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TECHNOLOGICAL POTENTIAL OF *Hevea brasiliensis* CLONES FOR ENERGY USES AND FURNITURE

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TECHNOLOGICAL POTENTIAL OF *Hevea brasiliensis* CLONES FOR ENERGY AND FURNITURE USES

Dissertação apresentada ao Programa de Pós-Graduação em Planejamento de Usos dos Recursos Renováveis para obtenção do título de Mestre em Planejamento e Uso de Recursos Renováveis

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Orientador: Drº Eduardo Luiz Longui

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Em mentes quadradas, ideias não circulam!

(Beatriz Amaral)

RESUMO

AMORIM, Erick Phelipe. Potencial tecnológico de clones de *Hevea brasiliensis* para usos energéticos e móveis. 2020. 90f. Dissertação (Mestrado em “Planejamento e Uso dos Recursos Renováveis”) - CCTS Centro de Ciências e Tecnologias para a Sustentabilidade, Universidade Federal de São Carlos, Sorocaba, 2020.

Hevea brasiliensis é uma importante espécie florestal brasileira, pois tem como principal produto o látex, responsável por originar vários produtos sintéticos para diferentes usos. O estado de São Paulo é o líder de plantios da espécie, representando 56% de áreas plantadas. Essa liderança é devido as pesquisas do IAC- Instituto Agronômico de Campinas, que vem buscando desenvolver clones com dupla aptidão para produção de látex e madeira. O ciclo de extração do látex de um seringal varia de 25 a 30 anos, em seguida é realizado o replantio e a madeira é destinada para uso de menor valor agregado, geralmente usos domésticos, havendo poucos estudos que abordem suas características tecnológicas. Diante do exposto, os objetivos do trabalho foram caracterizar as propriedades tecnológicas de 10 clones aos 12 anos de idade: IAC 40, IAC 41, 64B 850, IAC 311, IAC 301, IAN 873, GT1, PB 330 e FX 2261 para potencial usos energéticos, produção de móveis, caracterização do arranjo anatômico e densidade básica no sentido medula-casca. O trabalho foi dividido em quatro capítulos. O primeiro traz uma introdução geral sobre os aspectos da espécie. O segundo capítulo caracteriza a madeira para uso energético por meio da determinação das características químicas, energéticas, densidade básica, dimensões das fibras, caracterização do perfil termogravimétrico (TGA) e espectroscopia do Infravermelho Próximo (FTIR). O terceiro capítulo aborda a densidade básica, retratibilidade, compressão paralela às fibras, flexão estática e usinagem da madeira visando a produção de móveis. O quarto capítulo caracteriza a anatomia e a densidade básica da madeira no sentido da medula-casca, visto que há poucos trabalhos que relatem essas propriedades e sua variação na madeira dos clones cultivados no país. Os resultados mostram que os clones apresentam características satisfatórias para a usos bioenergéticos sendo observadas características superiores para o clone IAC 311, semelhantes a outros clones. Entretanto, os clones IAC 301 e FX 2261, apresentaram características inferiores como fonte energética. Os clones foram classificados por apresentar baixa densidade, média estabilidade dimensional e valores satisfatórios de módulo de elasticidade e ruptura. Na análise da superfície por meio dos testes de usinagem, a madeira foi classificada de boa a excelente, apresentando levantamento leve de grã, baixa porcentagem de rachadura e arrepiamento leve da grã na superfície. Foram observadas características físicas e mecânicas superiores para os clones 64B 850 e GT1 para movelaria. Contudo, os outros clones apresentam caracteristicas similares podendo ser utilizados para a produção de móveis o que agregaria valor a madeira. Observou-se, arranjos anatômicos distintos entre os clones. A maioria dos clones são caracterizados radialmente por apresentarem aumento do comprimento de fibra e diminuição da espessura da parede das fibras, aumento no diâmetro de vaso e diminuição da frequência da medula para a casca. As dimensões e frequência dos raios mostraram comportamentos diferentes, no entanto, para a maioria dos clones, há um aumento na altura e largura e uma diminuição na frequência da medula para a casca. A densidade básica apresentou diferentes padrões entre os clones, foi observado para a maioria dos clones maiores densidades nas posições intermédiarias.

Palavras chaves: Qualidade da madeira, Caracterização tecnológica, Propriedades da madeira.

ABSTRACT

AMORIM, Erick Phelipe. Technological potential of Hevea brasiliensis clones for energy and furniture uses. 2020. 90f. Dissertation (Master in “Planning and Use of Renewable Resources”) – Science and Technologies Center for Sustainability, Federal University of São Carlos, Sorocaba, 2020.

Hevea brasiliensis is an important Brazilian forest species, as its main product is latex, responsible for originating various synthetic products for different uses. The state of São Paulo is the leader of plantations of species, representing 56% of planted areas, this leadership is due to research by IAC-Instituto Agronômico de Campinas, which has been seeking to develop clones with dual aptitude for latex and wood production. The latex extraction cycle from a rubber plantation varies from 25 to 30 years, after this period there is replanting, and wood is destined for lower added value uses, generally domestic uses, with few studies addressing its technological characteristics. Based on the above, the objectives of work were to characterize technological properties of 10 clones of 12-year-old: IAC 40, IAC 41, 64B 850, IAC 311, IAC 301, IAN 873, GT1, PB 330 and FX 2261 clones for potential energy uses, furniture production, characterization of anatomical arrangement and basic density from pith-bark. The work was divided into four chapters. The first provides a general introduction to aspects of the species. The second chapter characterizes wood for energy use through chemical, energetic characteristics, basic wood density, fiber dimensions, thermogravimetric profile (TGA) and spectroscopy Infrared (FTIR). The third chapter addresses physical properties as to basic density, volumetric shrinkage and mechanical properties as to compression parallel to the grain, static flexion being obtained elasticity and rupture modules and wood machining aiming furniture production. The fourth chapter characterizes anatomy and basic density of wood from pith to thebark, since there are few studies that report these properties of clones cultivated in Brazil. The results show that clones present satisfactory characteristics for bioenergetic uses, being observed superior characteristics for clone IAC 311, being similar to other clones. However, clones IAC 301 and FX 2261, presented characteristics inferior to the others for this purpose of use. In the study of physical and mechanical properties, clones are classified as having low density, medium dimensional stability and satisfactory values of modulus of elasticity and rupture. In the analysis of surface through machining tests, wood is classified as good to excellent, presenting light grain lift, low percentage of cracking and light grain chilling on the surface. Superior physical and mechanical characteristics were observed for clones 64B 850 and GT1. However, the other clones have similar characteristics and can be used to furniture production and reduce the exploitation of native forests for this purpose and adding value to wood. In the study of the radial variation of anatomical features and basic density, distinct anatomical arrangements were observed between clones. Most of clones are radially characterized by increasing fiber length and decreasing fiber wall thickness, increasing vessel diameter and decreasing vessel frequency. The dimensions and frequency of rays showed different behaviors, however, for most clones, there is an increase in height and width and a decrease in frequency. The basic density presents different patterns between clones, higher densities in the middle positions was observed for most of clones.

Keywords: Wood quality, Technological characterization, Wood properties.

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CHAPTER 1- GENERAL INTRODUCTION

Rubberwood [*Hevea brasiliensis* (Willd. *Ex* Adr. From Juss.) Muell-Arg.], Euphorbiaceae, native from the Amazon region, is the main source of natural rubber, and a raw material of great economic importance, quality to synthetic product used. It is a species well known for producing lactated exudate, a raw material used for the manufacture of diverse products (Silva, 2019).

Although it is a native Brazilian specie, Brazil only produces about 30% of the demand for the exportation internal market of the species. Asian countries hold about three-quarters of the world's natural rubber production, being the main producers Thailand, Indonesia, Malaysia and Vietnam (Scaloppi et al. 2017).

Ferreira, Calonego and Severo (2011) report that latex exploration life cycle of species in Brazil is about 30 years depending on the frequency of planting and exploration, after extraction phase of latex, rubber tree wood is cut to reform the “seringal”. Then, wood had neglected uses, being generally used as firewood and coal although it has favorable physical, mechanical and machinability characteristics in higher added value products when compared to other species (Hashim et al. 2005; Teoh et al. 2011).

In Brazil there is no habit of using *Hevea brasiliensis* wood after latex exploratory cycle, except for energetic uses (Okino et al. 2009). However, Eufrade-Junior et al. (2015) describes good wood technological qualities for higher added-value uses.

Its wood is classified as lower quality due to its low density, clear coloration and high starch content (sugars and carbohydrates) favoring the attack of xylophages. The range of starch contents for most forest species is between 1-3% (SANTANA; EIRAS 1999), while some papers report that rubber tree species have a starch content between 7.5-10.2% (Kadir and

Sudin, 1989), 3.3-7.2% (Servolo Filho, 2013), and the most recent work quantifying the radially starch contents, Cherelli (2018), reported a content from 7.3 and 16.4%.

According to Gonçalves (2010), *H. brasiliensis* in the São Paulo state in 2015 reached 13,088 tons, being harvested in an area of 60,358 hectares and located in the northwest of state. The projections for 2039 and 2043 have a goal of more than 90,000 m³ of wood. It is a forest specie of economic importance and occurs in twelve tem 11 Brazilian states: São Paulo, Mato Grosso, Minas Gerais, Goiás, Espírito Santo, Pará, Tocantins, Mato Grosso do Sul, Paraná, Amazonas and Acre (BRAGA, 2015), with São Paulo being the largest producer, with approximately 60% of national production (Oliveira et al. 2015).

Brazil is the country with highest productivity in the forestry sector, 7.84 million planted forests, mainly composed by *Pinus* (1.6 million hectares) and *Eucalyptus* (5.7 million) that are used for energy production (IBA, 2017).

The use of rubber tree wood after latex production cycle is an alternative for reducing the exploitation of native forests and adds value to generated residue, for furniture productionand can be used for energy uses, since *Eucalyptus* are the most used for this purpose. However, studies characterizing wood technological properties between *H. brasiliensis* clones are scarce, requiring a study that addresses these characteristics to evidence potential wood use for applications with greater aggregated value.

1.2 OBJECTIVES

1.2.1 General objective

Technologically characterize 10 clones of H*evea brasiliensis* for energy and furniture use.

1.2.2 Specific objectives

Evaluated the technological characteristics of wood for bioenergy (chapter 2);

Analyze the physical and mechanical properties and wood machining for furniture production (chapter 3);

Determine wood anatomical and basic density variations, pith to the bark (chapter 4).

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CHAPTER 2- WOOD QUALITY OF 10 *HEVEA BRASILIENSIS* CLONES AS RAW MATERIALS FOR BIOENERGY

1. INTRODUCTION

Biomass recently contributes about 15% of the world energy supplies as heat, electricity and fuels for transportations and it was estimated that by 2050, up to 33-50% of the world´s current primary energy cold be met by biomass, the annual world production of biomass with potential energy application at present is considered to be approximately 7 billion tones (Demirbas, 2009).

Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg (Euphorbiaceae) is a native species, not endemic to Brazil, with geographical distribution in the northern and northeastern regions of Brazil (Cordeiro and Secco, 2015). The species in Brazil is widely used for latex exploration which is responsible for originating various synthetic products that are employed in various industry segments. Ferreira et al. (2011) points out that the life cycle for the latex exploration from *H. brasiliensis* in Brazil is 30 years. ofter this period, the wood is generally used as energy sources, however, there are few works that characterize its properties for this use.

Brazil is the country with the highest productivity in the forestry sector, totalizing 7.84 million hectares of planted forests, mainly composed by *Pinus* (1.6 million hectares) and *Eucalyptus* (5.7 million) Brazilian Tree Industry (2017). *Hevea brasiliensis*, in the state of São Paulo, reached in 2015 a total of 13,088 tons that were harvested in an area of 60,358 hectares, being most of this production located in the northwest part of the state and projections for 2039 and 2043 estimate a goal of more than 90,000 m³ (Gonçalves, 2010)

The use of *H. brasiliensis* wood after latex exploration cycle in the state of São Paulo is focused on the production of furniture, however wood residue can be used for bioenergy production, which requires studies that address its characteristics for this purpose (Eufrade-Junior, 2015).

In order to use a biomass as a bioenergetic source, it is necessary to know their anatomical, physical, chemical and energetic characteristics in order to use it for energy purposes (Santos,2019). The physical and energy properties of biomass influence the combustion process yield, specially energy properties such as calorific power, volatile materials content, fixed carbon, ash (Mckendry, 2002) and extractives, holocellulose and lignin content (Singh and Mahanta, 2017)

Thermal degradation analyses of TGA and FTIR biomass is an efficient tool for knowledge of properties related to the thermal resistance of wood and characterization of chemical components as a potential raw material for the energy production (Santos et al. 2012).

In this context, the objective of this work was to determine whether the wood of 10 clones of *Hevea brasiliensis* has potential for use in the production of bioenergy.

2.MATERIALS AND METHODS

2.1Selection of species and planting

Wood samples of 12-year-old *H. brasiliensis* were collected from 30 trees, three of each clone, in the municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W, elevation 350m). The *H. brasiliensis* plantation was established in 2006 at a spacing of 3 × 3 m from seeds of free-pollinated clones (from crossing clones of IAC 40, IAC 41, 64B-850, IAC 311, IAC 301, IAN 873, GT1, PB 330, FX 2261, and RRIM 725). Soil in the experimental area was classified as Red Latosol, a clayey texture (Santos et al. 2006).

In 2018, selected trees were felled and discs 10 cm in thickness from each tree at breast height (1.3 m from the ground) were cut. From each tree, a DBH disc (diameter at breast height – 1.30 m) was obtained and from each disc, samples close to the bark were used to determine higher heating value, chemical constituents, wood density and fiber dimensions. Mean height and DBH are shown in Table 1.

Table 2- Dendrometric data of 10 clones of 12-year-old *Hevea brasiliensis* trees.

Clone	Mean height (m)	Mean DBH (cm)
IAC 40	15.6	9.6
IAC 41	13.4	13.2
64B 850	14.6	12.1
IAC 311	17.8	14.4
IAC 301	13.8	12.6
IAN 873	16.6	14.4
GT1	15.0	11.9
PB 330	15.2	15.2
FX 2261	14.8	10.7
RRIM 725	14.5	12.0

DBH = diameter at breast height (1.3 m from the ground)

2.2 Determination of chemical and energy properties

Wood was ground in a Willey knife mill, being transformed into sawdust, then it was sieved from 40-60 mesh in order to characterize their chemical and energetic properties later.

2.2.1 Higher Heating Value

The samples were fragmented into smaller pieces witha hammer and chisel and milled in a micro mill. Higher heating value was determined after thermal rectification with dry samples. To perform the analysis, the isoperibolic method was used with an IKA C200 calorimeter, according to ASTM D5865-98.

2.2.2 Proximate analysis

Proximate analysis Prior to these analyses, the biomasses (all treatments) were dried in an oven at 100 °C. The determination of the ash content was held according to the standard ASTM D1102-84 (2007), and the volatile content, according to ASTM E872-82 (2013); both tests done in triplicates. Both standards were adapted, since all the material was used for the calculation. The fixed carbon content was calculated according to the Eq. (1):

$FCC = 100 - (AC + VC)$ (2) The variables shown in the equation represent: FCC = fixed carbon content (%); AC = ashes content (%); and VC = volatile content (%).

2.2.3 Chemical Assays

To determine extractives (EX) and lignin (LI) contents, TAPPI standards T204 (2004a) and T222 (2004b) were used, respectively. The samples were fragmented into smaller pieces with a hammer and chisel and milled in a micro mill. The resulting powder was sieved through 40 and 60 mesh screens, and the material retained on the last sieve was used for analysis. The analyses were sequential such that the extractives were first removed, then lignin by acid treatment and holocellulose content was calculated. For extractive contents, solutions of toluene:alcohol (2:1v:v)and alcohol extractions were employed, at times exceeding 12 h in a Soxhlet extractor. For lignin, extractive-free powder was prepared in several stages with 72% sulfuric acid to obtain insoluble and soluble lignin (Cary 100 UV–visible spectrophotometer). Finally, the two values of lignin were added. Insoluble lignin (IL) content was determined as IL =[(DWlig) / (DW)] × 100, where DW=dry sawdust weight, and DWlig=dry weight of insoluble lignin. Soluble lignin(SL)filtrates were analyzed and the blank were read at two wavelengths (215 nm and 280 nm) using quartz cuvettes, soluble lignin content was determined as the SL=[4.53× (L.215– blank)– (L.280– blank)/ (300× DW) × 100], where DW=dry sawdust weight. Ex and Li were expressed as a percentage (%) of oven-dry weight of unextracted wood. Then, the holocellulose (HO) content was determined as Ho= [100−(Ex + Li)]. Both tests done in triplicates for each clone of *Hevea brasiliensis.*

2.3 Basic density

Basic density was determined by ratio between dry mass (g) and saturated volume (cm³). The samples (5x3x2 cm) were immersed in water and were considered saturated when they presented constant mass during monitoring in the laboratory. Subsequently, the samples were dried in an oven at 103 ± 2°C to obtain the dry mass. The saturation volume was obtained by hydrostatic balance method. Wood basic density was calculated by relationship between dry mass and saturated volume in accordance with the Brazilian standard NBR 7190 (NBR 7190 1997) by equation, ρbas= Dm/Sv. Where, ρbas = basic density ($g.cm^{-3}$), Dm = Dry mass (g) and Sv = satured volume (cm^{-3}), 30 samples were used for each clone.

2.4 Fiber analysis

Small pieces were cut from the side of samples, and macerations were prepared according to the modified Franklin method (Berlyn and Miksche 1976), modification is due to differences in the concentration of hydrogen peroxide in solution that is higher in our study.

Macerations were stained with alcoholic safranin and mounted in a solution of water and glycerin (1:1). Fiber measurements were performed on an Olympus CX 31 microscope equipped with a camera (Olympus Evolt E330) and a computer with image analyzer software (Image-Pro 6.3). Terminology followed the IAWA list (IAWA,1989). Fiber length (FL) and fiber wall thickness (FWT) were evaluated.

2.5 Thermogravimetric analysis (TGA)

The sieved samples, using what was retained in the 30-mesh sieve. Approximately 20 mg of each clone material was heated from 0 to 700ºC, in heating scale 20ºC.min^{-1} under Nitrogen atmosphere, using a TGA 55 equipment. The degradation analysis of each thermogravimetric event of H*evea brasiliensis* clones.

2.6 Fourier Transform Infrared Spectroscopy (FTIR)

The sieved samples, using what was retained in the 30-mesh sieve. Approximately 10 mg of the material were used to read the absorbance spectra using a spectrometer Perkin Elmer model Spectrum 65 in the region from 500 to 4000 cm^{-1}, spectral resolution of 4 cm^{-1} and 32 scans.

2.7 Statistical analysis

Descriptive statistical analysis was initially performed. This was followed by performing a normality test to observe the data distribution. For the comparison among *H. brasiliensis* clones, a parametric analysis of variance (One Way Analysis of Variance) was applied. In the case of significant difference, Tukey´s test was applied to identify pairwise determinants of differences. Results with $p<0.001$ were considered as significant. All statistical analyses were performed using the SigmaPlot software - Exact Graphs and Data Analysis - version 12.3 (Systat Software Inc, San Jose, CA, USA).

3.RESULTS AND DISCUSSION

3.1Chemical and energetic properties, density basic and fibers analysis

Table 3 shows the values for the energy properties to 10 *H. brasiliensis* clones. The values of HHV ranged from 18357 kJ.kg^{-1} (IAC-301) to 19070 kJ.kg^{-1} (IAC-311), fixed carbon from 15.16% (IAC-40) to 15.72% (IAC-311), volatile material from 82.79% (IAC-311) to 83.92% (IAC-301) and ash contents from 0.42% (IAC-311) to 1.49% (IAC-301). The values oscillated between the different clones of *H. brasiliensis*, presenting different values in their energy and chemical properties.

Table 2- Comparison among 10 clones of 12-year-old *Hevea brasiliensis* by energy properties, chemicals, basic density and fiber analysis

Clones	IAC 40	IAC 41	64B 850	IAC 311	IAC 301	IAN 873	GT1	PB 330	FX 2261	RRIM 725
HHV (kJ.kg^{-1})	18895ab	18827ab	18770abc	19070 a	18357c	18729abc	18791abc	18895ab	18524bc	18867abc
CC (%)	15.16c	15.70 a	15.42bc	15.72 a	15.66ab	15.25c	15.39bc	15.61ab	15.27c	15.56ab
VMC (%)	83.75ab	83.44cd	83.39d	82.79e	83.92 a	83.67b	83.23d	83.55d	83.65bc	83.69b
AC (%)	1.08b	0.87cd	0.86cd	1.49e	0.42 a	1.08b	1.38a	1.03bc	0.74d	0.75d
EC (%)	8.0a	5.9bc	4.8c	7.1ab	6.6b	6.6b	6.8b	7.1ab	6.3b	6.9ab
LC (%)	23.4abcd	24.0ab	23.1abcd	24.5 a	23.9abc	23.8abc	22.5cd	24.1ab	21.9d	22.9bcd
HC (%)	68.6bc	70.1abc	72.1a	68.4c	69.56bc	69.6bc	70.7ab	68.8c	71.8abc	70.3bc
ρ bas (g.cm$^{-3)}$	0.423bc	0.440b	0.495a	0.429bc	0.404c	0.422bc	0.447b	0.448b	0.452b	0.452b
FL (µm)	1025bc	992c	1024c	1077abc	981c	1165a	1139a	1115ab	1051abc	1069abc
FWT (µm)	3.0bcd	3.5abc	3.0cd	3.7abc	2.7d	4.3a	3.7abc	3.2bcd	3.2bcd	3.8ab

HHV= Higher heating value; CC = carbon content; VMC = volatile matter content; AC = ash content; EC = extractives content; LC = lignin content; HC = holocellulose content; ρbas = basic density; FL fiber length; FWT = fiber wall thickness. Distinct letters in line differ statistically ($P<0.001$) by Tukey’s test.

The values of the energy and chemical characteristics, basic density and wood fibers of *H. brasiliensis* clones showed different behaviors. Clones IAC-311, PB 330, IAC 41, IAC 301, IAN 873 presented higher lignin and fixed carbon levels, that consequently contributed to higher HHV (Table 3), presenting a superior energy performance than other clones. According to Trugilho and Silva (2001), these differences in energy properties can be associated to the chemical composition that have influence in the energy characteristics of biomass.

According to Ratnasigam and Scholz (2009) besides the latex, *H. brasiliensis* produces a large amount of biomass, it is estimated that each tree produces 2.1 m^3 of it. Therefore, it is necessary to identify a possible reuse of this biomass as well as studies to identify the potential use of waste for production energy, in order to reduce the fossil fuels dependence in energy production (Franz; Kuenzi and Stamm, 1975).

HHV of wood for power generation for decades was considered 18830 $kJ.kg^{-1}$ Muzel et al. (2014), however, in Brazil forest species widely used for energy generation present higher HHV, as aforementioned by the author above. Telmo and Lousada (2011), studying the wood of clones of *Eucalyptus grandis* and *H. brasiliensis*, reported HHV of 17895 and 17897 $kJ.kg^{-1}$ with similarity between the species that emphasize widely use of *Eucalyptus* in Brazil for the energy generation.

The HHV differences between clones observed in this study can be explained by the ecological group of the wood Tan (1989), hardwoods, in which clones of *H. brasiliensis* have an expected HHV of 19089 $kJ.kg^{-1}$, fact observed in the present study, where the values ranged from 18357 $kJ.kg^{-1}$ (IAC 301) to 19070 $kJ.kg^{-1}$ (IAC 311). The work of Tan (1989b) reports an HHV for the *H. brasiliensis* of 19700 $Kj.kg^{-1}$, Werther and Saenger (2000) report an HHV for

H. brasiliensis residues of 18410 kJ.kg^{-1}. According to the Brazilian market, values between 16500 and 18000 kJ.kg^{-1} are approved for energy uses.

Clones with higher volatile and ash material contents had lower HHV, IAC 301 (83.92%), IAC 40 (83.75%), RRIM 725 (83.69%), IAN 873 (83.67%), FX 2261(83.65%), PB 330(83.55%), GT1 (83.23%) IAC 41 (83.44%), IAC 311 (82.79%), which consequently reduces the energy potential of the fuel. However, the fixed carbon content has a direct relationship with calorific power, a higher fixed carbon content implies greater resistance to thermal degradation of biomass within the burning apparatus for power generation (Chaves et al. 2013).

For Brito and Barrichello (1982), wood used for bioenergy should have a volatile material between 75-85% and fixed carbon in the range of 15-25%. Therefore, based on the classification proposed by Brito and Barrichello (1982) the clones used in the present study are within the expected standard, providing good quality energy. The ash content should be in the range of 1-3% for good energy performance Schoninger and Zinelli (2012). Thus, the values for this energy characteristic are within the expected pattern for good energy yield, once that the ash values ranged from 0.42% (IAC 301) and 1.49% (IAC 311).

In Brazil species of *Eucalyptus* are widely used for energy production due to their characteristics of rapid growth and energy properties Nogueira and Iora (2003). However, recent studies show similarity in the energy properties between *H. brasiliensis* clones. Bersh and Brum (2018) characterized *Eucalyptus* and reported HHV values between 13970-14250 kJ.kg^{-1}, volatile materials of 83.17-86.16%, 0.57-0.60% of ash content and 13.27-14.25% of fixed carbon content, showing that *H. brasiliensis* clones have similarity and superiority properties, highlighting its use for bioenergy production when compared to *Eucalyptus* wood.

There is a relationship between anatomical characters, such as fiber length and wall thickness and chemical properties for energy production as observed in the present work. larger and thicker clones tend to present higher lignin and extractive content in their constitution, but this fact was not observed for the clone IAC 301. According to Paula (2003) the clones woods that have higher fiber, wall thicknesses and length present in their constitution higher lignin and extractive content, being more recommended for energy production due to its increase in the biomass production, resulting in a greater amount of mass per unit of volume and, consequently, greater energy release capacity. Woods with high lignin content contribute to high gravimetric yield and gives greater resistance to the charcoal thermal degradation, since the wood has more condensed structures that degrade at higher temperatures (Castro et al., 2013; Oliveira et al., 2010).

In this context, clones of higher basic densities present larger dimensions in their anatomical constitution. This fact is not a rule, however clone IAC 301 presented lower density and smaller dimensions of the fibers. The increase in wood density is followed by an increase of the fiber wall thickness and length (Oliveira et al., 2010b), fact that was not observed in this study. IAN 873 had higher height and width, but lower density than other woods.

As lignin and extractive content increase, density increases proportionally, thus there is an increase in the energy yield of fixed carbon content and HHV Dias-Júnior et al., (2015). This premise was not observed for the *H. brasiliensis* clones IAN 873 and IAC 40, they presented lower basic density, however, an HHV and fixed carbon content higher than other clones. It was evident that IAC 301 had a lower basic density and HHV value, which may be related to the age of the tree and anatomical characteristics of the species itself (Protásio et al., 2014).

Density basic is an important property of wood and should be considered for energy use of a given biomass, once that it is directly related to energy production. That is, the higher the density, the greater the amount of energy stocked per unit volume (Queiroz et al., 2004). It is recommended that a wood used as an energy source should present values above 0.40 $g.cm^{-3}$ of basic density (Alzete et al. 2005), data confirmed for all clones de according table 3.

According to Silvério et al. (2006) there is a relationship between fixed carbon content, volatile material and HHV. Clones IAC 311, PB 330, IAC 41, IAN 873, RRIM 725 have higher HHV, higher fixed carbon content and lower volatile material content, while other clones had lower HHV, lower fixed carbon levels and higher volatile levels.

The differences found in the energy properties of wood between *H. brasiliensis* clones are due the biomass chemical composition values, fiber dimensions and basic density. Studies developed with other species cite that HHV is mainly dependent on lignin and extractive content. High levels of lignin favor the energy properties of fixed carbon and HHV, which can be attributed to carbon-carbon bonds between monomeric phenyl-propane units present in lignin, which hinder their decomposition, and to the higher content of carbon of this molecular component of biomass (Bufalino et al. 2012; Demirbas 2000; Dietenberger and Hausburg 2016).

Holocellulose is considered the most abundant component of the cell wall, however it is amorphous and does not resist to high temperatures of thermal degradation, hampering its use in energy production because of their negative interference in the biomass energy, HHV and physics properties (Tan and largervist 2011). Clones with higher holocellulose levels present lower HHV, specifically 64B 850, FX 2261, IAC 41, GT1.

The approach to obtain energy from biomass is usually through thermochemical technologies, especially combustion. The high ash content is disadvantageous because it decreases the transfer of heat in fuel and increases corrosion of the equipment used in the process Brand (2010), in addition it decreases the HHV of biomass (Protássio et al., 2011; Brand 2010 and Soares et al., 2014).

Although there are few studies that report the characteristics of wood for energy purposes, Menucelli et al. (2019) studied 10 clones of *H. brasiliensis* and reported superior characteristics to clones evaluated in the present study, such as fiber length between 1189-1097µm, fiber wall thickness of 4.55-5.13µm, extractive contents between 12.42-16.34%, lignin content between 27.51-22.47%, basic density from 0.57 to 0.66 $g.cm^{-3}$. These wood characteristics influenced the higher HHV content between 18592-19757 $kJ.kg^{-1}$, being superior to the clones of this study, which can be associated to the differences in genetic material Soares et al., (2014).

3.2 Fourier Transform Infrared Spectroscopy (FTIR)

Table 4 summarizes the main functional chemical groups found in *H. brasiliensis* clones wood, being identified by the wave number of carboxylic groups: =C-H (902 cm^{-1}), C-O-O (1114 cm^{-1}),-C-H (1464 cm^{-1}), C=O (1743 cm^{-1}), O-H (2924 cm^{-1}) and O-H (3370 cm^{-1}).

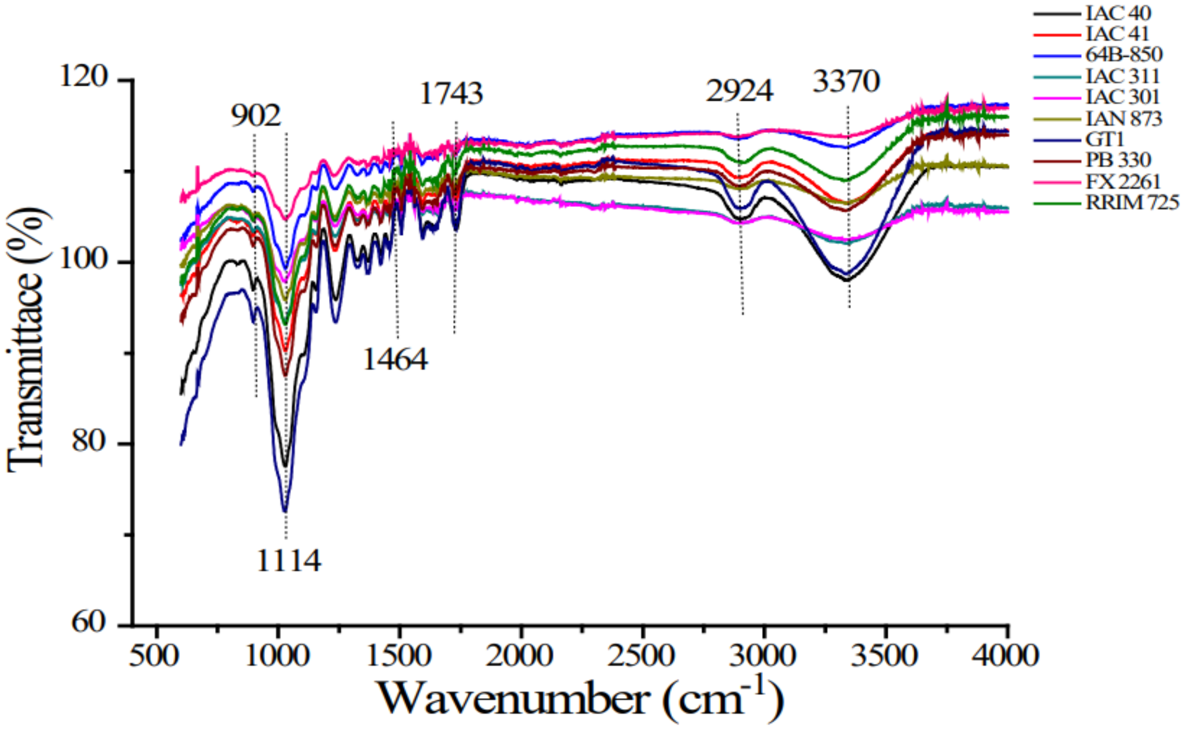
Table 3-Characteristic bands of infrared spectra (FTIR) for *Hevea brasiliensis* clones, and their respective functional groups

Wavenumber (cm^{-1})	Functional group	Chemical group	Ref.
902	=C-H	Cellulose	Colom et al. (2003)
1114	C-O-C	Cellulose and Hemicellulose	Pires et al. (2012)
1464	C-H	Lignin and Carbohydrate	Pandey and Pitman (2003)
1743	C=O	Lignin and Hemicellulose	Faenkler et al. (2010)
2924	O-H	Hemicellulose and Phenols	Tolva and Faix (1995)
3370	O-H	Phenols	Mclellan et al. (1991)

Figure 1 shows the main spectra obtained in the wood of *H. brasiliensis* clones, the decrease in the intensity of absorbance found for the clones, between bands 902 and 1114 cm^{-1}, is characterized by the increase of guaiacyl-lignin in relation to carbohydrate components C-H deformation in the guaiacyl unit with C-O deformation in primary alcohol) Pandey and Pitman (2003). The different behaviors of absorbance spectra are related due to differences in chemical composition reported in Table 4.

One can observe that all clones have strong absorption at 1114 cm^{-1}, where the lignin present in wood is located Hon (1989). However, clones IAC 40, GT1, PB330, IAC 41, RRIM 725, IAN 873 had higher wavelength in this spectrum. This fact is related to the chemical structure of wood because these clones have higher levels of lignin (Table 4), and higher resistance to thermal degradation of the material, being this band characterized to the stretch mode of the combination O-H (phenolic group).

Figure 1-shows the main spectra obtained for *Hevea brasiliensis* clones wood



According to Figure 1, the group found at 1743 cm^{-1}, can be attributed to group C=O, indicating the presence of acetyl or carboxylic acid group derived from lignin. The high proportion of these chemical groups indicates an increase in HHV (Table 1). The same behavior was reported by Hon (1989).

It was possible to notice a strong striation between bands 1743-2924 cm^{-1}, larger than the other spectral bands reported. The bands are characterized by strong bonding between hemicellulose and lignin, which is characterized mainly by C-H, N-H and O-H groups that are desirable for energy production Popescu (2011).

At band 3370 cm^{-1}, the phenolic groups bonded to hydrogen formed chemical groups O-H and C-H Pandey and Pitman (2003). This group is responsible for the high degradation resistance of the wood, which is dependent on lignin content, as it was possible to observe in this study. Clones with higher lignin levels present higher absorption spectra IAC 40 and GT1 (Figure 1). Unlikely, the clones IAC 301 and IAC 311 present lower absorption spectra, mainly due to the thermochemical, anatomical and basic density characteristics reported in Table 3.

3.3 Thermogravimetric analysis (TGA)

Biomass degradation can be interpreted as a process consistent by three stages, based on different thermal characteristics of its main components: cellulose, hemicellulose and lignin (Junges, 2015), the extent that they degrade is marked by an event (I, II, III, and IV) to a characteristic mass loss of the degraded material that can be observed according to Table 5. The differences observed between Tonset and Tendset (ºC) are related to thermochemical composition, basic density and biomass fiber dimensions.

Table 4- Initial (T*onset*) and final temperature (T*endset*) ºC and percentage of mass loss for clones of *Hevea brasiliensis* after each thermal degradation event

Clone	Events	Tonset ºC	Tendset ºC	Mass losses (%)
IAC 40	I	57	81	1
	II	81	336	65
	III	336	380	34
	IV	380	-	-
IAC 41	I	55	78	1
	II	78	306	74

	III	306	385	25
	IV	385	-	-
64B 850	I	57	81	1
	II	81	291	67
	III	291	367	32
	IV	367	-	-
IAC 311	I	57	79	1
	II	79	346	68
	III	346	372	31
	IV	372	-	-
IAC 301	I	58	81	2
	II	81	342	62
	III	342	375	36
	IV	375	-	-
FX 2261	I	55	77	1
	II	77	296	65
	III	296	375	34
	IV	375	-	-
GT1	I	50	71	2
	II	71	297	66
	III	297	393	32
	IV	393	-	-
IAN 873	I	56	79	1

	II	79	307	68
	III	307	354	31
	IV	376	-	-
PB 330	I	50	71	2
	II	71	300	62
	III	300	371	36
	IV	371	-	-
RRIM 725	I	57	79	1
	II	79	295	62
	III	295	365	37
	IV	365	-	-

Event I was characterized by the loss of free water from the biomass, with trace of inorganic compounds and other non-combustible products at temperatures below 140ºC Luangkiattikhun et al. (2008), being observed for all clones' temperatures below 50 ºC (PB 330) Tonset and 81 ºC (IAC 301) for the Tendset.

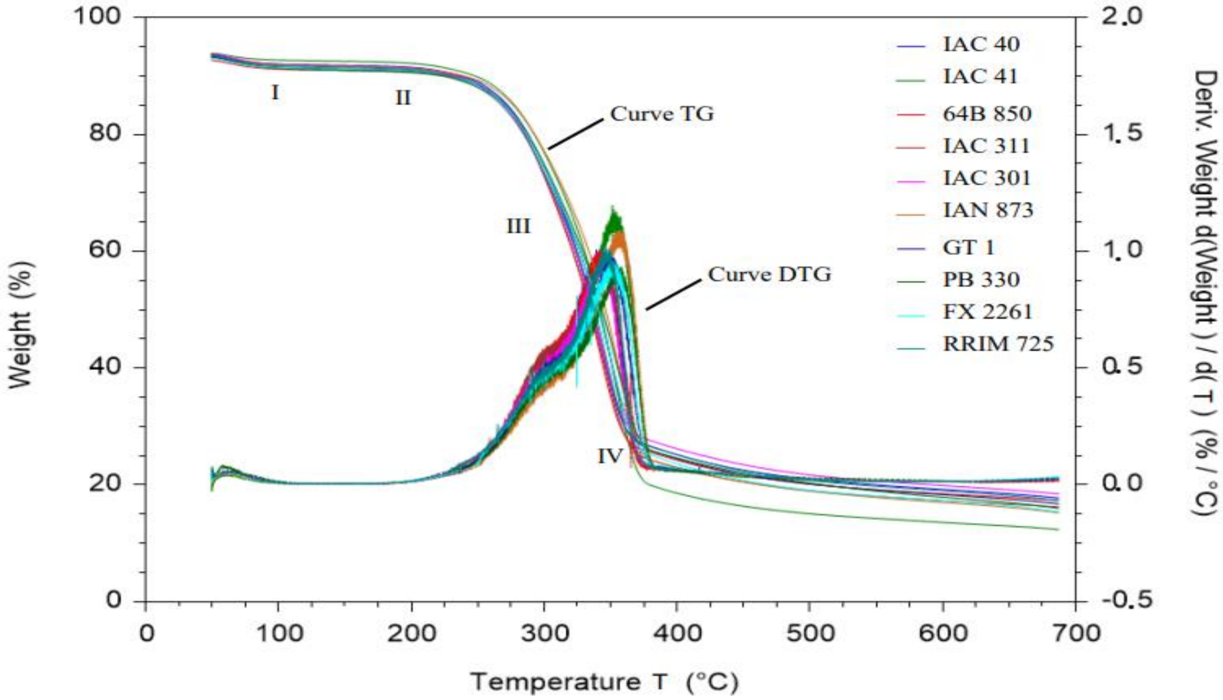
Event II is known as the main event of degradation of lignocellulosic materials, because it presents an increase in the rate of degradation due to the beginning of the cell wall chemical compounds conversion (cellulose and hemicellulose) of biomass as and onset degradation of lignin, in the intervals between 200 and 400ºC Luangkiattikhun et al. (2008) .

The main components of biomass were degraded at different temperature peaks. According to Willian and Besler (1993), the decomposition of hemicellulose occurs between 250 and 350 ºC, cellulose from 250 to 360 ºC and lignin between 180 and 500 ºC. One can observe that the clones with higher HHV levels, IAC 311 (19070 kJ.kg^{-1}), IAC 40 (18895 kJ.kg^{-1}), PB 330 (18895 kJ.kg^{-1}) and IAC 41 (18827 kJ.kg^{-1}), demand higher temperatures for lignin degradation in events II and III, Table 5.

Dientenberger and Hasburgh (2016) define that the wood chemical composition has influence on the HHV values, reporting values for cellulose and hemicellulose HHV (18.6 kJ.kg^{-1}), lignin (23.2-25.6 kJ.kg^{-1}) and extractive (32-37 kJ.kg^{-1}). These values show that extractive and lignin contents have greater influences on the thermal degradation of wood and HHV than holocellulose contents. This behavior was also observed in this study, clones that presented higher percentage of HHV, lignin and extractives demanded higher temperatures for thermal degradation in events II and III, which is favorable for energy production.

When evaluating the other events in the process of material degradation, event III begins after a decrease in mass loss, that represents the beginning of conversion associated to the most resistant compounds. The degradation of lignin ends when the degradation rate reaches minimum values and it no longer occurs, this event is characterized by the greater mass loss of lignin. The event IV shows the residual mass of biomass represented by the nonflammable and inorganic portion (ash), with no mass losses according to Table 5. The TG and DTG curves of thermal degradation events are presented in Figure 2.

Figure. 2- TG curves and DTG of *Hevea brasiliensis* clones in nitrogen atmosphere



At temperatures close to 400 °C (Figure 2), one can verify that the thermal degradation of wood has become lower, corresponding mainly to lignin degradation. At this temperature, a great portion of the cellulose and hemicellulose chemical components in wood have been already degraded, thus mass loss at this stage is low, about 5% Pereira et al., (2013). At temperatures up to 600 ºC, mass losses are greater than 95% for hemicellulose and greater than 80% for cellulose, while lignin mass losses do not exceed 60% of the total mass (Bartkowiak and Zakrzewski, 2004).

4. CONCLUSIONS

The results found in this article corroborate with those from other species used for energy generation. In general, a biomass with higher higher heating value contributes to the increase in other energy properties such as fixed carbon, which is dependent on chemical. Therefore, differences were observed between the chemical, physical and energetic characteristics of clones IAC 311, IAC 40, IAC 41, PB 330, 64B 850, GT1, IAN 873 and RRIM 725, once that they presented energy characteristics higher than clones IAC 301 and FX 2261.

The basic density of *Hevea brasiliensis* clones also showed influence on energetic properties of wood. Higher density clones have higher HHV, fixed carbon and higher ash contents. However, clone IAC 301 had lower basic density and lower HHV, the decrease observed can be related to lower values of fiber length and thickness dimensions of this clone.

The infrared spectrocospy showed functional groups characteristic of wood, =C-H, C-O-O, -C-H, C=O and O-H. They are part of the chemical composition of the wood and are satisfactory for the energy production, once that they increase the energy yield of biomass in combustion.

In the thermogravimetric analysis (TGA), higher mass losses (%) at events II and III can be associated to a greater degradation of hemicellulose and lignin. One can observe that clones with higher values of chemical and energetic constituents demanded higher temperatures for degradation, making the wood more reactive and durable in furnaces used for energy generation.

Despite the differences observed between the clones of *Hevea brasiliensis*, mainly related to the biomass composition, it was possible to observe satisfactory characteristics of this wood as a source for energy production, without restrictions.

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CHAPTER 3- PHYSICO-MECHANICAL CHARACTERIZATION AND WOOD MACHINING FROM 10 CLONES OF 12-YEAR-OLD *HEVEA BRASILIENSIS* WITH POTENTIAL FOR FURNITURE

1.INTRODUCTION

Hevea brasiliensis is a native species from Amazon Forest and has high economic importance in Brazil, as it is widely used in obtaining latex for rubber production (Iwakiri et al. 2017). In Brazil, after the latex extraction cycle ≈ 25 to 30 years, plantations are cut and replaced, and wood is traditionally used as a source of energy for domestic purposes (Eufrade-Junior et al. 2015), requiring a study that addresses its machining characteristics and physical and mechanical properties to obtain products with greater added value.

For furniture industries, knowledge of wood properties is essential to guarantee final product quality and optimize the use of raw material, especially when referring to characteristics of species that have been scarce studied and that present excellent properties for multiple uses. Wood machining includes several operations, including: planing, molding, cutting, drilling etc. In this context of machining for furniture production, the relationship between physical-mechanical wood behavior is essential to characterize the performance of raw material and use of most appropriate equipment for each purpose (Taques and Arruda, 2016).

The physical and mechanical properties interfere in the final product. Wood basic density is related to other fundamental technological properties, being the most important physical property from technological point of view and has a close relationship with mechanical properties (Braz et al. 2013). Volumetric shrinkage is an important property of wood, which, according to Mori et al. (2003), varies greatly from one species to another and is influenced by environment moisture content, which may swell or retract. The authors point out that the smaller retractions in the different orthotropic axes of the wood, the better its properties. This property should be considered when recommending wood for uses that require good dimensional stability, avoiding the appearance of cracks and warps.

The mechanical properties define wood behavior when submitted to efforts of mechanical nature, allowing to compare it with other woods of known properties and by analogy to indicate the additional tests necessary to know its use (Lahr et al. 2017).

According to Brazilian Association of Technical Standards NBR 7190/1997, compression parallel to the grain is a mechanical property that allows the wood to be framed in different resistance classes: C20, C30, C40 and C60, the higher the resistance class being the more resistant it is the wood in supporting mechanical forces.

The values of mechanical properties vary according to the species, wood moisture, density and duration of load in mechanical test, among other factors. The modulus of elasticity (MOE) and modulus of rupture (MOR) are two parameters normally evaluated in static bending tests, being MOE of greatest importance in wood technological characterization, representing the strength of material when subjected to a applied load (Scanavaca Júnior and Garcia, 2004).

We founded some studies that characterize the technological properties of *Hevea brasiliensis* wood, e.g., Killmann and Hong (2000), Hashim et al. (2005) and Teoh et al. (2011), which showed favorable physical, mechanical and machining properties, in addition to good workability and also aesthetic characteristics, since the wood has a light color, making it possible to carry out treatments to obtain other hues. However, there is no tradition of using *H. brasiliensis* wood in Brazil (Okino et al. 2009) to obtain a product with greater added value.

In Brazil, wood for furniture production comes from native forests, which has accelerated extinction rate of native species and degradation of natural environments. Thus, *H. brasiliensis* wood, after latex exploratory cycle becomes viable to reduce the exploitation of native forests. In this context, the aim of this study was physico-mechanical and wood machining characterization of 10 *Hevea brasiliensis* clones with potential for furniture production.

2. MATERIAL AND METHODS

2.1 Location and sampling

Wood samples of 12-year-old *H. brasiliensis* were collected from 30 trees (Table 1), three of each clone, in the municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W, elevation 350m). The *H. brasiliensis* plantation was established in 2006 at a spacing of 3 × 3 m from seeds of free-pollinated clones (from crossing clones of IAC 40, IAC 41, 64B-850, IAC 311, IAC 301, IAN 873, GT1, PB 330, FX 2261, and RRIM 725). Soil in the experimental area was classified as Red Latosol, a clayey texture (Santos et al. 2006). In 2018, selected trees were felled and logs (≈1 m in length) were taken from the main trunks of trees to physical-mechanical and machining tests.

Table 1- Dendrometric data of 10 clones of 12-year-old *Hevea brasiliensis* trees. DBH = diameter at breast height (1.3 m from the ground)

Clone	Mean height (m)	Mean DBH (cm)
IAC 40	15.6	9.6
IAC 41	13.4	13.2
64B 850	14.6	12.1
IAC 311	17.8	14.4
IAC 301	13.8	12.6
IAN 873	16.6	14.4
GT1	15.0	11.9
PB 330	15.2	15.2
FX 2261	14.8	10.7
RRIM 725	14.5	12.0

Ten samples were used for each clone, totaling 100 samples. For physical-mechanical tests, specimens were cut according to the standards described in each item. For machining tests, samples were cut and treated with chromated copper arsenate (CCA) to protect wood against fungi, bacteria, insects and weather resistance. Then samples was air-dried, protected from rain, samples were positioned in vertical stacking, keeping samples out of contact with soil to prevent fungi, bacteria, insects attacks and to avoid soil humidity affecting the drying process. The samples remained so for eight months, after that period workability tests were started.

2.2 Physical properties

Basic density was determined by ratio between dry mass and saturated volume. The specimens (5x3x2cm) were immersed in water and were considered saturated when they presented constant mass during monitoring in the laboratory. Subsequently, the specimens were dried in an oven at 105 °C ± 2°C to obtain the dry mass. The saturation volume was obtained by hydrostatic balance method. Wood basic density was calculated by relationship between dry mass and saturated volume in accordance with the Brazilian standard NBR:11941 (ABNT, 2003). by equation, ρbas= Dm/Sv. Where, ρbas = basic density ($g.cm^{-3}$), Dm = Dry mass (g) and Sv = satured volume (cm^{-3}).

The volumetric shrinkage was obtained from the same samples as those used for the basic density (ABNT, 1997). The samples were saturated in water, their dimensions measured with a caliper (accuracy = 0.001mm) taking three measurements per direction, then oven-dried at 102 ± 3°C, followed by determination of the dry volume of each sample. Volumetric shrinkage (as a percentage) is the difference between initial saturated and oven-dried volume divided by initial volume. The anisotropic factor was used by dividing the βtang /βrad divisions.

2.3 Mechanical properties

Mechanical characterization was carried out with the following tests: compression strength parallel to grain (σc‖), modulus of rupture (MOR), and modulus of elasticity (MOE) in static bending (three-point test). These tests were performed in a computer-controlled 300kN electromechanical testing machine (INSTRON/EMIC, Paraná, Brazil). Deformations in bending were evaluated using a mechanical extensometer (accuracy = 0.01mm).

All variables of the mechanical tests were adopted according to NBR7190 (NBR 7190 1997). Compression tests were performed on 20mm x 20mm x 60mm specimens and bending tests on 20mm x 20mm x 460mm specimens and a span length of 420mm. Both tests used a loading speed of 10MPa/min. Initial results of strength and elastic properties (modulus of elasticity) were corrected to the Equilibrium Moisture Content - EMC (12%) using a conversion coefficient of 3% (of variation per 1% of variation in the MC) for strength properties and 2% for elastic properties.

In the Brazilian standard (NBR7190, 1997), the characteristic value of compression strength parallel to the grain is used to classify the wood in the system of strength classes (Table 2), guiding the choice of the most suitable species for structural projects.

Table 2- Strength classes and characteristic values for hardwoods at 12 % MC, according to the NBR 7190 (ABNT, 1997)

Hardwoods					
Classes	$\sigma_{c\parallel,k}$ (MPa)	$\sigma_{s,k}$ (MPa)	$E_{c\parallel,m}$ (MPa)	D_b (g.cm^{-3})	D_{12} (g.cm^{-3})
C20	20	4	9500	0.500	0.650
C30	30	5	14500	0.650	0.800
C40	40	6	19500	0.750	0.950
C60	60	8	24500	0.800	1.000

$\sigma_{c\parallel,k}$ = Compression parallel to the grain. $\sigma_{s,k}$ = volumetric shrinkage. $E_{c\parallel,m}$ = modulus of elasticity. D_b = basic density. D_{12} = apparent density.

2.4 Maching

Ten samples were used for each clone, totaling 100 samples. For machining tests application, samples were uncapped at both ends parallel to the grain (60cm x 10cm x 2cm, length, width and thickness, respectively).

2.4.1Planning

In planing test, an Invicta Delta planer with 3 knives, 3460 RPM, knife holder head and sidewalk knife with carbide, 16 cm long, 4 cm thick, with advance speed 9m*min^{-1} was used. The surfaces and sides of each sample were planed (Figure 1a).

2.4.2 Thickening

After planing test, samples were subjected to thickening test adjusted for samples to assume 2 cm of thickness for later analysis of the surface. The thickener machine Model Invicta Mescla DME was used, with 1730 RPM, 5 (hp), 2 low rotation knives (Figure 1b).

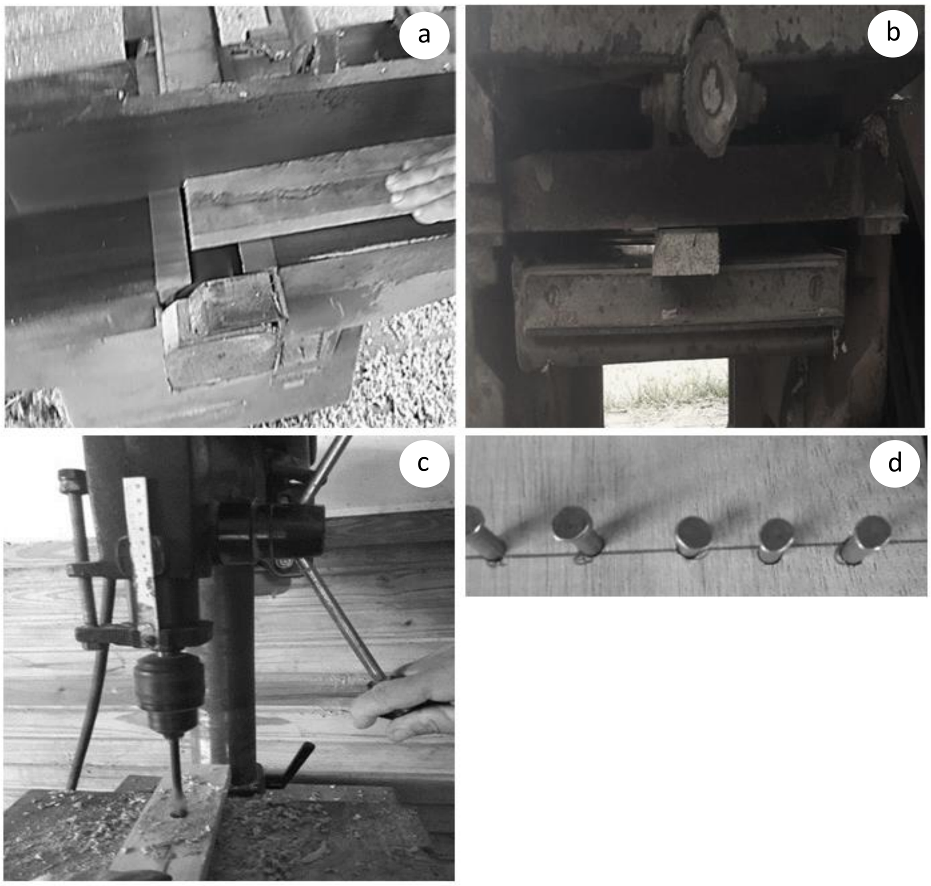
2.4.3 Bolt hole

For bolt drilling test, a FBS 16 Schulz 1720 RPM and 0.37 (cv) bench drill was used, adapted from ASTM D1116 (1987), which recommends 3600 RPM and 3 horsepower (cv). A 12 mm drill was used, with holes 10 cm from end in the length direction, and hole 1 cm from the edge in the width direction (Figure 1c).

2.4.4 Cracking by nails

The nail cracking test used nails of 15 x 15 x 30 mm in length and 2 mm in diameter. Five nails were inserted 10 cm from the end towards the length of the sample, and 10 mm of distance between nails (Figure 1d).

Figure 1. Machining tests in *Hevea brasiliensis* wood. a. Surface and lateral planing test. b. Thickening test. c. Bolt drilling test submitted to a bench drill. d. Nail cracking test.



After tests, samples were analyzed superficially and scores were given according to the degree of defects in the parts. The grades were given according to the ASTM D: 1116 (1987) standard (Table 3).

Table 3- Quality classes of machined wood surfaces

Grade	**Planed surface quality**
1	Excellent (free from defects)
2	Good (less than 50%)
3	Regular (50%)
4	Bad (more than 50%)

2.5 Statistical Analysis

Descriptive statistical analysis was initially performed. This was followed by performing a normality test to observe the data distribution. For the comparison among *Hevea brasiliensis* clones, a parametric analysis of variance (one-way analysis of variance) was applied. In the case of significant difference, Tukey's test was applied to identify pairwise determinants of differences. Results with $p < 0.001$ were considered as significant. All statistical analyses were performed using the SigmaPlot software – Exact Graphs and Data Analysis - version 11.0 (Systat Software Inc., San Jose, CA, USA).

3. RESULTS AND DISCUSSION

3.1 Physical-mechanical properties of wood

Mean values of physical-mechanical properties for *Hevea brasiliensis* wood clones are shown in table 4.

Table 4- Comparison among 10 clones of 12-year-old *Hevea brasiliensis* by physical-mechanical properties.

Clones	IAC 40	IAC 41	64B 850	IAC 311	IAC 301	IAN 873	GT1	PB 330	FX 2261	RRIM 725
ρbas (g.cm^{-3})	0.423bc	0.440b	0,495a	0.429bc	0.404c	0.422bc	0.447b	0.448b	0.452b	0.452b
βrad(%)	4.18ab	4.81a	3.97ab	3.92ab	3.60ab	3.27ab	2.81b	3.55ab	4.61a	3.16ab
βtan (%)	4.37bc	7.17a	5.23abc	4.29bc	4.14bc	4.10bc	3.05c	5.95ab	6.16ab	3.99bc
βlg(%)	1.24ab	1.24ab	1.18ab	1.09ab	1.07ab	1.04ab	0,85b	1.47a	1.01ab	1.00a
βvol(%)	10.46abc	15.86ab	11.55bc	11.70bc	9.67bc	9.53c	6.32c	11.52bc	18.33a	8.08c
θ	1.93ab	1.82ab	1.72ab	1.62b	1.78ab	1.91ab	2.01a	2.08a	2.02a	1.88ab
fco (MPa)	37.18cd	42.14ab	39.76bc	43.02a	41.57ab	36.71d	42.56ab	38.23cd	42.95a	41.98ab
MOR(MPa)	126.91c	75.36de	150.73b	80.26d	74.54de	77.73de	180.50a	68.72e	82.96d	57.78f
MOE (MPa)	8768bc	6860de	11666a	7484cde	8218bcd	7492cd	9575b	6392ef	9263e	5922f

ρbas= basic density; βrad= radial retraction; βtan= tangencial retraction; βlg= longitudinal retraction;βvol=volumetric retration; θ=factor anisotropic; fc0= strength parallel; MOE=Modulus of elasticity; MOR= Rupture module.

The basic density varied from 0.404 (IAC 301) to 0.495 g.cm-3 (64B 850), this latter clone is statistically different from the others. According to Silveira (2013) and Silva (2015), *H. brasiliensis* wood clones is classified as low density. Basic density is the most important physical property and defines the wood uses for furniture, since all other properties are related to it . In this context it is an essential property to be studied to define wood quality species and propose its most suitable application.

Other studies show that different clones at different ages may differ from clones we investigated. Naji et al. (2012) analyzing wood basic density among *H. brasiliensis* Malaysian clones at age 9, reports densities between 0.530 to 0.560 g.cm^{-3}. Santana et al. (2001) studied *H. brasiliensis* clones in São Paulo, Brazil at 40-44 years, and reported basic densities from 0.470 g.cm^{-3} to 0.510 g.cm^{-3}, respectively. In addition to genetic variability, spacing between trees, soil characteristics, temperature and precipitation should be analyzed for a more complete comparison between different clones.

We observed variation in volumetric shrinkage between clones, in all wood directions. GT1 clone showed lower radial, tangential, longitudinal and consequently volumetric shrinkage. Conversely, IAC 41 clone showed higher retractability in radial and tangential directions, the higher volumetric shrinkage was observed in FX 2261 clone. Although we have found few studies that explore physical properties of *H. brasiliensis*. The observed values are mostly higher than Leonelo (2011), who studying GT 1 and RRIM 600 clones at 8 years, in which he found 5.83% in tangential direction, 2.78% in radial direction, 0.28% in longitudinal direction. A lower difference between radial and tangential retractions indicates a more stable wood, which was observed for GT 1 clone, with lower retractions.

High wood retractions are undesirable property depending on their use. Oliveira (1997) mentioned that volumetric shrinkage, despite expressing the total variation, which occurred in hygroscopic variation, are linear retractions that occur along wood directions, most of the times more important, because they are make wood anisotropic material.

The anisotropic factor is the direct relationship between retractability in the tangential and radial directions. According to Oliveira et al. (2010), the ideal situation, rarely found, would be one in which the tensions arising from the anisotropic nature would cancel each other out according to directions, in which the retractability manifested itself.

Anisotropy index ranged from 1.62 in IAC 301 clone to 2.08 in PB 330. Boerhendy et al. (2011), analyzing anistropy index of six *H. brasiliensis* clones in Indonesia, report values between 1.25 to 2.53, a range similar to our study. Durlo and Marchiori (1992) presented the following wood classification criteria for anisotropic index: 1.2-1.5 - excellent, 1.5-2.0 - normal, and above 2.0 - poor.

When comparing values from studied clones, *H. brasiliensis* wood is classified as normal with medium dimensional stability. Thus, it can be used to produce furniture that allows small bends. However, correct wood drying techniques must be employed to reduce defects and obtain desirable characteristics in the final product.

We observed differences in mechanical properties between clones. For compression parallel to the grain, values ranged from 36.71 (IAN 873) to 43.02 MPa (IAC 311). The modulus of rupture (MOR) from 57.78 (RRIM 725) to 180.50 MPa (GT1). The modulus of elasticity (MOE), values ranged from 5922 (RRIM 725) to 11666 MPa (64B 850).

According to ABNT 7190 (1997) classification (Table 2), which deals with wood characterization in strength classes, IAC 40, 64B 850, IAN 873 and PB 330 clones are classified as C30, the other clones are classified as C40.

Santana et al. (2001) characterizing mechanical properties of four *H. brasiliensis* clones: AV 1301, GT 711, IAN 717 and IAN 873, reported that compression parallel to the grain ranging from 43.3, 42.4, 42 and 41.7 MPa, respectively. The compression parallel to the grain value mentioned by Santana et al. (2001) for IAN 873 was higher than we found in the present study (36.71 MPa). The authors mention that wood in the resistance class C30 and C40, can be used in civil construction projects and in furniture production, as they support medium to high mechanical efforts.

Considering that trees we studied are 12 years old, we observed that wood have satisfactory properties for structural and furniture uses, since mechanical strength classes obtained in compression test were similar and superior to those of several native species, widely employed for these uses.

Eufrade-Junior et al. (2015), studying mechanical properties of *H. brasiliensis* for structural uses from GT1 and RRIM600 clones at 20 and 30 years, concluded that species has similar to superior properties compared to several brazilian native species and currently commercialized. The authors mention *Cedrela* spp., *Cedrelinga caterniformis*, *Vochysia* spp. and *Erisma* spp. Eufrade-Junior et al. (2015) state that *H. brasiliensis* wood use, from planting, becomes ecologically viable, as it reduces the exploitation of native forests. Wood use after the exploratory latex cycle can be used for other applications of greater added value, due to the fact that wood has satisfactory physical and mechanical properties for use in other purposes, e.g., furniture production.

Santana (2001) studying *H. brasiliensis* clones between 36 and 45 years reports higher MOE values (11000 to 13000 MPa) and similar MOR values (81.5 to 96.9 MPa) compared to clones we studied (Table 4). Thus, we suggest that youngest wood may present satisfactory properties for different uses, with added value. The issue here is wood volume, that is lower in young compared to that older trees.

3.2 Wood machining

From 100 samples, we observed grain defects in 38 samples: fuzzy grain in 34 samples and raised grain in four samples. The defects observed in planing are related to grain orientation type of *Hevea brasiliensis* wood. The analyzed wood samples showed straight grain. Nasir and Cool (2018), mentions that this grain type favors machining processes and good surface finishing. Figure 2a shows defect considered severe in raised grain.

In bolt drilling test, *H. brasiliensis* wood clones showed levels 1 and 2, we observed a slight defect in a sample for fuzzy grain and eight samples showed crushed grain (Table 5), indicating easily workable wood. *Hevea brasiliensis* wood is considered light and soft, which favors optimization and operation in industrial processes. According to Silva (2002), wood anatomy and physico-mechanical, and chemical properties define wood behavior in machining. However, is expected that wood does not burn during pin drilling. The observed defects such as lifting, fluffing and crushing the grain can be corrected by sanding the surface.

Table 5 - Results test machining test for each hevea brasiliensis clone10 clones of 12-year-old *Hevea brasiliensis* wood.

Test	**Clones**									
	IAC 40	**IAC 41**	**64B 850**	**IAC 311**	**IAC 301**	**IAN 873**	**GT 1**	**FX 2261**	**PB 330**	**RRIM 725**
Planning	3	2	2	2	2	2	2	2	2	2
Thickening	2	2	3	2	3	1	2	2	1	2
Bolt hole	1	1	1	1	1	2	1	1	1	1
Cracking by nails	1	2	2	1	2	2	2	2	2	1

Silva et al. (2007) recommend that to minimize grain pullout effects in bolt drilling test, higher cutting speeds should be used, which facilitate the incisions of the grains. However, it is essential to carry out tests of most appropriate speeds to avoid burning surface, with darkening, which detracts quality of raw material. In figure 2c it is possible to verify defect of the lifting type of the light type fiber.

For the nail cracking test (Table 6), in 86 from 100 *H. brasiliensis* wood samples we did not observe any cracking. Showing a favorable characteristic for machining process optimization and lower depreciation in wood workability (Aguilera, 2011) . Figure 2d shown crack by nail cracking test.

Table 6- Results of nail cracking test on 10 clones of 12-year-old *Hevea brasiliensis* wood

	Samples percentage (%)
Without cracking	86
With cracking	14

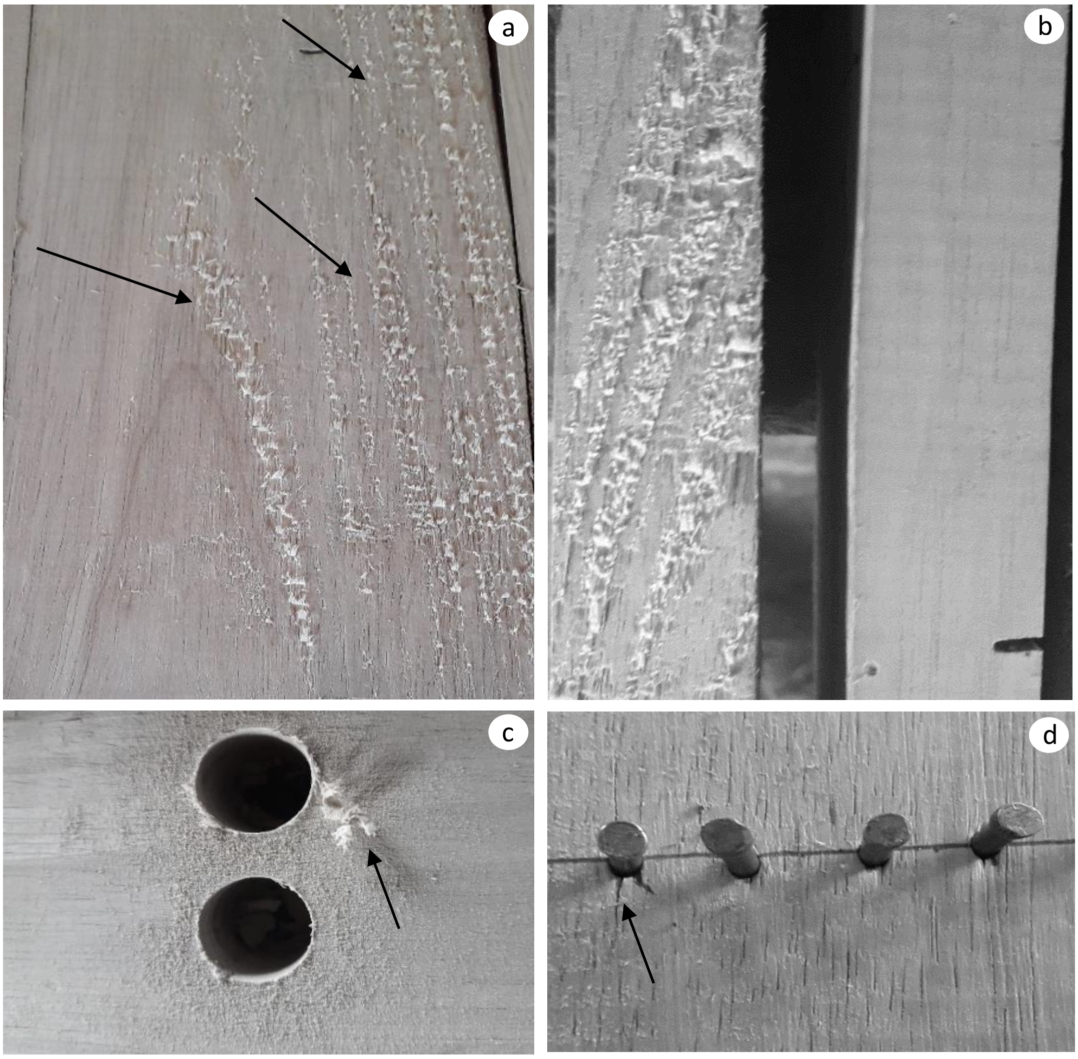


Figure 2-Results of machining tests in *Hevea brasiliensis* wood. a. Severe grain pullout defect on wood surface (arrow) to planing test. b. One sample with severe defect (left) and another sample free from defects (rigth) in thickening test. c. Fiber raised (arrow) in bolt drilling test. d. Crack (arrow) observed in nails application test.

Although wood is part from living being and variations are expected, which in many cases produces unique pieces and desirable effects. On a large scale, it is necessary that a wooden surface be free from defects, such as cracks or grain lift, which leads to loss of quality and aesthetics of manufactured part. Additionally, a flawless surface allows good adhesion to paints and varnishes used in the finishing (Lucas Filho, 2014).

We summarize results of planing, thickening, bolt drilling, and nail cracking tests in table 7. *Hevea brasiliensis* wood clones shows excellent behavior for bolt drilling and nail cracking tests, which allows us to state that wood accepts to be punctured and nailed with ease. In planing and thickening tests, we observed some samples with a defect on surface, with supercifial finish being considered good to very good.

Table 7- Summary of machining tests on 10 clones of 12-year-old *Hevea brasiliensis* wood

Description	Plaining	Thickening	Cracking by nails	Bolt hole
Free from defects (%)	62	73	86	91
Surface finish	Good	Very good	Excellent	Excellent
Defects observed	Grain pullout	Grain slightly lifting	Grain slightly lifting	Slightly cracked.

Dhamodaram (2008) analyzing *H. brasiliensis* wood surface against machining tests reports results from good to excellent, similar results to those found in our study. Therefore, we suggest that *H. brasiliensis* wood clones we analyzed has great functionality and workability, being suitable to furniture.

4.CONCLUSIONS

The wood has a low basic density values. In general, lower densities clones had lower mechanical properties. We observed medium values to dimensional stability wood, which allows the use in furniture production that allows small warps. We observed that 64B 850 and GT1 clones have higher properties compared to other clones, however similar to others, we suggested that all clones present favorable physical and mechanical properties to furniture.

In wood machining, we observed that wood responds with quality to planing, thickening, bolt drilling and nail cracking tests. Thus allows production of solid furniture with a good surface finish. In general, our study shows that 12-year-old *Hevea brasiliensis* wood has relevant technological properties to furniture, and should be used for this purpose from younger ages. Thus, a viable wood to be used to reduce the exploitation of native forests for the furniture market.

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CHAPTER 4- RADIAL VARIATION OF WOOD ANATOMY AND BASIC DENSITY *Hevea brasiliensis* CLONES

1. INTRODUCTION

Wood comes from a complex biological system, making it a material of extreme variability. Its anatomical structure influences other wood characteristics, specifically its physical and mechanical properties, and vary between species, between trees of the same species and even between different parts of the same tree. The variability, usually found within an individual, is probably due to changes in vacular cambium during aging and changes imposed by environmental conditions (Oliveira and Silva, 2003).

Radial variation is the most important source of variation within a tree. This variation is mainly determined by juvenile wood proportion in the trunk, its physical-chemical and anatomical features. The variations that occur during the juvenile period are mainly related to cell dimensions, cell wall structure and physical-chemical wood characteristics (Gonçalves et al., 2007).

Due the demand for forest products growing every year, even with use of widespread species for various applications, such as *Eucalyptus* and *Pinus* species, forests are still an important source of raw material (Pinheiro and Carmo, 1993). It is necessary to carry out research with other species in order to expand the knowledge of their properties.

Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg (Euphorbiaceae) occurs naturally in 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 (Nobuchi et al., 2011; Saffian et al., 2014).

There are some studies that report anatomy, density, and other properties of *Hevea brasiliensis* wood (Mohiuddin, 1993; Menucelli et al., 2019). However, further studies are needed aiming at the industrial use of wood, and in these cases it is essential to know the anatomical structure from the pith to the bark, and how this potential variation influences wood mechanical resistance, drying, adhesion and workability. Factors related to genetics are determinant in wood formation, and the physical and mechanical properties are influenced by anatomical features (Marcati et al., 2001).

Thus, our objective was to determine potential wood anatomical, and basic density variations, from pith to the bark, in 10 clones of 12-year-old *Hevea brasiliensis* trees.

2 MATERIAL AND METHODS

2.1 Selection of species and planting

Wood samples of *Hevea brasiliensis* were collected from 30 trees, three of each clone, in the municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W, elevation 350m). *Hevea brasiliensis* plantation was established in 2006 at a spacing of 3 × 3 m from seeds of free-pollinated clones (from crossing clones of IAC 40, IAC 41, 64B 850, IAC 311, IAC 301, IAN 873, GT1, PB 330, FX 2261, and RRIM 725). Soil in the experimental area was classified as Red Latosol, a clayey texture (Santos et al. 2006).

In 2018, selected trees were felled and discs 10 cm in thickness from each tree at breast height (1.3 m from the ground) were cut. From each tree, a DBH disc (diameter at breast height – 1.30 m) was obtained and from each disc three radial positions were established: the nearest part of trunk center, which was designated as pith, a middle position, and a position close to the bark, which was designated as bark (Figure 1). Mean height and DBH are shown in Table 1.

Table 1-Dendrometric data of 10 clones of 12-year-old *Hevea brasiliensis* trees.

Clone	Height (m)	DBH (cm)
IAC 40	15.6	9.6
IAC 41	13.4	13.2
64B 850	14.6	12.1
IAC 311	17.8	14.4
IAC 301	13.8	12.6
IAN 873	16.6	14.4
GT1	15	11.9
PB 330	15.26	15.2
FX 2261	14.8	10.7
RRIM 725	14.5	12

DBH = diameter at breast height (1.3 m from the ground).

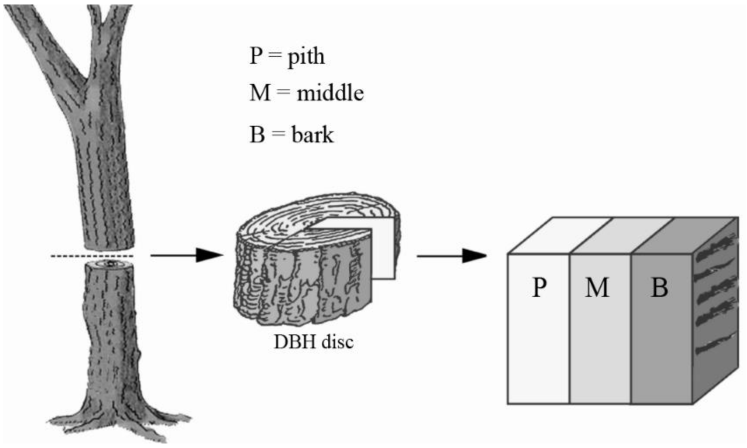

Figure 1. Schematic representation of wood sample collection.

2.2 Radial variation of wood anatomy

We cut small pieces of wood from each sample for maceration using Franklin's method (Berlyn and Miksche, 1976). Wood fragments were stained with aqueous safranin and mounted temporarily in a solution of water and glycerin (1:1). Samples of 1 cm^3 were softened in boiling water and glycerin (4:1) for 1-2 hours. From these samples, transverse and longitudinal sections 20-25 μm in thickness were obtained with a sliding microtome. Sections were bleached with sodium hypochlorite (60%), washed thoroughly in water, and stained with 1% safranin (Johansen, 1940). Measurements followed the recommendations of the IAWA Committee (IAWA, 1989). Quantitative data are based on at least 25 measurements for each characteristic from each tree, thus fulfilling statistical requirements for the minimum number of measurements.

2.3 Basic density

Basic density was determined by ratio 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 during monitoring in the laboratory. Subsequently, the specimens were dried in an oven at 103 °C ± 2°C to obtain the dry mass. The saturation volume was obtained by hydrostatic balance method. Wood basic density was calculated by relationship between dry mass and saturated volume in accordance with the Brazilian standard ABNT (NBR 11941:2003) by equation: $\rho bas= Dm/Sv$. Where. ρbas = basic density ($g.cm^{-3}$). Dm = Dry mass (g) and Sv = satured volume (cm^{-3}). 5 samples are used per region of each clone

2.4 Statistical analysis

Descriptive statistical analysis was initially performed. This was followed by performing a normality test to observe the data distribution. For the comparison among *Hevea brasiliensis* clones. a parametric analysis of variance (One Way Analysis of Variance) was applied. In the case of significant difference. Tukey´s test was applied to identify pairwise determinants of differences. Results with $p<0.001$ were considered as significant. All statistical analyses were performed using the SigmaPlot software - Exact Graphs and Data Analysis - version 12.3 (Systat Software Inc. San Jose. CA. USA).

3. RESULTS AND DISCUSSION

Several studies mention that gradual increase in some anatomical features in radial variation is a rule in most wood species (Lanchenbruch et al., 2011). However, these variations must be studied and understood in each species. Although there is a gradual increase in anatomical features in radial directions, it does not mean that there will be statistical differences. What was observed in some anatomical features in this study. It was possible to observe specific and distinct variations for each anatomical features individually in each clone (Table 2).

Table 2-Radial variation of wood anatomical features and basic density of 10 clones of 12-year-old *Hevea brasiliensis*.

Radial position	FL µm	FWT µm	DV µm	FV (nºmm^{-2})	RH µm	RW µm	LF (nºmm^{-1})	BD (g.cm^{-3})
IAC 40								
Pith	873b	3.9a	82b	1.8a	314a	37a	6.8b	0.393b
Middle	1005a	3.0b	92 a	1.4 a	306a	41a	7.8a	0.394b
Bark	1025a	3.0b	99 a	1.3a	307a	40a	7.0ab	0.415^{a}
Mean	967CD	3.3C	91DE	1.5BCD	309DE	39D	7.2BCD	0.414B
IAC 41								
Pith	821b	3.6a	104b	1.6a	425a	52a	7.7b	0.425^{a}
Middle	939 a	4.2a	118 a	1.1b	326b	42b	7.1b	0.409^{a}
Bark	981 a	3.5a	130 a	1.2ab	346b	53a	8.9a	0.407^{a}
Mean	914D	3.7A	117 A	1.37BCD	366B	49BC	7.9AB	0.413B
64B 850								
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	0.472^{a}
Bark	1024b	3.0a	102 a	1.2a	374a	49a	7.0a	0.437b
Mean	1043AB	3.1C	112AB	1.24CDE	366B	49B	6.9DE	0.456AB
IAC 311								
Pith	969b	3.0b	98 a	1.4a	376b	51b	7.8a	0.447b
Middle	1003ab	2.5b	104 a	0.9a	456a	59a	7.7a	0.465^{a}
Bark	1077 a	3.7a	105 a	0.9a	416ab	61a	7.3a	0.443b
Mean	1017BC	3.0C	102BC	1.08A	416A	57A	7.6BC	0.451B

IAC 301								
Pith	929a	3.0a	70c	1.3b	338b	35b	10.1a	0.435b
Middle	951 a	2.3b	91 a	1.6b	305b	38b	8.5b	0.461^{a}
Bark	992 a	2.7ab	79b	2.3a	407a	48a	6.6c	0.408b
Mean	957D	2.6D	80EF	1.77AB	350BC	40D	8.4A	0.435B
IAN 873								
Pith	1179 a	4.2a	109 a	2.2a	393a	52a	5.0a	0.451^{a}
Middle	961b	3.8a	82b	2.1a	341b	44b	4.8a	0.404^{a}
Bark	1165a	4.3a	92b	1.9a	361ab	48ab	4.6a	0.419^{a}
Mean	1102A	4.1AB	94CD	2.13A	365B	48BC	4.8H	0.426B
GT1								
Pith	844b	3.9a	64c	2.5a	302b	38b	6.4a	0.459^{a}
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	0.433^{a}
Mean	966CD	3.4C	82DEF	1.66BC	358B	41D	5.9FGH	0.433B
PB 330								
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	0.447^{a}
Mean	995BC	3.4C	113 A	1.10E	320CDE	46C	6.4EF	0.405B
FX 2261								
Pith	1024a	3.8a	85b	0.8b	335a	42a	8.1a	0.433b
Middle	1045a	3.3ab	97ab	1.2ab	361a	41a	7.2b	0.493^{a}
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
RRIM 725								
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	0.531^{a}
Mean	956CD	3.6BC	98CD	1.67BC	300E	50BC	6.0G	0.491^{a}
Mean of all clones	995	3.4	98	1.43	350	46	6.9	0.436

FL fiber length; FWT = fiber wall thickness; DV= vessel diameter; N= vessel density; RH= ray height; RW= radius width; RF= ray frequency and BD= Basic Density. Distinct letters in column differ statistically (P<0.001) by Tukey’s test. The difference between the radial positions is represented by lowercase letters, while the comparison between the clones is represented by uppercase letters.

An increase in fiber length was observed radially, except for clone 64B 850, in which middle position has longer fibers and is different from the other positions. Zobel and Talbert (1984) mention that in some species, the change from juvenile to adult wood can be abrupt, while in others, it can be gradual or not present a pattern in anatomical features.

Mean values for each fiber length position show, generally, increase from the pith to the bark. According to Tsoumis (1968), this variation is normal and occurs in most woody species. During wood development, it is followed by adult wood formation, characterized by structural organization, in which there is greater stability in physiological activities, thus influencing vascular cambium, consequently influencing anatomical structure.

In our study, fiber wall thickness showed different radial patterns. Clones IAC 40, IAC 41, IAC 301, PB 330, and FX 2261 showed a decrease in pith-bark direction. While clones GT1, IAC 311, and RRIM 725 showed an increase. Clones 64B-850 and IAN-873 showed no differences between radial positions. Malan (1992), observed an increase in fiber wall the thickness for *Eucalyptus* species, however report that in some forest species, the increase fiber wall thickness towards to the bark, occurs from 8 to 15 years of age. The trees we studied are 12 years old, according to Malan's proposal, they would be in this transition phase, so maybe we found this variation among the clones. Teoh et al. (2011), reports in 25-year-old *Hevea brasiliensis* cultivated in Malaysia, fiber wall thickness 5 to 7 µm. These values are higher than our values, that ranging from 2.3 µm in intermediate position of IAC 301 clone to 4.3 µm bark position of IAN 873 clone. Thus, we estimate that fiber wall thickness from planting trees we studied should increase with the age.

Vessel diameter followed the pattern most commonly found, i.e., an increase in diameter towards the bark (Aloni and Zimmermann 1983). In the present study, this pattern occurred in the majority of *Hevea brasiliensis* clones. Although the pattern is quite common, vessel diameter can vary between clones, Naji et al. (2012) in a study with Malaysian clones of RRIM 2020 and 2025, at 9 years of age, reported values from 127 to 208 µm from pith to the bark. This same pattern was observed by Florsheim et al. (2009) in *Eucalyptus dunii*, and in two native Brazilian species, *Luehea divaricata* (Longui et al., 2009) and *Cariniana legalis* (Lima et al., 2011).

According to Norul et al. (2008) a decrease in vessel frequency towards to the bark is expected, a result we noted for most of *H. brasiliensis* clones. However, we noted other radial variation pattern. There was a decrease towards to the bark for IAC 40, IAN 873, GT1 and PB 330 clones. However, IAC 301 presented an increase in pith to the bark direction. Clones IAC 41, IAC 311, 64B 850, FX 2261 and RRIM-725 showed lower vessel frequency in the middle position.

A possible explanation for different patterns in vessel frequency may be related to growth rate of tree in genetic materials with different origins (Zobel and Van Buijetenen 1989). Based on this knowledge is possible to estimate variations in basic density and consequently in technological behavior, e.g., in drying rate of the wood.

When we analyze mean values of each clone for diameter and frequency of vessels, we observe some differences, which may be linked to genetics, since they are different clones. Another explanation can be given by the polar movement of auxinic hormones (AIA) produced in young leaves. Once AIA flows into the wood, higher hormonal concentrations increase cell expansion, while low levels stimulate cell differentiation, which allows more time for cell development until deposition of the secondary wall, resulting in wider vessels, and possibly less frequency in a specific region of the trunk (Aloni, 2007).

Ray radial variation is less studied for commercial purposes and the patterns are not evident compared to vessels and fibers patterns. According to Florsheim et al. (2000) in a study with *E. saligna*, the pattern of ray radial variation is to become taller and wider with lower frequencies towards to the bark. Urbinati et al. (2003) also observed a decrease in ray frequency in pith-bark direction in *Terminalia ivorensis*. In the present study, exception PB 330, IAC 41 and 64B 850 clones with an increase in ray frequency towards to the bark, in most of clones we observed an increase in height and width, as well as a decrease in ray frequency from the pith to the bark. Bhat and Priya (2004) state that for most forest species bulkier rays and in lesser quantities are expected close to the bark.

Differences in radial patterns in height, width and frequency of rays are related to their functions performed on the tree. These anatomical elements are responsible for storage and lateral transport of nutritive substances, and their behavior is modulated by environmental conditions (Melo-Junior et al. 2016). Another explanation is the variation in size of ray initial cells, which change as the tree grows and gets older, and these initials cells directly interfere in cell ray size and consequently in height and width of rays (Urbinati et al. 2003).

We observed radial variation of basic density in most of clones, except for IAC 41 and IAN 873. In some clones, we noticed a higher density in middle position, a result that is not common for most forest species. In studies with *Eucalyptus* and *Pinus* clones, the most common result is increase of density towards to the bark (Malan, 1992; Polli et al, 2006; Wilkes, 1984). However, Lima et al. (2011) studying *Cariniana legalis* report a decrease in density from the pith to the bark. This indicates that pattern may be different in native trees, or that results we found in *H. brasiliensis* may be related to youth of trees and that the pattern may change over time.

According to Fujiwara et al. (1991) it is expected that wood presents a positive relation between basic density and fiber length and fiber wall thickness, which was not observed for most of clones, in clone RRIM 725 we observe a higher basic density and shorter fiber compared to other clones. However, we observe that clones with lower basic density have higher ray frequency, which can contribute to decrease in density, since ray cells have a thinner wall compared with fibers and should contribute less to wood mass and consequently with density.

4. CONCLUSIONS

In general, *Hevea brasiliensis* wood clones is characterized radially (pith-bark):

Increased in fiber length and decreased in fiber wall thickness;

Most of clone presents increase in vessel diameter and 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, being a characteristic of young wood;

Basic density presents different patterns among clones, with increase, decrease towards to the bark or higher density in the middle position.

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CONSIDERAÇÕES FINAIS

Estudos como esse são importantes para caracterizar uma determinada espécie que possui potencial para geração de produtos de maior valor agregado.

Considerando que os clones estudados apresentam 12 anos de idade quando foram caracterizadas suas propriedades tecnológicas, nota-se que a espécie desde idades mais jovem possui características tecnológicas satisfatórias, para usos como fonte bioenergética e uso para produção de móveis.

A utilização da madeira contribuirá ainda mais com a liderança do Brasil no setor de energia renováveis. Visto que hoje a madeira do gênero eucalipto é a matéria prima mais consagrada para essa finalidade. Contudo, clones de *Hevea brasiliensis* aos 12 anos de idade também apresentam características energéticas satisfatórias para serem utilizadas como bioenergia. Fato que pode contribuir ainda mais para a liderança brasileira no setor energético.

A madeira de *Hevea brasiliensis* é uma alternativa viável para utilização e diminuição da exploração de florestas nativas para móveis, pois apresenta como características principais, coloração clara, que pode ser combinada e manipulada para obtenção de outras matizes quando é levada em consideração a estética e rusticidade de peças de origem de florestas nativas.

RECOMENDAÇÕES FINAIS

Analisar a madeira com diferentes idades, para determinar qual é a idade em que a madeira apresentará características tecnológicas satisfatórias antes da renovação do plantio. Exemplo: 8, 13, 18, 23 e 28 anos;

Elaboração de um programa de secagem convencional e ao ar para prever os principais problemas que ocorrem nas peças de madeira e como diminuir a ocorrências de defeitos que depreciam a qualidade final do produto;

Correlacionar todas as propriedades da madeira com a usinagem para determinar qual a propriedade que mais afeta a qualidade da superfície da madeira para usos de finalidade moveleira.