Physicomechanical characterization and wood machining from 10 12-year-old *Hevea* progeny clones with potential for furniture

Caracterização físico-mecânica e usinagem de madeira de 10 progênies clonais de *Hevea* de 12 anos com potencial para móveis

Caracterización fisicomecánica y mecanizado de madera de 10 progenies clonales de *Hevea* de 12 años con potencial para muebles

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Abstract
The objective of this work was to evaluate the physical, mechanical, and wood machining properties of 10 clonal progenies with 12 years of age aiming to produce furniture. A total of 10 progenies and three trees per progenies were used, totalling 30 trees analyzed. The basic density ranged from 0.404 g.cm^{-3} (IAC 301) to 0.495 g.cm^{-3} (IAC 326), being it considered a light wood. The anisotropy coefficient values ranged from 1.05 (IAC 40) to 1.68 (PB 330) considered low to medium dimensional instability allowing the use of wood to produce furniture with low dimensional movements. In the compression test most clones fall under class C30. For MOR and MOE, it was observed greater values for IAC 326 (11666 MPa) and GT1 (9575 MPa). In wood machining tests, slightly raised large and few defects on the surface, being them considered easy to work. The results obtained for *Hevea brasiliensis*, 12 years old, allow us to affirm that wood from a younger age is an alternative for furniture production and will consequently contribute to the reduction of the exploitation and degradation of native forests in Brazil for this purpose.
Keywords: Rubber tree; Wood quality; Wood properties.

Resumo

O objetivo deste trabalho foi avaliar as propriedades físicas, mecânicas e trabalhabilidade da madeira de 10 progênies clonais de *Hevea brasiliensis* aos 12 anos de idade para a produção de móveis. Foi utilizada três árvores por progénie, totalizando 30 árvores para o estudo. A densidade básica variou de 0,404 g.cm^{-3} (IAC 301) a 0,495 g.cm^{-3} (IAC 326), sendo considerada uma madeira leve. Os valores do coeficiente de anisotropia variaram de 1,05 (IAC 40) a 1,68 (PB 330) considerado de instabilidade de baixa a média dimensão, permitindo a utilização de madeira para produzir móveis que permite pequenas movimentações. No teste de compressão, a maioria dos clones enquadram-se na classe C30. Para as propriedades mecânicas MOR e MOE, foram observados valores superiores para IAC 326 (11666 MPa) e GT1 (9575 MPa). Nos testes de trabalhabilidade de madeira, foram detectados leve arrepiamento da fibra com poucos defeitos na superfície, sendo consideradas de fáceis de trabalhabilidade. Os resultados obtidos para a madeira de *Hevea brasiliensis*, aos 12 anos de idade, permitem afirmar que a madeira desde uma idade mais jovem é uma alternativa para a produção de móveis e, consequentemente, contribuirá para a redução da exploração e degradação das florestas nativas no Brasil para este fim.
Palavras-chave: Seringueira; Qualidade da madeira; Propriedades da madeira.

Resumen

El objetivo de este trabajo fue evaluar las propiedades físicas, mecánicas y de trabajabilidad de la madera de 10 progenies clonales de *Hevea brasiliensis* a los 12 años de edad para la producción de muebles. Se utilizaron tres árboles por progenie, con un total de 30 árboles para el estudio. La densidad básica varió de 0,404 g.cm^{-3} (IAC 301) a 0,495 g.cm^{-3} (IAC 326), considerándose una madera ligera. Los valores del coeficiente de anisotropía variaron de 1,05 (IAC 40) a 1,68 (PB 330), considerados de baja a media inestabilidad, lo que permite el uso de la madera para fabricar muebles que permiten pequeños movimientos. En la prueba de compresión, la mayoría de los clones entran en la clase C30. Para las propiedades mecánicas MOR y MOE, se observaron valores más altos para IAC 326 (11666 MPa) y GT1 (9575 MPa). En las pruebas de trabajabilidad de la madera, se detectó una ligera fluencia de las fibras con pocos defectos superficiales, considerándose de fácil trabajabilidad. Los resultados obtenidos para la madera de *Hevea brasiliensis* de 12 años de edad permiten afirmar que la madera de menor edad es una alternativa para la producción de muebles y, en consecuencia, contribuirá a la reducción de la explotación y degradación de los bosques nativos de Brasil para este fin.
Palabras clave: Seringueira; Calidad de la madera; Propiedades de la madera.

1. Introduction

Hevea brasiliensis is an important forest species because it has as main purpose latex, responsible for originating several synthetic products for industrial uses: surgical gloves, condoms, production of automotive tires and various types of coating. However, the production cycle of latex per tree in Brazil is 25 years according to Lima et al. (2020). Subsequently the trees are cut to reformulate the plantation, and the wood is discarded, without the knowledge of its physical, mechanical and workability characteristics that can a raw material to be used for the production of furniture according to Ramos et al. (2016).

Currently 71% of the world's natural rubber is consumed by Southeast Asian countries. According to The Brazilian Service of Support to Micro and Small Enterprises- SEBRAE (2018), the geographical concentration in Southeast Asia can also be elected as a characteristic, with 92% of global production concentrated in the region, with 61% in only 2 countries (Thailand and Indonesia) and another 26% in 4 countries (Vietnam, China, Malaysia and India). Brazil is one of the 10 largest producers in the world, being the largest producer in Latin America according to Scaloppi-Júnior et al. (2017).

In Brazil, the state of São Paulo has been established since 1995, as the main producer of the species, representing 56% of the production in the country (Gonçalves et al. 2001). The planted area in Brazil has been increasing significantly, from 159,500 ha, to 218,307 ha in 2018, and the growth of the species is expected to increase in the next decade according to the Brazilian Tree Industry - IBA (2020).

For the furniture industry, knowledge of wood properties is essential to guarantee final product quality and optimize the use of raw material, especially for wood presenting excellent properties for multiple uses, but little studied for those purposes. Wood machining includes several operations, such as planing, molding, cutting, and drilling. In this context, understanding the relationship between the physical and mechanical properties of wood is essential to characterize the performance of raw material and use the most appropriate equipment for each purpose (Taques and Arruda, 2016). In addition, Moya et al. (2015) highlights that tropical region facilitates the establishment of new woody tree species for commercial use. However, the limiting factor is the lack of knowledge of its physical, mechanical and workability properties of wood that later allows the wood to be framed in various purposes of use.

Plantations with native species are characterized by a promising productivity, well developed in degraded areas, bring benefits to the soil, possibility of development of agroforestry and silvipastoral systems, fixation and sequestration of carbon, and use of wood for industrial use through its technological characterization according to Tenório et al. (2015).

The viability of the final product is determined by this relationship. In particular, wood density is a fundamental metric and is closely related to mechanical properties (Braz et al. 2013). Dimensional stability is also an important consideration whenever wood is exposed to large moisture flutuations in service (Glass and Zelinka, 2010). Dimensional stability is expressed by the individual shrinkage of wood in its three orthotropic axes or by its volumetric shrinkage. Shrinkage of wood varies greatly among species (Mori et al, 2003) and is affected by a number of variables like density, size and shape of a piece of wood and rate of drying. Low values of volumetric shrinkage, as well as tangential and radial shrinkage, to avoid dimensional distortion, warps and cracks are desirable and associated with good wood quality.

The mechanical properties, or properties of strength, express wood behavior when submitted to mechanical stress, and measurement of these properties allows coMParison with woods of known properties as an indication of any additional tests necessary to validate the intended use (Lahr et al. 2017). Compression parallel to grain is a mechanical property used by the Brazilian Association of Technical Standards (NBR 7190/1997) to grade lumber in different strength classes, namely, C20, C30, C40 and C60, such that the higher the class of wood, the higher its mechanical performance. Among other factors, mechanical properties vary according to species, wood moisture, density and duration of load in mechanical testing. The modulus of elasticity (MOE) and modulus of rupture (MOR) are two parameters normally evaluated in static bending tests. Both are necessary in the technical characterization of wood. MOR is also an accepted criterion of strength (Kretschmann, 2010), representing, respectively, stiffness and strength of wood in bending.

In the literature, we found some studies that characterize the technical properties of *Hevea* wood, e.g., Killmann and Hong (2000), Hashim et al. (2005), Teoh et al. (2011), Eufrade Jr. et al. (2015) and Menucelli et al. (2019). These studies showed favorable physical, mechanical and machining properties, in addition to good workability and aesthetic characteristics, with its light-colored wood, making it possible to carry out treatments to obtain other hues. However, Brazil has no history of using *Hevea* wood (Okino et al. 2009) to obtain a product with greater added value.

The work of Bandeira (2015) states that the production of furniture in Brazil is performed in an exploratory way of the Amazon rainforest and illegally on forest resources. Also, according to the author, the Amazon forest has already lost a significant area of vegetation cover and presents a large forest area already explored. The natural forests of Brazil have already lost about 12% of their forest cover to serve the Imazon furniture production market (2002). Thus, the new trend of the forest market to avoid the exhaustion and collapse of natural forests for the production of furniture is to establish forest plantations with native species and through the genetic improvement of clonal progenies to characterize the quality of the wood of the species with the purpose of selecting superior clones to be established and later marketed to meet the furniture production market.

The genetic improvement of *Hevea brasiliensis* in Brazil is recent and has been seeking clonal progenies with double aptitude for higher yield in latéx and sawn wood for industrial uses (Foelkel, 2014). However, there are few scientific works that characterize the quality of wood to produce furniture, since it is the species is widely cultivated in Brazil. Therefore, the objective of this work was to characterize the physical, mechanical and workability properties of wood at 12 years of age aiming at the use of wood for furniture.

2. Methodology

Twelve-year-old samples of rubber tree wood were collected from 30 trees (Table 1), ten clones from each of three progeny (Table 1). The trial was established in the experimental area of the University of São Paulo (UNESP), municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W, elevation 350m). The plantation was established in 2006 folowing spacing the 3 × 3 m from seeds of free-pollinated (IAC 40, IAC 41, IAC 326, 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. 2018). Twelve years later, in 2018, selected trees were felled, and logs (≈1 m in length) were taken from the main trunks of trees for physico-mechanical and machining tests.

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
IAC 326	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

Source: Authors (2021).

Ten samples were used for each progeny, totaling 100 samples. For physicomechanical tests, total samples were cut according to the standards described in each item following standard recommendations for each test. For machining tests, samples were cut and treated with chromated copper arsenate (CCA) to protect wood against fungi, bacteria, and insects, while enhancing weather resistance. Then samples were air-dried, protected from rain, and positioned in vertical stacking to keep them from contact with soil to prevent herbivory and avoid soil humidity that could affect the drying process. The samples remained so for eight months, after which workability tests were started.

2.1 Physical properties

Basic density was determined by the ratio between dry mass and saturated volume, according to Brazilian standard NBR:11941 procedures (ABNT, 2003). Individual shrinkage of wood in its three orthotropic axes and volumetric shrinkage were obtained from the same samples as those used in basic density determinations (ABNT, 1997). The samples were saturated in water and their dimensions measured with a caliper (accuracy = 0.001mm), taking three measurements per direction, followed by oven-drying at 103 ± 2°C and, finally, 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 the initial volume. The anisotropic factor was determined by the relationship between tangential shrinkage and radial shrinkage, according to the methodology of Eufrade Jr. et al. (2015).

2.2 Mechanical properties

Mechanical tests evaluated strength in compression parallel to grain, modulus of rupture (MOR), and modulus of elasticity (MOE) in static bending (three-point test), using a computer-controlled 300 kN electromechanical testing machine (INSTRON/EMIC).

Tests were performed according to the Brazilian Standard for the Design of Wooden Structures (NBR 7190, 1997). Compression tests were performed on 20mm×20mm×60mm specimens, and bending tests used 20mm × 20mm × 460mm samples and a span length of 420mm. All results were reported to the EMC (12%), using a conversion coefficient of 3% (of variation per 1% of MC variation) for strength properties and 2% for elastic properties. Strength class was attributed to *Hevea* wood by associating its characteristic strength in compression parallel to grain (Eufrade Jr.et al., 2015) to the stress grades defined in NBR 7190 (ABNT, 1997).

2.3. Machining

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

2.3.1.Planing

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

2.3.2. Thickening

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

2.3.3. Bolt hole

For the bolt drilling test, an FBS 16 Schulz 1720 RPM and 0.37 (cv) bench drill was used, as adapted from ASTM D1116-87 (1995), which recommends 3600 RPM and 3 horsepower (cv). A 12 mm drill was used with holes 10 cm from the end in length, and hole 1 cm from the edge in width (Figure 1c).

2.3.4. Cracking by nails

The nail cracking test used nails 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 between nails (Figure 1d).

2.3.5. Sanding

For the application of the test we used a vertical sander with 3.10 m length, 2 mm sandpaper of 50 grit, and 14 cm width, with a three-phase motor of 5 Kba power. The samples were supported on the wood support and placed perpendicular to the sandpaper, and then the samples were sanded on the front and back to verify the degree of fiber lifting and if there were any defects on the surface (Figure 1e). 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: 1116-87 (1995) standard (Table 2).

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.

Source: Authors (2021).

Table 2. 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%)

Source: Authors (2021).

2.4 Statistical Analyses

Descriptive statistical analyses were initially performed. This was followed by performing a normality test to observe the data distribution. For the coMParison among elite *Hevea* progeny clones, a parametric analysis of variance (one-way analysis of variance) was applied. In 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. Physicomechanical properties of wood

Mean values of physicomechanical properties for rubber tree wood elite progeny clones are shown in Table 3. Wood density varied from 0.404 (IAC 301) to 0.495 g.cm^{-3} (IAC 326). IAC326 is statistically different from the others. According to Silveira (2013) and Silva (2015), the wood from rubber tree elite progenies is classified as low density. Basic density is an essential physical property of wood, as all other properties are related to it, thus defining its suitability for proposed applications, in this case furniture manufacturing.

Other studies show that different progenies at different ages may differ from progenies we investigated. Analyzing wood density among rubber tree Malaysian clones at age 9, Naji et al. (2012) reported densities between 0.530 and 0.560 g.cm^{-3}. Santana et al. (2001) studied rubber tree clones in São Paulo, Brazil, at 40-44 years, and they 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 among different clones.

Eleotéreo et al. (2014) classifies the volumetric contractions by basic density, density between 0.40-0.50 g.cm^3, a range that the clones presented, the authors mention that the wood should present up to 3.50% in the radial direction, with a maximum of 7.40% in the tangential and volumetric direction up to 12.30%. However, other authors point out that the radial and tangential directions define the volumetric contraction, the latter being the basis for classification of wood use, so, according to Table 3, the wood of the clonal progenies Fx 2261 and IAC 41, obtained 18.33% and 15.86%, respectively, and drying techniques should be adopted for the use of wood. For the other clonal progenies, bands lower than 12.30% of volumetric contraction were observed, which is a positive aspect on the use of wood for the production of furniture, since volumetric contraction defines the dimensional movement of wood in different moisture gradients Oliveira et al. (2010)

Anisotropy coefficient and high volumetric contractions alter the dimensions of wood causing defects, limiting its use for various purposes, and requiring appropriate processing techniques and use according to Trianoski et al. (2013). It is ideal that wood presents low anisotropy coefficient values close to 1, Santos et al. (2017). According to Table 3 values close to 1, were observed for clones IAC 40, IAC 311, and GT 1, which indicates superiority of clones in furniture production in relation to the others. Thus, the study and knowledge of the behavior of these dimensional changes in different clonal progenies are essential for their correct industrial use, both in civil construction and in the production of furniture and other solid products of higher added value according to Trianoski et al. (2013).

Caceres et al. (2017) mention that wood with lower basic density and high volumetric contractions that was observed for the clonal progenies IAC 301 and IAN 873, should be used for the production of manufactured and dry structural products to avoid problems in wood, consequently the use with lower density will be pre-selected with the commitment of industrial aspects. We observed differences in mechanical properties among progenies. For compression parallel to the grain, values ranged from 36.71 (IAN 873) to 43.02 MPa (IAC 311). The modulus of rupture (MOR) values ranged from 57.78 (RRIM 725) to 180.50 MPa (GT1). The modulus of elasticity (MOE) values ranged from 5922 (RRIM 725) to 11666 MPa (IAC 326).

Table 3. Means of 12-year-old *Hevea* wood progeny clones in relation to wood physicomechanical properties. Selviria, Mato Grosso, southern Brazil.

Progenies/ Traits	IAC 40 ill.	IAC 41 ill.	IAC 326 ill.	IAC 311 ill.	IAC 301 ill.	IAN 873 ill.	GT1 ill.	PB 330 ill.	Fx 2261 ill.	RRIM 725 ill.
ρbas ($g.cm^{-3}$)	0.423 bc	0.440 b	0,495 a	0.429 bc	0.404 c	0.422 bc	0.447 b	0.448 b	0.452 b	0.452 b
βrad (%)	4.18 ab	4.81 a	3.97 ab	3.92 ab	3.60 ab	3.27 ab	2.81 b	3.55 ab	4.61 a	3.16 ab
βtan (%)	4.37 bc	7.17 a	5.23 abc	4.29 bc	4.14 bc	4.10 bc	3.05 c	5.95 ab	6.16 ab	3.99 bc
βlg (%)	1.24 ab	1.24 ab	1.18 ab	1.09 ab	1.07 ab	1.04 ab	0.85 b	1.47 a	1.01 ab	1.00 a
βvol (%)	10.46 abc	15.86 ab	11.55 bc	11.70 bc	9.67 bc	9.53 c	6.32 c	11.52 bc	18.33 a	8.08 c
θ	1.05 ab	1.49 ab	1.32 ab	1.09 ab	1.15 ab	1.25 ab	1.09 ab	1.68 a	1.34 a	1.26 ab
fc0(MPa)	37.18 cd	42.14 ab	39.76 bc	43.02 a	41.57 ab	36.71 d	42.56 ab	38.23 cd	42.95 a	41.98 ab
MOR(MPa)	126.91 c	75.36 de	150.73 b	80.26 d	74.54 de	77.73 de	180.50 a	68.72 e	82.96 d	57.78 f
MOE (MPa)	8768 bc	6860 de	11666 a	7484 cde	8218 bcd	7492 cd	9575 b	6392 ef	6263 e	5922 f

ρbas= basic density; βrad= radial shrinkage; βtan= tangential shrinkage; βlg= longitudinal shrinkage;βvol=volumetric shrinkage; θ= anisotropic factor; fc0= compression strength parallel to grain; MOE=Modulus of elasticity; MOR= Modulus of rupture. "Along the same line" means followed by at least one equal letter do not differ ($p<0,05$).
Source: Authors (2021).

According to the ABNT 7190 (1997) classification, which characterizes wood in strength classes, IAC 40, IAC 326, IAN 873 and PB 330 are classified as C20, and the other progenies are classified as C30.

Santana et al. (2001) characterized the mechanical properties of four rubber tree clones, including AVROS 1301, GT 711, IAN 717 and IAN 873. They reported compression parallel to grain strength of 43.30, 42.40, 42.00 and 41.70 MPa, respectively. The compression parallel to grain strength mentioned by Santana et al. (2001) for IAN 873 was higher than that found in the present study (36.71 MPa). The authors mention that wood in strength classes C30 and C40 is more suitable for use in civil construction, as well as furniture production, since it effectively resists higher mechanical stress. We did evaluate very young 12-year-old rubber trees; nonetheless, we note that the wood had already achieved satisfactory properties for structural and furniture uses.

The modulus of rupture (MOR) and the modulus of elasticity (MOE) are parameters normally evaluated in static bending tests, being the modulus of elasticity of greater importance in the technological characterization of wood, because it represents the resistance of the material submitted to a force applied perpendicular to the longitudinal axis of the wood Gonçalves et al. (2009). The wood of the clonal progenies GT1 and IAC 326 present higher values of MOR and MOE in Table 3, being preferable for furniture confection, however, this factor does not limit the use of other clones and should be used for the production of furniture that require less physical and mechanical efforts.

Santana (2001), studying rubber tree 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 the studied progenies (Table 3). Thus, we suggest that the youngest wood may present satisfactory properties for different uses with added value. Of the mechanical properties studied, the rupture module (MOR) presents a greater variation in absolute values among rubber tree progenies, as this is a characteristic that indicates superior progenies for use in furniture.

In fact, mechanical strength classes obtained in the compression test were similar, or even superior to, those of several native species widely employed for the same uses. Studying mechanical properties of rubber trees for structural uses from GT1 and RRIM600 progenies at 20 and 30 years, Eufrade-Junior et al. (2015) concluded that species have similar, or sometimes superior, properties coMPared to several Brazilian native species currently commercialized. The authors mention *Cedrela* spp., *Cedrelinga caterniformis*, *Vochysia* spp. And *Erisma* spp. Eufrade-Junior et al. (2015) further state that rubber tree wood use, from planting, becomes ecologically viable by the reduction of otherwise exploited native forests.

Therefore, based on the results obtained, it was verified that the wood quality of the clonal progenies of *Hevea brasiliensis* has a resistant wood that can be used for the production of furniture and becomes a promising species since used for this purpose and will help in the reduction of exploitation of native forests in Brazil, being a raw material to be used for wood supply in the forestry industry for the production of furniture.

3.2 Wood machining

From 100 samples, we observed grain defects in 38 samples: fuzzy grain in 34 samples and raised grain (Figures 2a and 2b) in four samples. The defects observed in planing are related to the type of grain orientation in rubber tree wood. The analyzed wood samples showed straight grain. Vahid and Cool (2018) mention that this grain type favors machining processes and good surface finishing.

Table 4. Results of machining test for ten 12-years-old clones of rubber tree progenies.

	Progenies									
Test	IAC40	IAC41	IAC326	IAC311	IAC301	IAN873	GT1	Fx2261	PB330	RRIM725
Planing	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
Sanding	1	2	1	1	3	2	1	1	3	2

Source: Authors (2021).

In the bolt drilling test, rubber tree 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 4), indicating easily workable wood. Rubber tree wood is considered light and soft, which favorsoptimization and operation in industrial processes. According to Silva (2007), wood anatomy, along with physicomechanical and chemical properties, can define wood behavior in machining. However, it is expected that wood will not burn during pin drilling. Such observed defects as lifting, fluffing and crushing the grain can be corrected by sanding the surface.

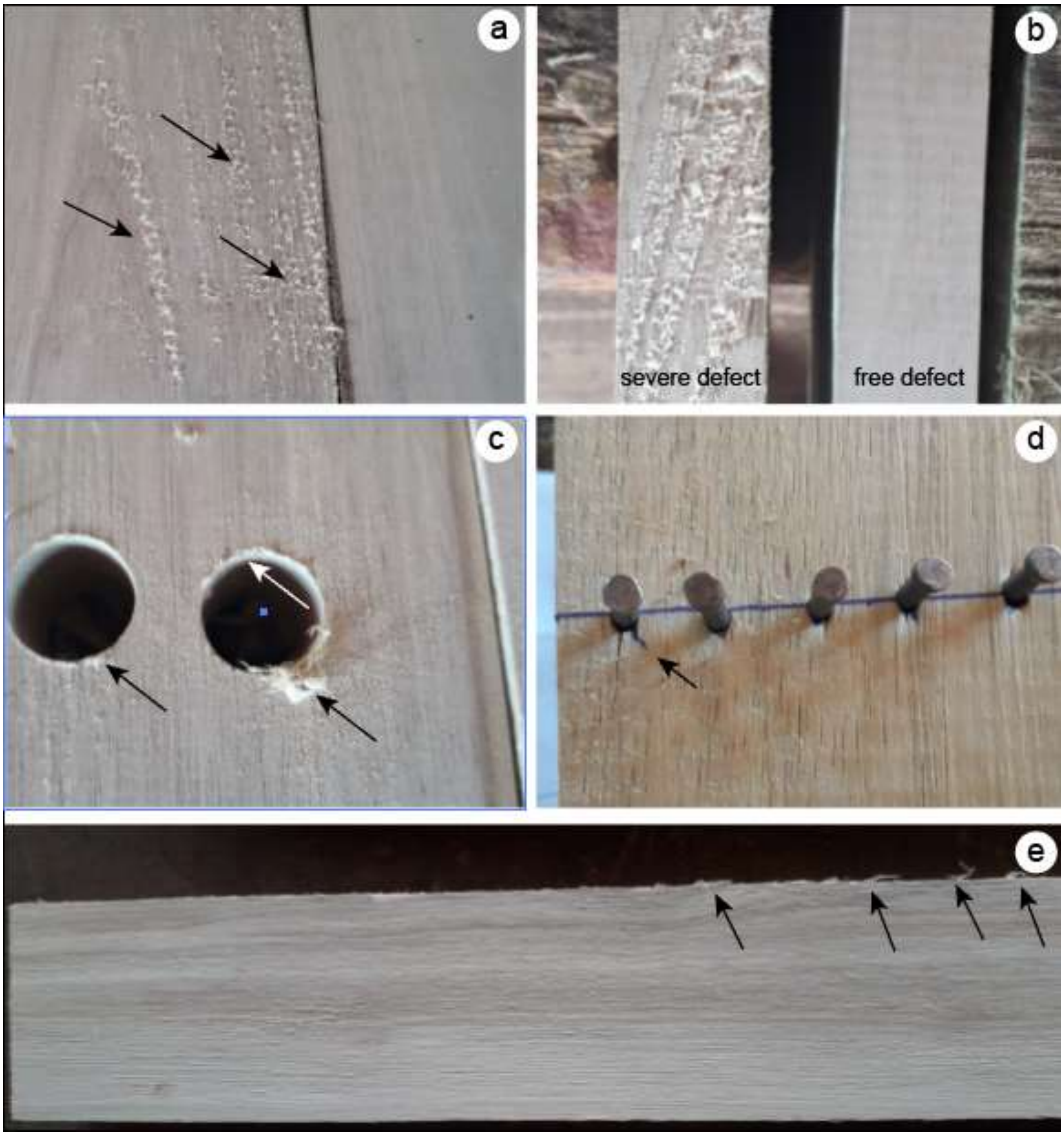
To minimize grain pullout effects in the bolt drilling test, Silva et al. (2007) recommend that higher cutting speeds should be used, as this will facilitate incision of the grains. However, it is essential to carry out this test with the most appropriate speeds to avoid burning the surface, which will have a darkening effect, thereby detracting from the quality of the raw material. The raised fiber defect was observed in rubber tree wood (Figure 2c).

For the nail cracking test (Figure 2d), 86 out of 100 rubber tree wood samples did not show any cracking. This represents a favorable characteristic for machining optimization and lower depreciation in wood workability (Aguilera, 2011).

Variations can be expected since wood derives from a living organism; at the same time, such variation can result in the production of many unique pieces and desirable effects. On a large scale, a wooden surface should be free from defects, such as cracks or grain lift, which will lead to loss of quality and aesthetics of the final product. Additionally, a flawless surface allows good adhesion of paints and varnishes used in the finishing (Lucas-Filho, 2007).

Sanding is a non-conventional machining process, based on abrasive grain abrasion on the part and has the function of improving the surface finish, ensuring proper dimensions and roughness. Since it is a subsequent process to the primary machining operations, it should only be performed when the previous processes are not able to ensure the surface finish (Fonseca, 2016). Wood industries, mainly furniture industries, use sanding in the manufacture of their products, making this study fundamental fundamental to improve the process seeking to make it more effective and more efficient (Varasquim et al. 2012). The wood from *Hevea brasiliensis* clones present good characteristics in the application of the sanding test, because many wood samples were free of defects, which is beneficial in the furniture production industry, because it reduces the finishing process of the pieces, optimizing time.

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. and e. Grain lifting observed in the application of the grinding test.



Source: Authors (2021).

In our study, it was possible to verify that all clonal progenies of *Hevea brasiliensis* present good quality in the workability tests. We noted that the wood from the clonal progenies IAC 311.

We summarize results of planing, thickening, bolt drilling, and nail cracking tests in Table 5. Rubber tree wood progeny clones show excellent behavior for bolt drilling and nail cracking tests, allowing us to state that wood can be punctured and nailed with ease. In planing and thickening tests, we observed some samples with a surface defect, but a superficial finish was considered good to very good.

Table 5. Summary of machining tests on the wood of 10 12-year-old rubber tree progeny clones.

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

Source: Authors (2021).

Analyzing rubber tree wood surface against machining tests, Dhamodaram (2008) reported results from good to excellent, very similar to results found in our study. Therefore, we suggest that the rubber tree wood clones we analyzed have remarkable functionality and workability and that the wood is suitable for the manufacture of furniture.

4. Conclusion

We observed low to medium values for wood anisotropy coefficient, allowing *Hevea* to be a dimensionally stable wood for use in furniture production. Since IAC 326 and GT1 progenies have stronger, but still stimilar, properties coMPared to other progenies, we suggested that all progenies present physicomechanical properties favorable to furniture production.

In wood machining, rubber tree wood presented good results in the planing, thickening, bolt drilling, nail cracking and sanding tests, thus allowing production of solid furniture with good surface finish. In general, our study shows that 12-year-old *Hevea* wood meets the technical requirements for furniture manufacturing and that such younger trees should be used for this purpose. This makes rubber tree wood viable for both reducing the exploitation of native forests and producing a commercially valuable product.

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