNOWLEDGEMENTS

This study was financed, in part, by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, Brazil, Finance-Code 001. The authors thank Sônia Regina Campião and Juraci Andrade Barbosa (Instituto Florestal de São Paulo - IFSP) for laboratory support. Researchers Eduardo L. Longui (Instituto Florestal de São Paulo - IFSP), Mario L.T. Moraes (Universidade Estadual Paulista - UNESP, *Campus* de Ilha Solteira, SP), Miguel L.M. Freitas (Instituto Florestal de São Paulo – IFSP) and Paulo S. Gonçalves (Instituto Agronômico de Campinas – IAC) were supported by a research scholarship from the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, Brazil.

REFERENCES

ALONI, R. Phytohormonal mechanisms that control wood quality formation in young and mature trees. In: THE COMPROMISED WOOD WORKSHOP, 2007, Christchurch: The Wood Technology Research Centre - University of Canterbury, 2007. p. 1-22.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT. **Norma NBR 11941:** determinação da densidade básica. Rio de Janeiro, 2003. v. 1, 6 p.

BERLYN, G. P.; MIKSCHE, J.P. **Botanical microtechnique and cytochemistry**. Arnes: The Iowa State University Press, 1976. v. 1, 326 p.

BHAT, K.M.; PRIYA. P.B. Influence of provenance variation on wood properties of teak from the Western Ghat region in India. **IAWA Journal**, v. 25, n. 3, p. 273-282, 2004.

DÉTIENNE, P.; VERNAY, M. Les espèces du genre *Tabebuia* susceptibles de fournir le bois d'ipé. (Species of the genus *Tabebuia* likely to provide ipe wood). **Bois et Forêts des Tropiques**, v. 307, n. 1, p. 69-77, 2011.

DOWNES, G.M.; DREW, D.M. Climate, and growth influences on wood formation and utilization. **Southern Forests**, v. 70, n. 2, p. 155-167, 2008.

EUFRADE-JUNIOR, H.J. et al. Potential of Rubberwood (*Hevea brasiliensis*) for structural use after the period of latex exploration: a case study in Brazil. **Journal of Wood Science**, v. 61, p. 384-390, 2015.

FLORSHEIM, S.M.B. et al. Variação da estrutura anatômica da madeira de *Eucalyptus saligna* aos sete anos. **Revista do Instituto Florestal**, v. 12, n. 2, p. 170-191, 2000.

______. Variações nas dimensões dos elementos anatômicos da madeira de *Eucalyptus dunnii* aos sete anos de idade. **Revista do Instituto Florestal**, v. 21, n. 1, p. 79-91, 2009.

FRANÇA, T.S.F.A. et al. Características anatômicas e propriedades físico-mecânicas das madeiras de duas espécies de mogno africano. **Cerne**, v. 21, n. 4, p. 633-640, 2015.

FRANKLIN, G.L. Preparation of thin sectons of synthetic resins and wood: resin composites and a new macerating method for wood. **Nature**, v. 155, n. 3924, p. 51-55, 1945.

GONÇALVES, P.D.S. et al. **Manual de Heveicultura para o estado de São Paulo**. Campinas: Instituto Agronômico de Campinas, 2001. v. 189, 78 p.

INDÚSTRIA BRASILEIRA DE ÁRVORES – IBÁ. **Anuário estatístico da IBA:** ano base 2019, 2020. Disponível em: <https://iba.org/datafiles/publicacoes/relatorios/iba-relatorioanual2019.pdf>. Acesso: 27 out. 2020.

INTERNATIONAL ASSOCIATION OF WOOD ANATOMIST – IAWA. List of Microscopic features for hardwood identification. **IAWA Bulletin**, v. 10, n. 3, p. 221-332, 1989.

JOHANSEN, D.A. **Plant microtechnique**. New York: McGraw-Hill Book, 1940, v. 1, 523 p.

LIMA, I.L. et al. Variação radial da densidade básicas e dimensões celulares da madeira de *Cariniana legalis* (Mart.) O.Kutze em função da procedência. **Cerne**, v. 17, n. 4.p. 517-524, 2011.

______. Caracterização das propriedades mecânicas da madeira de clones de *Hevea brasiliensis* (Will. ex.Adri). **Scientia forestalis**, v. 48, n. 125, p. 1-12, 2020.

LIU, Y. et al. Anatomical features, and its radial variations among different Catalpa bungee clones. **Forests**, v. 11, n. 824, p. 1-17, 2020.

LONGUI, E.L. et al. Variação anatômica radial do lenho de açoita cavalo (*Luehea divaricata*) e sua influência na densidade aparente. **Revista do Instituto Florestal**, v. 21, n. 2, p.181-190, 2009.

______. Radial variation of wood anatomy and basic density of *Anadenanthera colubrina* (Vell.) Brenan. **Revista do Instituto Florestal**, v. 26, n. 2, p. 193-201, 2014.

MELO-JUNIOR, J.C.F.; SILVA, M.M.; SOFFIATTI, P. Anatomia ecológica da madeira de *Rudgea viburnoides* (Cham.) Benth. em campo cerrado e rupestre. **Balduinia**, v. 2, n. 54, p. 22-31, 2016.

MELO, L.E.L. et al. Influence of genetic material and radial position on the anatomical structure and basic density of wood from *Eucalyptus* spp. and *Corymbia citriodora*. **Scientia Forestalis**, v. 44, n. 111, p. 611-621, 2016.

MENUCELLI, J.R. et al. Potential of *Hevea brasiliensis* clones, *Eucalyptus pellita* and *Eucalyptus tereticornis* wood as raw materials for bioenergy based on higher heating value. **Bioenergy Research**, v. 12, n. 1, p. 1-8, 2019.

NAJI, H.R. et al. The effect of growth rate on wood density and anatomical characteristics of Rubberwood (*Hevea brasiliensis* Muell. Arg.) in two different clonal trails. Journal Natural Products. **Plants Resources**, v. 1, n. 2, p. 71-80, 2011.

______. Clonal and planting density effects on some properties of rubber wood (*Hevea brasiliensis* Muell. Arg.). **BioResources**, v. 7, n. 1, p. 189-202, 2012.

NIRSATMANTO, A. et al. Wood anatomical structures of tropical acacias and its implication to tree breeding. **International Journal Forest Horticulture**, v. 3, n. 3, p. 9-16, 2017.

NORUL IZANI, M.A.; HAMAMI, M.H. Wood and cellular properties of four new *Hevea brasiliensis* species. In: FORTROP III INTERNATIONAL CONFERENCE, 1., 2008, Bangkok. **Anais…** Thailand, 2008. v. 1, p. 17-20.

PARRA-SERRANO, L.J. et al. Uso de madeira de borracha de *Hevea brasiliensis* para produção de feixe de Glulam. **Floresta e Ambiente**, v. 25, n. 2, p. 1-7, 2018.

RATNASINGAM, J. et al. Production potential of rubberwood in Malaysia: its economic challenges. **Notulae Botanicae Horti Agrobotanici Cluj-Napoca**, v. 40, n. 2, p. 317-322, 2012.

RUNGWATANNA, K.; HIETZ, P. Radial variation of wood functional traits reflect size-related adaptations of tree mechanics and hydraulics. **Funcional Ecology**, v. 32, p. 260-272, 2017.

SALVO, L. et al. Radial variation of density and anatomical features of *Eucalyptus nitens* trees. **Wood and Fiber Science**, v. 39, n. 2, p. 301-311, 2017.

SANTOS, H.D. et al. **Sistema brasileiro de classificação de solos**. Brasília: Embrapa - Solos, 2018. v. 1, 306 p.

TEOH, P.Y.; DON, M.M.; UJANG, S. Assessment of the properties, utilization, and preservation of rubberwood (*Hevea brasiliensis*): a case study in Malaysia. **Journal Wood Science**, v. 57, p. 255-266, 2011.

TRAORÉ, M.; KAAL, J.; CORTIZAS, A.M. Differentiation between pine woods according to species and growing location using FTIR-ATR. **Wood Science and Technology**, v. 52, p. 487-504, 2018.

URBINATI, C.V. et al. Variação estrutural quantitativa no lenho de *Terminalia ivorensis* A. Chev. Combretaceae. **Acta Botânica Brasileira**, v. 17, n. 3, p. 421-437, 2003.

ZANUNCIO, A.J.V. et al. Relationship between the anatomy and drying in *Eucalyptus grandis* X *Eucalyptus urophylla* wood. **Revista Árvore**, v. 40, n. 4, p. 723-729, 2016.

ZAQUE, L.A.M. et al. Variação radial e longitudinal da massa específica básica da madeira de *Araucaria angustifolia* com diferentes idades. **Pesquisa Florestal Brasileira**, v. 38, n. 1 p. 1-5, 2018.

ZHANG, S. et al. Wood anatomy of boreal species in a warning world: A review. **iForest**, v. 13, n. 2, p. 130-138, 2020.

ZHAO, X. Effects of cambial age and flow path-length on vessel characteristics in birch. **Journal Forest Research**, v. 20, n. 1, p. 175-185, 2015.