Research, Society and Development, v. 10, n. 10 e549101019102, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i10.19102

Technological potential of fibers from 20 *Hevea brasiliensis* clones for use as pulp, paper, and composite materials

Potencial tecnológico das fibras de 20 clones de *Hevea brasiliensis* para uso como celulose, papel e materiais compósitos

Potencial tecnológico de las fibras de 20 clones de *Hevea brasiliensis* para su uso como pulpa, papel y materiales compuestos

Received: 08/05/2021 | Reviewed: 08/13/2021 | Accept: 08/16/2021 | Published: 08/18/2021

Erick Phelipe Amorim
ORCID: https://orcid.org/0000-0002-8964-0770
Universidade Federal de São Carlos, Brazil
E-mail: erick.amorim95@hotmail.com
João Roberto Menucelli
ORCID: https://orcid.org/0000-0002-5615-6448
Universidade Federal de São Carlos, Brazil
E-mail:jmenucelli@hotmail.com
Aline Delfino Germano
ORCID: https://orcid.org/0000-0002-0728-1517
Universidade Federal de São Carlos, Brazil
E-mail:germanoad@outlook.com.br
Rubens Francisco Pereira de Farias
ORCID: https://orcid.org/0000-0002-8439-9332
Universidade Federal de São Carlos, Brazil
E-mail: rpereira.ecoflorestaljr@gmail.com
Juraci de Andrade Barbosa
ORCID: https://orcid.org/0000-0002-8306-4514
Instituto de Pesquisas Ambientais do Estado de São Paulo, Brazil
E-mail: juraci_andrade@hotmail.com
Franciane Andrade de Pádua
ORCID: https://orcid.org/0000-0002-3349-8648
Universidade Federal de São Carlos, Brazil
E-mail: franciane@ufscar.br
Miguel Luiz Menezes de Freitas
ORCID: https://orcid.org/0000-0001-8882-0908
Instituto de Pesquisas Ambientais do Estado de São Paulo, Brazil
E-mail:miguellmfreitas@yahoo.com.br
Marcela Aparecida de Moraes
ORCID: https://orcid.org/0000-0003-3572-9291
Universidade Estadual Paulista, Brazil
E-mail: marcela.apmoraes@gmail.com
José Cambuim
ORCID: https://orcid.org/0000-0003-0839-633X
Universidade Estadual Paulista, Brazil
E-mail: josecambuim@yahoo.com.br
Mário Luiz Teixeira de Moraes
ORCID: https://orcid.org/0000-0002-1076-9812
Universidade Estadual Paulista, Brazil
E-mail: mario.moraes@unesp.br
Paulo de Souza Gonçalves
ORCID: https://orcid.org/0000-0002-5019-1832
Instituto Agronômico de Campinas, Brazil
E-mail: paulog@iac.sp.gov.br
Eduardo Luiz Longui
ORCID: https://orcid.org/0000-0002-7610-9147
Instituto de Pesquisas Ambientais do Estado de São Paulo, Brazil
E-mail:edulongui@gmail.com

Abstract

Based on the use of *Hevea brasiliensis* in latex production, the species has a consolidated role in the Brazilian economy. However, at the end of the production cycle, which lasts from 25 to 30 years, resulting wood, in general, has no added value and is normally used for firewood, without further exploring its technological properties. Seeking to introduce this species into the pulp and paper industry, we aimed to determine the fiber quality of 20 commercial clones. Wood samples were collected from planted trees (11 to 12 years old) in the municipality of Selvíria - MS. We calculated wood quality indexes of *H. brasiliensis* for cellulose and paper, including Flexibility coefficient, Wall proportion, Runkel ratio, Slenderness ratio (Aspect ratio), and Luce's Shape Factor. The fiber quality indexes that best indicate the potential use of wood from Hevea brasiliensis clones for cellulose and paper production were Wall Fraction, Runkel Ratio and Luce's Shape Factor, indicating that *H. brasiliensis* fibers, if used for proper industrial purposes, will give origin of a rigid paper with greater bonding contact on the surface. The clones that presented better results for fiber quality indexes were IAC 311, IAC 41, IAN 873, IAC 326, IAC 40 and RRIM 725. Enabling the use of wood after the latex exploratory cycle for pulp and paper will serve as a basis for genetic improvement of these clones and expansion of forest plantations for this purpose.

Keywords: Fiber dimensions; Native species; Qualitative wood indexes; Wood quality.

Resumo

Devido ao uso de *Hevea brasiliensis* na produção de látex, a espécie tem um papel consolidado na economia brasileira. No entanto, ao final do ciclo produtivo, que dura de 25 a 30 anos, a madeira resultante, em geral, não apresenta valor agregado e é normalmente utilizada na produção de lenha, sem conhecimento de suas propriedades tecnológicas. Buscando introduzir esta espécie na indústria de celulose e papel, objetivamos determinar a qualidade das fibras de 20 clones comerciais. Amostras de madeira foram coletadas de árvores plantadas (11 a 12 anos) no município de Selvíria – MS. Calculamos os índices de qualidade da madeira de *H. brasiliensis* para celulose e papel: coeficiente de flexibilidade, fração de parede, índice de Runkel, razão esbeltez (razão de aspecto), fator de forma de Luce. Os índices de qualidade das fibras que melhor indicam o potencial emprego da madeira dos clones de *Hevea brasiliensis* para a produção de celulose e papel foram: Fração Parede, Razão Runkel e Fator de Forma de Luce, indicando que as fibras da espécie se utilizadas pela indústria dará origem a um papel rígido, com maior contato de união na superfície. Os clones que apresentaram melhores índices de qualidade das fibras foram IAC 311, IAC 41, IAN 873, IAC 326, IAC 40 e RRIM 725. Possibilitando a utilização da madeira pós ciclo exploratório do latéx para a celulose e papel e servindo de base para melhoramento genético desses clones e ampliação dos plantios florestais para essa finalidade.

Palavras-chave: Dimensões das fibras; Espécie nativa; Índices qualitativos da madeira; Qualidade da madeira.

Resumen

Atribuido al uso de Hevea brasiliensis en la producción de látex, una especie tiene un papel consolidado en la economía brasileña. Sin embargo, al final del ciclo de producción, que dura de 25 a 30 años, la madera resultante, por lo general, no tiene valor agregado y se utiliza normalmente en la producción de leña, sin conocimiento de sus propiedades tecnológicas. Con el objetivo de introducir esta especie en la industria de la pulpa y el papel, nos propusimos determinar la calidad de la fibra de 20 clones comerciales. Se recolectaron muestras de madera de árboles plantados (de 11 a 12 años) en la ciudad de Selvíria - MS. Calculamos los índices de calidad de la madera de H. brasiliensis para pulpa y papel: coeficiente de flexibilidad, fracción de pared, índice de Runkel, relación de esbeltez (relación de aspecto), factor de forma Luce. Los índices de calidad de la fibra que mejor indican el uso potencial de madera de clones de Hevea brasiliensis para la producción de celulosa y papel fueron: Wall Fraction, Runkel Ratio y Luce Form Factor, lo que indica que las fibras de la especie son utilizadas por los orígenes diseñados por la industria. a un papel rígido, con mayor contacto de unión en la superficie. Los clones con los mejores índices de calidad de fibra fueron IAC 311, IAC 41, IAN 873, IAC 326, IAC 40 y RRIM 725. Habilitar el uso de madera después del ciclo exploratorio del látex para pulpa y papel y servir como base para la mejora genética de clones y expansión de plantaciones forestales para estos metales.

Palabras clave: Dimensiones de la fibra; Especies nativas; Índices de madera cualitativos; Calidad de la madera.

1. Introduction

Pulp production in Brazil has grown at rates higher than those seen by other producers in the world. According to Industria Brasileira de Árvores (2020), Brazil is the world's second largest producer of cellulose, behind only the United States, and ranks tenth in the world in paper production.

The success of Brazilian industry in pulp and paper production was the result of forest genetic improvement strategies, mainly for *Eucalyptus* spp., owing to its rapid growth, short rotation and excellent physical and chemical wood properties (Alves et al. 2021).

In the face of new technologies, common sense would be sufficient to predict a decrease in paper use. However, in practice, the demand for pulp and paper has remained stable or demonstrated an increasing bias. Therefore, it is worthwhile looking for new species that can meet this demand. In this context, we highlight the rubber tree, another species native to Brazil, with long-standing importance in the Brazilian forest industry. Lima et al. (2000) reports that the rubber tree is native to the Amazon region and that Brazil has ten of the eleven known species. Botanically, the rubber tree is a dicotyledon from the *Hevea* genus, Euphorbiaceae family, all species of which are arboreal. These species have good edaphoclimatic adaptation characteristics and fast growth in tropical and subtropical environments (Santos et al. 2020).

According to Carretero and Mello (1988), in 1972, the first rubber tree production program was created with the goal of reaching 18 thousand planted hectares, in 1977 the second program with a goal of 120 thousand hectares, and in 1981, the third program with a goal of 40 thousand hectares. In 1988, approximately 150 thousand hectares were financed for the planting of rubber trees in Brazil.

Since 1995, the State of São Paulo has been consolidated as the main producer of the species, representing 56% of the country's production (Gonçalves et al. 2001). This can be attributed to genetic improvement research carried out by the Instituto Agronômico de Campinas-IAC. The planted area in Brazil has been increasing significantly from 159,500 ha to 218,307 ha in 2018, and the growth of forest plantations of the species should increase in the next decade, according to projections in the most recent report of the Brazilian Tree Industry - IBA (2020).

The expansion of rubber tree planting in Brazil resulted in an abundant supply of wood from this culture at the end of its rotation (25-30 years), leading to interest in studies on this raw material. In Brazil, wood obtained at the end of the latex production cycle is traditionally used as firewood, despite its good workability characteristics, such as gluing, nailing, and perforation, being easily bent with the use of steam and easily dyed (Eufrade Junior et al. 2015). Research shows that *Hevea brasiliensis* wood has potential for use as a raw material for bioenergy (Menucelli et al. 2019) and reconstituted panels (Okino et al. 2009; Iwakiri et al. 2017). Furthermore, this wood has good mechanical properties (Leonello et al. 2012), as well as colorimetric characteristics for indoor use (Autran; Gonçalez, 2006).

Although it is a tradition in Brazil to use fibers from *Eucalyptus grandis*, *E. saligna*, and hybrid *E. grandis* x *E. urophylla* for pulp and paper production, the characterization of wood from alternative species, such as *Hevea brasiliensis*, especially from different genetic materials at an early age, is strategic for the proper disposal of clonal materials in post-exploitation stands and for ensuring the supply of fibers to the market. In addition, *Hevea brasilienses* fibers can be used as reinforcement in composite materials. The application of vegetable fibers as reinforcement in composites depends on the availability, cost and inherent properties of each fiber. Reinforcement capacity depends on the type of fiber, amount used, its geometry, and length and thickness ratio (aspect ratio) (Ardanuy et al. 2015).

The economic importance of *Hevea brasiliensis* is well established, and productive areas have advanced in Brazil, but available scientific information on the technological characterization of the species is lacking. Therefore, our goal here was to determine the technological potential of 20 clones of *Hevea brasiliensis* for paper and cellulose production, as well as fiber potential for use in composite materials.

2. Methodology

Hevea brasiliensis wood samples were collected from 60 trees, three from each clone, in the municipality of Selvíria, State of Mato Grosso do Sul (20 ° 20 ′ S, 51 ° 24 ′ W, elevation 350 m). The planting of Hevea brasiliensis was established in 2006 at a spacing of 3 × 3 m from the seeds of free-pollinated clones (Table 1). The collection of study material was carried out in 2017 and 2018 at 11 and 12 years of age. The soil of the experimental area was classified as Red Latosol, clayey texture, typical clayey dystrophic, moderate A horizon, hypodystrophic, alic, kaolinitic, ferric, compacted, very deep and moderately acidic (LVd) (Santos et al., 2018) The relief it is characterized as moderately flat and wavy. The local climate is of the Aw type, according to Köppen's classification, with an average annual temperature of 24.5 °C, an average annual humidity of 64.8%, an average annual precipitation of 1232.2 mm and an average insolation of 7.3 hours / day (Hernandez; Lemos Filho; Buzetti, 1995). The origin of the genetic material of the clones studied is reported in Table 1. The material was split into disks in the forest products laboratory of the São Paulo Forestry Institute. The origin of the genetic material of the studied clones is reported in Table 1.

Table 1. Parental clone of the 20 clones of *Hevea brasiliensis* used for technological characterization of wood.

Progenies	Material genetics	Source
IAC 15	[RRIM 507 (Pil B 84 x Pil A 44) x RRIM 600 (Tjir x PB 86)]ill.	Brazil
IAC 40	[RRIM 608 (AVROS 33 x Tjir 1) x AVROS 1279 (AVROS 256 x AVROS 374)]ill.	Brazil
IAC 41	[RRIM 608 (AVROS 33 x Tjir 1) x AVROS 1279 (AVROS 256 x AVROS 374)]ill.	Brazil
IAC 44	[IAN 2325 (PB 86 x Fx 3993) x AVROS 1328 (AVROS 214 x AVROS 374)]ill.	Brazil
IAC 301	[RRIM 605 (Tjir 1x PB 49) x AVROS 1518 (AVROS 214 x AVROS 256)ill.	Brazil
IAC 307	AVROS [1328 (AVROS 214 x AVROS 317) x PR 107]ill.	Brazil
IAC 311	[AVROS 509 (Pil A 44 x Lun N) x Fx 25(F 351 x AVROS 49)]ill.	Brazil
IAC 326	[RRIM 623(PB 49 x Pil B 84) x Fx 25(F351 x AVROS 49)]ill.	Brazil
IAN 873	(PB 86 x FB 1717)ill.	Brazil
Fx 2261	(F1619 x AVROS 183)ill.	Brazil
Fx 3864	(PB 86 x FB 38)ill.	Brazil
ROI 110	Primary Clone	Brazil
MT 45	Primary Clone	Brazil
RRIM 600	(Tjir 1 x PB 86)ill.	Malaysia
RRIM 725	Fx 25 (F351 x AVROS 49) ill.	Malaysia
PB 235	[PB 5/51(PB 56 x PB 24) x PB 5/78 (PB 49 x PB 25)]ill.	Malaysia
PB 330	[PB 51/51 (PB 56 x PB 24) x PB 32/36(PB 49x PB 186)] ill.	Malaysia
1-12-56-77	Primary Clone	Malaysia
GT1	Primary clone	Indonesia
IRCA 111	[RRIM 507 (Pil B 50 x Pil B 84) x Fx 25 (F361 x AVROS 49)]ill.	Costa do Marfim

ill., illegitimate: (clone obtained from an open-pollinated parent plant); Brazilian clones (Fx: Ford; IAN: Instituto Agronômico do Norte; IAC: Instituto Agronômico de Campinas, MT: Mato Grosso, RO: Rondônia); Indonesian clones (GT: Godang Tapen); Malaysian clones (PB: Prang Besar, RRIM: Rubber Research Institute of Malaysia); Clone from Côte d'Ivoire (IRCA: Institute de Recherches sur le Caoutchou) Primary clone: from unknown parents obtained from the vegetative multiplication of a parent tree with desirable characters.
Source: Authors.

Small wood samples from each clone were used for maceration using Franklin's method (Berlyn and Miksche, 1976). Then they were transformed into small samples for dissociation in hydrogen peroxide following the methodology proposed by Johansen (1940). Then these wood fragments were stained with aqueous safranin and temporarily mounted in a solution of water and glycerin (1:1). Measures followed by the recommendations of the IAWA Committee (1989). Quantitative data is based on at least 30 measurements for each characteristic of each tree, thus meeting the statistical requirements for the minimum number of measurements.

From the values of length (L), diameter (D), lumen diameter (d) and fiber wall thickness (w), we calculated the following ratios for pulp and paper: coefficient of flexibility (FC), wall proportion (WP), runkel ratio (RR), slenderness ratio or aspect ratio (SR), Luce form factor (LSF) (Pirralho et al. 2014) and aspect ratio (AR) (Hull and Clyne 1996).

$$\text{Flexibility coefficient} = \frac{d}{D} \qquad Eq.1$$

$$\text{Wall proportion} = \frac{2w}{D} x\ 100 \qquad Eq.2$$

$$\text{Runkel ratio} = \frac{2w}{d} \qquad Eq.3$$

$$\text{Slenderness ratio or Aspect ratio} = \frac{L}{D} \qquad Eq.4$$

$$Luce's\ Shape\ Factor = \frac{D^2 - d^2}{D^2 + d^2} \qquad Eq.5$$

Wood density was calculated according to NBR 11941, Brazilian Association of Technical Standards - ABNT (2003). The samples were saturated in water until the wood presented moisture above the fiber saturation point, then they were dried in ovens until they presented constant mass, we use ten bodies of evidence for each clone. The basic density was obtained according to equation 6.

$$\text{Wood density} = \frac{Dm\ (g)}{Sv\ (cm^3)} \qquad Eq.6$$

Cluster analyses were performed with means of clones and their variables. Later, data were standardized so that they all had a common scale, but without distorting their difference, where the mean was equal to zero, and standard deviation was equal to 1. For this standardization, the Standardize tool in the software was used. The Euclidean distance was used as a measure of similarity, and the unweighted pair group method with arithmetic mean (UPGMA) was used to determine the groups. Through the cophenetic correlation coefficient, the dendrogram generated was evaluated. Through the generation of clusters, clone averages in their given groups were used. The analyses were performed based on the correlation between data. For the number of principal components, it was determined that the sum of two components presented more than half of the data representation (*i.e.*, estimated variation in the ordinate of the auto values). All analyses were performed in the R statistical software environment (R Development core team, 2021).

3. Results and Discussion

Material quality for cellulose and paper production can be evaluated by wood properties, *e.g.*, basic density and fiber features (Istikowati et al. 2016). The distribution of cell types determines wood quality attributes of pulp and paper. For example, interconnection, tear resistance, compression, and tension are related to the junction of wood density and fiber features in a manner that defines the properties of the final product (Downes et al. 2002). Mean, maximum and minimum values of each variable are shown in Table 2.

Table 2. Mean, maximum and minimum values of descriptive statistics applied to original variables of 20 *Hevea brasiliensis* clones.

Statistics	WD	FL	FD	FLD	FWT	FC	WP	RR	SR/AR	LSF
Mean	0.46	1078.25	24.10	15.78	4.16	65.50	34.62	0.56	47.36	0.40
Maximum	0.65	2692.83	49.70	35.10	10.20	97.77	82.84	0.96	89.65	0.90
Minimum	0.30	503.97	14.34	9.40	3.00	23.20	10.15	0.22	20.19	0.20

WD: Wood Density; FL: Fiber Length; FD: Fiber Diameter; FLD: Fiber Lumen Diameter; FWT: Fiber Wall Thickness; FC: Flexibility Coefficient; WP: Wall Proportion; RR: Runkel Ratio; SR: Slenderness Ratio/AR: Aspect ratio; LSF: Luce's Shape Factor.
Source: Authors.

The mean density for 20 *Hevea brasiliensis* clones was 0.46 g.cm³, which is considered medium, according to the classification by Silva et al. (2015). Currently, the industrial standard for pulp and paper derived from *Eucalyptus* forests prefers density values between 0.40 to 0.55 g.cm³ (Dias; Simonelli, 2013). Woods with a density lower than 0.40 g.cm³ have reduced yield, higher consumption of reagents and a high reject content. Woods with a density above 0.55 g.cm³ present greater difficulties in chipping logs, which causes wear on the mincer knives (Dias; Simonelli, 2013), and pulps with less fiber binding (Ferreira et al. 1997). Thus, wood density of *H. brasiliensis* clones fits within acceptable limits of basic density for production and yield in the industrial production process.

Mean values of fiber features are close to those reported by Naji et al. (2011) who characterized the wood quality of 9-year-old *H. brasiliensis* Malay clones, considered juvenile, as having fiber length of 1187 μm, fiber diameter of 27.26 μm, fiber lumen diameter of 17.32 μm, and fiber wall thickness of 4.97 μm, as well as density varying from 0.55 to 0.60 g.cm³. Differences in the values of anatomical features are directly related to the edaphoclimatic conditions under which the tree develops (Rigatto et al. 2004), affecting its characteristics and consequently its use.

In characterizing wood fiber, flexibility coefficient values above 60% are desired for production of pulp and paper (Foelkel et al. 1987). However, with these FC values, looser and looser mesh papers are produced without much bonding between fibers. Thus, *H. brasiliensis* clones with an average FC value of 65.50% are likely to have longer and thicker fibers that can be used for purposes requiring mechanical effort, such as packaging and printing (Menegazzo, 2012).

Wall fraction is related to fiber firmness such that the higher its value, the more rigid it can become, affecting paper strength (Gonçalez et al. 2014). Currently, the reference value in the pulp and paper industry for *Eucalyptus* clones is 40% for production of writing and printing paper, as it results in greater fibrous pulping, greater intertwining of fibers and the potential of fiber-to-fiber contact. These properties improve traction, bursting, tearing, folding, surface resistance and internal resistance of the sheet, according to Baldin et al. (2017). For rubber tree clones, an average value of 34.62% was observed, suggesting that the paper produced will have good opacity, ink absorption and mechanical resistance.

The Runkel ratio measures the degree of fiber collapse during the paper production process such that the lower the RR, the greater the collapse. This allows the fibers to have a larger contact surface, establishing a greater number of bonds, which, in turn, results in paper with greater strength to traction and overflow (Talgatti et al. 2020). RR values can be classified, in general, from 0.56 as good, since Runkel (1952) proposed that fiber with an index up to 0.25 is considered excellent for paper. RR values from 0.25 to 0.50 can be considered very good, from 0.50 to 1.0 good, and 1.0 to 2.0 regular. RR values above 2.0 indicate fibers with thick or very thick walls and easy to tear, resulting in poor paper product. According to Nisgoski et al. (2012), high values are not desired since the fiber becomes rigid with greater difficulty in accommodation and union on the paper sheet. Therefore, RR values of *H. brasiliensis* clones in this study can be classified as good for paper production.

The slenderness ratio is directly related to tear and breakage strength of fibers. Therefore, values from 40 to 60% present good paper characteristics in tearing and double folding (Mongolon; Aguilera, 2002). The mean value in the present study was 43.81%, which is in line with industrial requirements based on the weakness in paper formation. Slenderness ratio is also related to digestibility of the pulp (Ohshima et al. 2005), meaning that it is easy to obtain water-soluble and absorbable pulp from *H. brasiliensis* wood.

In architecture, the slenderness ratio is an aspect ratio, *i.e.*, the quotient between building height and width. From this perspective, slenderness is used to calculate the propensity of a column to buckle (Willis, 2016). In this context, aspect ratio (slenderness ratio) is used in many studies on use of wood fibers together with other materials, categorized as composite material, which, according to Hull & Clyne (1996), is composed of two or more phases, which have different physicochemical properties. Composite materials have a matrix and another material that serves as reinforcement (*e.g.*, wood fibers), so the properties are determined by the combination of different materials used. The value of aspect ratio or slenderness ratio can vary, depending on fiber type and design, assuming values from approximately 50 to 500 (Hull; Clyne, 1996). Aspect ratios can affect properties, such as the strain to failure and toughness. A higher aspect ratio will result in lower values of strain at failure and toughness because angular particles induce crack formation (Oréfice et al., 2001).

Luce's shape factor is particularly important when considering the technological potential of *H. brasiliensis* wood for use in the pulp and paper industry. This measure is directly related to the final density of the paper sheet and thus a property used in the selection of wood quality in forest improvement programs. The mean value of *H. brasiliensis* clones was 0.40. This value is lower than the range of values from 0.50 to 0.60 for *Eucalyptus* spp. used for cellulose and paper production (Baldin et al. 2017; Pirralho et al. 2014), indicating the formation of a thinner, less dense, and lighter weight paper (g.m²).

It was possible to observe heterogeneity in relation to the grouping of variables for 20 clones in the formation of different clusters (Table 3), and four different clusters emerged from the dendrogram (Figure 1).

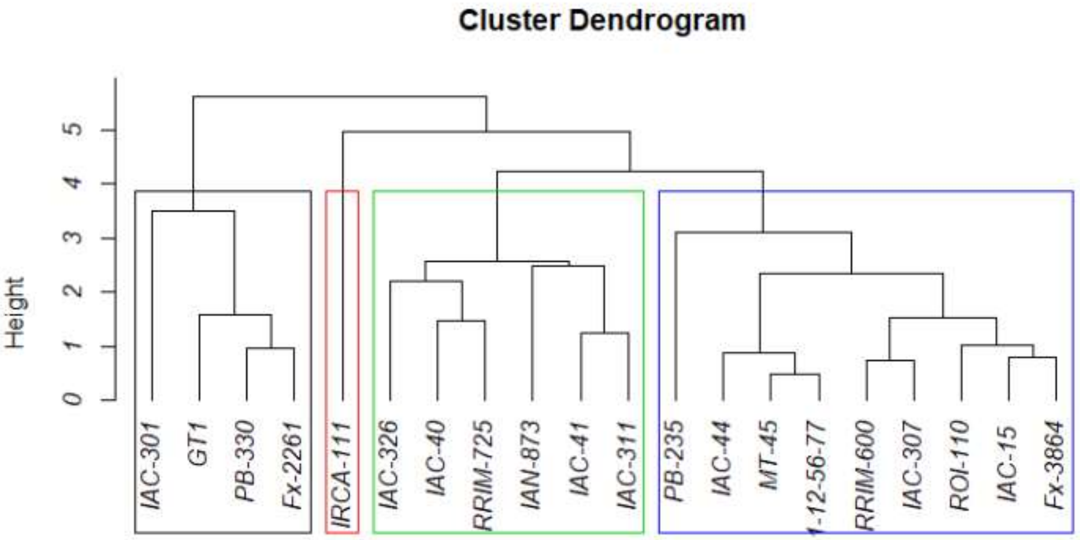
Table 3. Averages of clusters formed from fiber features and fiber quality indexes for pulp and paper of 20 *Hevea brasiliensis* clones.

Cluster	WD	FL	FD	FLD	FWT	FC	WP	RR	SR/AR	LSF	AR
1	0.44	935.63	19.42	13.37	3.02	68.40	31.60	0.50	54.70	0.36	0.44
2	0.46	1747.37	27.79	17.95	4.92	64.77	35.23	0.56	63.43	0.41	0.46
3	0.44	958.18	21.34	13.74	3.80	64.02	35.98	0.61	47.93	0.42	0.44
4	0.49	1147.33	27.61	17.98	4.82	65.27	34.99	0.55	41.94	0.40	0.49

WD: Wood Density; FL: Fiber Length; FD: Fiber Diameter; FLD: Fiber Lumen Diameter; FWT: Fiber Wall Thickness; FC: Flexibility Coefficient; WP: Wall Fraction; RR: Runkel Ratio; SR: Slenderness Ratio; AR: Aspect ratio; LSF: Luce's Shape Factor.
Source: Authors.

In the cluster analysis, cluster 1, formed by clones IAC 301, GT1, Fx 2261, and PB330, was united because the clone cluster presented lower densities and higher flexibility coefficients (mean of 68.40%) (Table 3), as well as flexibility coefficient close to that of cluster 2. In this group, it is noteworthy that clones Fx 2261 and IAC 301 (Table 1) indicate that this genetic material from Brazil should be used in genetic improvement programs for gains in flexibility coefficients, emphasizing that this index allows better intertwining of fibers in paper formation (Castelo, 2007; Magasha, 2019).

Figure 1. Cluster similarity dendrogram based on fiber features and fiber quality indexes for pulp and paper of 20 *Hevea brasiliensis* clones.



Source: Authors.

Cluster 2, formed by clone IRCA 111, the only clone in the study from Côte d'Ivoire, showed greater similarity with the others, especially with the clones in cluster 3, formed predominantly by Brazilian clones, except for clone RRIM 725 of Malay origin (Table 1). This cluster analysis demonstrates that clones genetically distinct from the Brazilian ones have similar characteristics of a product with greater added value. The characteristics that determined the similarity between the clones were Runkel ratio and Luce’s shape factor, indicating that these clones present good interconnection of fibers in paper formation (Magasha, 2019).

Cluster 4 presents the largest number of clones with similar characteristics, totaling nine according to the dendrogram analysis (Figure 1). The clones in this group were grouped according to their superiority in terms of wood density, fiber diameter and fiber wall thickness. It is expected that wood density presents higher values in the presence of increased diameter and thickness of fiber wall (Paulino; Lima, 2018) and that these features influenced the clustering by similarity among the clones.

The PCA analysis is shown in Table 4. Here, the fiber quality index least related to pulp and paper production is flexibility coefficient showing negative values in two axes. As mentioned in the study, this occurs because *H. brasiliensis* wood presents values above 60%, which provides for the formation of a loose paper network for bleached pulp, but still has interesting values for production of packaging paper. However, positive values were noted for PC1 and PC2 for wall fraction, Runkel ratio, and Luce’s shape factor, the latter being important in the selection of potential species for cellulose and paper based on fiber quality. Intrinsic behavior was observed for slenderness ratio, which has the first negative matrix and the second positive matrix, but with a low relationship, demonstrating that slenderness ratio has little influence on the selection of clones for pulp and paper, considering the influence on tear and fold of the paper.

Table 4. Principal component analysis of fiber features and fiber quality indexes for 20 *Hevea brasiliensis* clones.

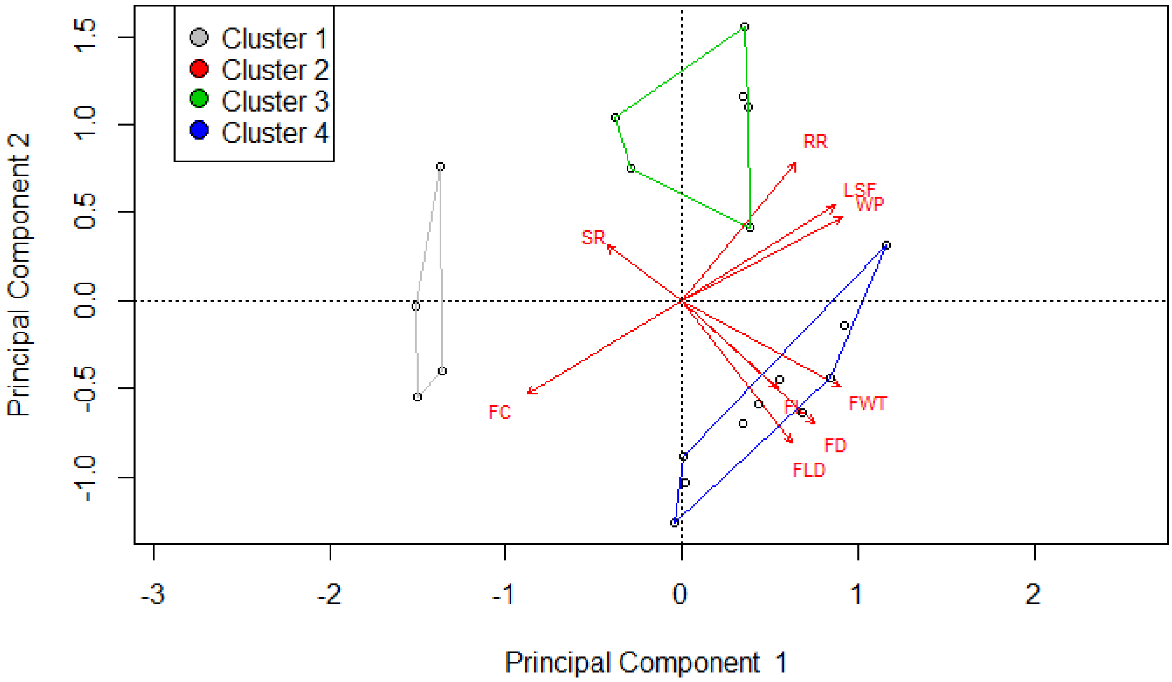
Variable	PC1	PC2
FL	0.53	-0.49
FD	0.73	-0.68
FLD	0.61	-0.79
FWT	0.88	-0.47
FC	-0.85	-0.52
WP	0.89	0.46
RR	0.63	0.76
SR/AR	-0.41	0.31
LSF	0.85	0.53

WD: Wood Density; FL: Fiber Length; FD: Fiber Diameter; FLD: Fiber Lumen Diameter; FWT: Fiber Wall Thickness; FC: Flexibility Coefficient; WP: Wall Fraction; RR: Runkel Ratio; SR: Slenderness Ratio; AR: Aspect ratio; LSF: Luce's Shape Factor.
Source: Authors.

Figure 2 shows the ordering of cluster groups created based on anatomical fiber features and cellulose and paper indices for 20 *H. brasiliensis* clones. As proof that forestry is already consolidated in this country, clones grouped into cluster 3 were predominantly Brazilian clones, including IAC 311, IAC 41, IAN 873, IAC 326, IAC 40, and clone RRIM 725 of Malay origin. Cluster 3 shows positive ordering and similarity in terms of fiber quality indexes with Runkel ratio, Luce's shape factor and wall fraction being the most suitable for pulp and paper production. These values highlight the potential of Brazilian forestry of these genetic materials for large-scale production.

The indices that stood out for presenting positive PC1 and PC2 were wall fraction, Runkel ratio and Luce's shape factor. These results indicate that *H. brasiliensis* fibers, if used by industry, will give rise to a rigid paper with greater contact in the surface union, as well as a paper with greater resistance to traction and bursting. Such properties make it possible to use this material from younger ages for this purpose and provides an economically viable use for the wood after the latex exploratory cycle.

Figure 2. Ranking generated by Principal Component Analysis based on the entire dataset obtained from anatomical features from 20 *Hevea brasiliensis* clones.



Source: Authors.

4. Conclusion

Hevea brasiliensis wood from younger ages presents potential for cellulose and paper production because fiber quality parameters indicate potential for the formation of rigid paper resistant to traction and bursting with greater contact at the surface union. The clones that show similarities in fiber quality indices were IAC 311, IAC 41, IAN 873, IAC 326, IAC 40 and RRIM 725. Most of these clones are from genetic origin developed in Brazil, indicating the capacity and quality of local forestry for the advancement and expansion of plantations of the species for this end purpose.

Additionally, a detailed chemical characterization and pulp yield for the species is recommended in order to determine the percentages that are in accordance with industrial requirements regarding ash content, extractive content, lignin content and holocellulose.

Acknowledgments

The authors thank Sonia Godoy Campião (Instituto de Pesquisas Ambientais) for laboratory assistance. Erick Phelipe Amorim was supported by a Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes: Finance Code 001). The authors are grateful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES, funding code-001. To Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq for the financial support to researchers Eduardo L. Longui and Miguel LM Freitas (Forestry Institute of São Paulo); Mario LT de Moraes (UNESP-Ilha Solteira) and Paulo S. Gonçalves (Campinas Agronomic Institute).

References

Agopyan, V., Savastano, H., John, V. M., & Cincotto, M. A. (2005). Developments on vegetable fibre–cement-based materials in São Paulo, Brazil: an overview. *Cement and Concrete Composites*, 27(5), 527–536. https://doi.org/10.1016/j.cemconcomp.2004.09.004

Alves, I.C.N., Gomide, J.L., Colodette, J.L., & Silva, H.D. (2011). Caracterização tecnológica da madeira de *Eucalyptus benthamii* para a produção de celulose Kraft. *Ciência Florestal*, 21 (1), 167-174.

Ardanuy, M., Claramunt, J., Garcia-Hortal, J.A., & Barra, M. (2011). Fiber-matriz interactions in cement mortar composites reinforced with cellulosic fibers. *Cellulose*, 18, 281-289. https://doi.org/10.1007/s10570-011-9493-3

Ardanuy, M., Claramunt, J., & Toledo Filho, R. D. (2015). Cellulosic fiber reinforced cement-based composites: A review of recent research. *Construction and Building Materials*, 9 (2015) 115–128. https://doi.org/10.1016/j.conbuildmat.2015.01.035

Associação Brasileira de Normas Técnicas – ABNT. Norma NBR 11941 (2003). Determinação da densidade básica. 1, 6.

Autran, C. S., & Gonçalez, J. C. (2006). Caracterização colorimétrica das madeiras de muirapiranga (*Brosimum rubescens* Taub.) e de seringueira (*Hevea brasiliensis*) visando à utilização em interiores. *Ciência Florestal*, 16 (4), 445-451.

Baldin, T., Marchiori, J.N.C., Nisgoski, S., Talgatti, M., & Denardi, L. (2017). Anatomia da madeira e potencial de produção de celulose e papel de quatro espécies jovens de Eucalyptus L'Hér. *Ciência da madeira*, 8 (2), 114-126. DOI: 10.12953/2177-6830/rcm.v8n2p114-126

Carratero, M.V., & De Mello, A.F.F., Produção de Latéx por clones de seringueira (*Hevea* spp.) no planalto e litoral do estado de São Paulo. (1998). *An. ESALQ*, 45 (1), 151-166.

Castelo, P. A. R. Avaliação da qualidade da madeira de Pinus taeda em diferentes sítios e espaçamentos através do método não destrutivo de ondas de tensão. (2007). *Tese de Doutorado em Ciências Florestais*.

Dias, O.A., & Simonelli, G. (2013) Qualidade da madeira para a produção de celulose e papel. *Enciclopédia Biosfera*. 9 (17), 3632-3646.

Downes, G.M., Wimmer, R., & Evans, R. Underestanding wood formation: gains to commercial forestry through tree-ring research. (2002). *Dendrochronologia*, 20(1-2), 37-51. DOI: 10.1078/1125-7865-00006

Eufrade- Junior, H. J., Ohto, J. M., Silva, L. L., Palma, H. A. L., & Ballarin, A. W. (2015). Potential of rubber wood (H*evea brasiliensis*) for structural use after the period of latex extraction: a case study in Brazil. *Journal of Wood Science*, 61(4), 384-390. http://dx.doi.org/10.1007/s10086-015-1478-7.

Ferreira, G.W., Gonzaga, J.V., Foelkel, C.E.B., Assis, T.F., Raitenks, E., & Silva, M.C.M. Qualidade da celulose kraft-antraquinona de *Eucalyptus dunnii* plantado em cinco espaçamentos em relação ao *Eucalyptus grandis* e *Eucalyptus saligna*. (1997). *Ciência Florestal*, 7 (1), 41-63.

Fischer, W.J., Mayr, M., Spirk, S., Reishofer, D., Jagiello, A., Schmiedt, R., Colson, J., Zankel, A., & Bauer, W. Pulp Fines—Characterization, Sheet Formation, and Comparison to Microfibrillated Cellulose. *Polymers*, 9(366), 2-12. Doi:10.3390/polym9080366

Fowler, P.A., Hughes, J.M., & Elias, R.M. (2006). Biocomposites: Technology, Environmental Credentials and Market Forces. *Journal of the Science of Food and Agriculture*, 86 (12), 1781-1789. https://doi.org/10.1002/jsfa.2558

Gonçalves, P.D.S. (2001). Manual de Heveicultura para o estado de São Paulo. Série tecnológica. Instituto Agronômico de Campinas.https://books.google.com.br/books/about/Manual_de_heveicultura_para_o_Estado_de.html?id=_nboZwEACAAJ&redir_esc=y

Gonçalez, J. C., Santos, G. L., Silva Junior, F. G., Martins, I. S., & Costa, J. A. (2014); Relações entre dimensões de fibras e de densidade da madeira ao longo do tronco de E*ucalyptus urograndis*. *Scientia Forestalis*, 42 (101),81- 89.

Hernandez, F. B. T.; Lemos Filho, M. A. F.; Buzetti, S. Software HIDRISA e o balanço hídrico de Ilha Solteira. (1995). Ilha Solteira: Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista, 45 p. https://www.scienceopen.com/document?vid=0b494ab4-e048-4759-b6ba-716542c96254

Hull, D., & Clyne, T.W. (1996). An introduction to composite materials: University Cambrigde Press.

Iawa committee. IAWA list of microscopic features for hardwood identifcation. (1989). *IAWA Bulletin*,10, 219-332.

Industria Brasileira de árvores- IBA. Relatório anual 2019. (2020). https://iba.org/datafiles/publicacoes/relatorios/iba-relatorioanual2019.pdf

Istikowati, W.T., Aiso, H., Sunaardi, B., Sutiya, F., Oshima, T., Lizuka, K., & Yokota, S. (2016). Wood, Chemical and pulp properties of woods from less-utilized fast growing tree species found in naturally regenerated secondary forest in south Kalimantan, Indonesia. *Journal of wood chemistry and technology*, 36 (4), 250-256. https://doi.org/10.1080/02773813.2015.1124121

Iwakiri, S., Trianoski, R., Weber, A. M., Junior, E. A. B., Pereira, G. F., Bueno, J. A., Cechin, L., & Raia, R. Z. (2017). Efeito do tratamento de partículas e aceleradores de endurecimento na produção de painéis cimento-madeira de *Hevea brasiliensis*. *Floresta*, 47 (3),289-296. http://dx.doi.org/10.5380/rf.v47i3.51636

Johansen, D. (1940). Plant microtechnique. New York: McGraw-Hill Book Company Inc.

Leonello, E. C., Ballarin, A. W., Ohto, J. M., Palma, H. A. L., & Escobar, J. F. Classificação estrutural e qualidade da madeira do clone GT1 de *Hevea brasiliensis* Muell. Arg. *Floresta e Ambiente*, 19 (2), 229-235, 2012. http://dx.doi.org/10.4322/floram.2012.027

Lima, R. R., Tourinho, M. M., & Costa, J. P. C. (2000). Várzeas fluvio-marinhas da Amazônia brasileira: características e possibilidades agropecuárias.

Magasha, L.A. Review on Effect of Select Wood properties on Pulp and Paper properties. (2019) *Journal of Forestry and Environment*. 1 (2), 16-22. DOI: 10.5829/idosi.jfe.2019.16.22

Mejia, J.E.B., Fiorelli, J., Savastano, J.R, H., & Vidil, L. Evaluation of the effect of Drying and Rewetting Cycles in Eucalyptus Pulps (2015). *Internacional Journal of Engineering and Technology*, 7 (5), 397-400, 2015.

Menegazzo, M.L. (2012). Características morfológicas de celuloses branqueadas de pinus e Eucalyptus em analisador óptico automático de fibras. *Dissertação de mestrado em Ciências Florestais*.

Menucelli, J.R., Amorim, E.P., Freitas, M.L.M., Zanata, M., Cambuim, J., Moraes, M.L.T., Yamaji, F.M., Silva-Júnior, F.G., & Longui, E.L. (2019) Potential of *Hevea brasiliensis* clones, *Eucalyptus pellita* and *Eucalyptus tereticornis* wood as raw materials for bioenergy based on higher heating value. *BioEnergy Research*, 12, 992-999. http://dx.doi.org/10.1007/s12155-019-10041-6.

Miranda, M.C.M., & Castelo, P.A.R. Avaliações anatômicas das fibras da madeira de *Parkia gigantocarpa* Ducke. Ciência da madeira, v. 3, n. 2, p. 80-89. 2012.

Mogollón, G.; & Aguilera, A. (2002). Guia teórica y prática de morfologia de la fibra. Mérida: Universidad de Los Andes.

Naji, H.R., Sahri, M.H., Nobuchi, T., & Bakar, E.S. (2011). The effect of growth rate on wood and anatomical characteristics of Rubberwood (*Hevea brasiliensis* Muell. Arg.) in two different clonal trails. *Scholars Research Library*, 1(2),71-80.

Nisgoski, S., De Muniz, G.I.B., Trianoski, R., De Matos, J.L.M., & Venson, I. (2012). Características anatômicas da madeira e índices de resistência do papel *Schizolobium parahyba* (Vell.) Blake em plantio experimental. *Scientia Forestalis*, 40(93), 203-211.

Okino, E. Y. A., Teixeira, D. E., Souza, M. R., Santana, M. A. E., Silva, C. B. G., Tomaz, R. B., & Sousa, M. E. (2009). Uso da madeira de seringueira, pinus e cipreste na produção de chapas OSB. *Floresta*, 39 (2), 457-468.

Ohshima, J., Yokota, S., Yoshizawa, N., & Ona, T. (2005). Representative heights for assessing whole-tree values and the within-tree variations of derived wood properties in *Eucalyptus camaldulensis* and *E. globulus*. *Wood Fibre Science*, 37 (1), 51-65. doi: 10.1007/978-4-431-53963-6_17

Oréfice, R. L., Hench, L. L., & Brennan, A. B. (2001). "Effect of particle morphology on the mechanical and thermo-mechanical behavior of polymer composites". *Journal of the Brazilian Society of Mechanical Sciences*. 23 (1), 1–8. doi:10.1590/S0100-73862001000100001.

Pasetto, R., Terracini, B., Marsili, D., & Comba, P. (2014). Occupational Burden of Asbestos-related Cancer in Argentina, Brazil, Colombia, and Mexico. *Annals of Global Health*, 80(4), 263–268. doi: 10.1016/j.aogh.2014.09.003.

Paulino, P., & Lima, I.L. (2018) Densidade básica e dimensões celulares da madeira em clones de Eucalyptus urophylla, aos oito ano de idade. Ciência da madeira, 9(1), 8-16. doi: 10.12953/2177-6830/rcm.v9n1p9-18

Pirralho, M., Flores, D., Sousa, V.B., Quilhó, T., Knapic, S., & Pereira, H. (2014). Evaluation on paper making potential of nine Eucalyptus species based on wood anatomical features. *Industrial Crops and Products*, 54, 327–334. https://doi.org/10.1016/j.indcrop.2014.01.040

R Core Team (2021). R. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Ramos, L.M.A., Latorraca, J.V.F., Neto, T.C., Martins, L.S., & Severo, E.T.D. (2016). Anatomical Characterization of tension wood in *Hevea brasiliensis* (Will.ex.A.Juss.). Mull. Arg. *Revista Árvore*, 40, 1099-1107. https://doi.org/10.1590/0100-67622016000600016.

Rigatto, P.A., Dedeck, R.A., & Monteiro, M.J.L. (2008). Influência dos atributos do solo sobre a qualidade da madeira de Pinus taeda para a produção de celulose Kraft. *Revista Árvore*, 28 (2), 267-273. https://doi.org/10.1590/S0100-67622004000200013.

Runkel, R.O.H. (1952). Pulp from tropical wood. *TAAP*, 35 (4), 174- 178.

Santos, H.D., Jacomine, P.K.T., Anjos, L.D., Oliveira, V.D., Oliveira, J.D., Coelho, M.R., Cunha, T.D. (2018). Sistema brasileiro de classificação de solos.

Santos, S. F., Tonoli, G. H. D., Mejia, J. E. B., Fiorelli, J., & Savastano, J.R.H. (2015). Compuestos cementantes no convencionales reforzados con fibras vegetales: Una revisião de estrategias para mejorar la durabilidad. *Materiales de Construcción*, 65(317).

Santos, Y.L.A., Ribon, A.A., Bitencourt, L.F.C., Barros, L.R., Fernandes, K., Correchel, V., Leandro, W.M., Backes, C., Santos, A.J.M., & Giongo, P.R. (2020). Physical and Chemical atributes of a soil cultivated with rubber tree under three management strategies. *Semina: ciências Agrárias*, 41 (5),1987-2002. Doi. 10.5433/1679-0359.2020v41n5Supl1p1987.

Silva, J.C., Vale, A.T., & Miguel, E.P. (2015). Densidade básica da madeira de espécies arbóreas de cerradão no estado de Tocantins. Pesquisa Florestal Brasileira. 35(82), 63-75. doi: 10.4336/2015.pfb.35.82.822.

Talgatti, M., Silveira, A.G., Baldin, T., Oliveira, L.H., Santini, E.J., & Pasa, D.L. (2020). Caracterização anatômica de clones comerciais de *Eucalyptus* para a produção de papel. *Biofix Scientia Journal*, 5(1), 65-70, 2020.