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Evaluation of *Araucaria angustifolia* (Bertol.) Kuntze wood for acoustic guitar production and musical acceptance of the instrument

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: The acoustic quality of a guitar is directly influenced by the wood species used in its construction. Brazil has a diverse range of tree species with potential for lutherie, which could reduce production costs and encourage sustainable cultivation. In this context, this study evaluated the suitability of Araucaria angustifolia, a native species from southern Brazil, for use in guitar manufacturing. Acoustic, anatomical, chemical, physical, and mechanical properties of wood samples from three trees were analyzed, followed by the construction and evaluation of a guitar prototype.

Results: The results demonstrated promising acoustic performance, with a sound velocity of 4657 $m{\cdot}s^{-1}$, a fundamental frequency of 199.1 Hz, and a logarithmic decay of 0.019 s. The wood showed suitability for use in the soundboard and back of the guitar. Significant correlations were observed between acoustic and mechanical properties and anatomical and chemical characteristics, including bordered pit diameter, solubility in ethanol and water, basic density, and tangential hardness. The wood exhibited a density of 430 $kg{\cdot}m^{-3}$ and lower shrinkage values compared with conventional tonewoods. Mechanical behavior was consistent with low-density woods, with an elastic modulus of 10,469 MPa. Evaluations conducted by professional musicians classified the instrument's tonal quality as "Good" or "Very Good".

Conclusions: The findings indicate that *Araucaria angustifolia* has significant potential for guitar manufacturing, especially in applications requiring lightweight tonewoods with favorable acoustic performance. The species represents a promising alternative for lutherie, contributing to the diversification of raw materials and the valorization of native Brazilian woods.

Keywords: *Araucaria, technological characterization, string instrument*

HIGHLIGHTS

Araucaria angustifolia wood proved suitable for acoustic guitar soundboard and back.
Its acoustic properties matched traditional tonewoods like spruce.
A lightweight tonewood: 430 kg/m^3 density and 10,469 MPa elastic modulus.
Acoustic quality tracked wood anatomy more than density or stiffness.
Professional musicians rated the guitar Good to Very Good in tone.

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INTRODUCTION

Musical instruments produce mechanical waves from different sound generation mechanisms and are classified into three main types: percussion, string, and wind instruments. Since sound propagates through materials, it is strongly influenced by the type of wood used in instrument construction (Bucur, 2006).

The woods traditionally employed in musical instrument manufacturing are well documented, including *Acer pseudoplatanus* (L.), *Acer campestre* (L.), *Acer platanoides* (L.), *Acer saccharum* (Marsh.), *Dalbergia latifolia* (Roxb.), *Diospyros crassiflora* (Hiern), *Diospyros ebenum* (J. Koenig ex Retz.), *Fraxinus americana* (L.), *Hymenaea courbaril* (L. LC), *Khaya* spp., *Juglans nigra* (L.), *Peltogyne paniculata* (Benth.), *Picea abies* (Karst.), *Picea sitchensis* (Bong) Carr., and *Platymiscium pinnatum* (Jacq.) Dugand. Additionally, several Brazilian native species have been utilized, such as *Caesalpinia echinata* (Lam.), *Dalbergia nigra* (Vell.), *Machaerium scleroxylon* (Tul.), and *Swietenia macrophylla* (King) (Bessa, 2000; D'Gucci, 2016; Sandoval, 2016; Souza, 2009; Hernandez, 2016). Several studies suggest that these species have been widely used due to their favorable acoustic properties, contributing to high-quality instrument craftsmanship as extensively discussed in literature (Bucur, 2019; Bucur, 2022; Bucur, 2023) and supported by experimental studies (Hounlonon *et al*., 2022).

As an acoustic instrument, the guitar's sound quality is directly influenced by the wood species used in its construction. The primary structural components of a guitar include the fingerboard, neck, soundboard (top), back, and sides, all of which must be made from wood that ensures structural stability, acoustic performance, and aesthetic appeal (Zaczéski, 2017). Given Brazil's vast diversity of timber species, Slooten and Souza (1987) observed that certain native species exhibit potential for musical instrument manufacturing.

The influence of wood properties on the sound quality of acoustic guitars highlights the critical role of material selection in lutherie (Zhou *et al*., 2022). Consequently, the use of native woods in musical instrument production enhances market competitiveness, providing an economic advantage for producers engaged in sustainable forest management. This practice may also contribute to the expansion of managed forest areas while simultaneously increasing the availability of high-quality materials for instrument manufacturing (SFB, 2017).

Acoustic properties are evaluated by analyzing the transmission of sound waves through the wood, including parameters such as wave propagation velocity, resonance frequency, and logarithmic decay (Bucur, 1995). However, in the absence of specialized equipment, luthiers—skilled artisans in instrument making—traditionally rely on empirical knowledge, assessing the wood's suitability through the sound produced. Additionally, the tonal quality of the instruments can be evaluated through subjective listening tests conducted by professional musicians.

In southern Brazil, the mixed ombrophilous forest is characterized by the dominance of *Araucaria angustifolia*. However, the use of this species in guitar manufacturing remains largely unexplored, emphasizing the need for studies investigating its technological and acoustic performance.

This study aimed to assess the feasibility of *A. angustifolia* wood for classical guitar construction. To achieve this, the wood's acoustic, anatomical, chemical, physical, and mechanical properties were analyzed, along with an evaluation of the guitar's sound quality through musician assessments.

MATERIAL AND METHODS

Wood sampling

Three *Araucaria angustifolia* individuals, measuring 7 meters in length and 40 cm in diameter, were used in this study. These specimens were obtained from a seizure conducted by the Environmental Military Police in the municipality of Bocaina do Sul, Santa Catarina, Brazil, and subsequently donated to the Santa Catarina State University.

To estimate the trees' age, a 10 cm-thick cross-sectional disc was extracted from the base of each individual. For further analysis, four 1-meter-long logs were sectioned from the remaining stem, starting from the base. From each log, two cross-sectional discs were obtained: one for determining the basic density and the other for anatomical and chemical analyses. The remaining 80 cm of each log was used to extract veneer sheets for guitar construction, as well as samples for evaluating apparent density, dimensional stability (shrinkage), mechanical properties, and acoustic performance (Figure 1).

From the harvested logs, central planks were extracted, with the medullary region discarded. Beams measuring 1 meter in length and 5 cm × 5 cm in cross-section were then cut from the remaining wood. From these beams, specimens were prepared following the dimensions specified in the relevant standards for acoustic, physical, and mechanical analyses (Figure 1)

Age estimation

To determine the average age of the trees, a cross-sectional disc was extracted from the basal region of each individual. From this disc, a central strip was isolated and subsequently sanded using a sequential process with three different abrasive grits: 280, 320, and 400. This sanding procedure enhanced the visibility of the growth rings, allowing for accurate age estimation.

Acoustics analysis

This analysis followed the methodology described by Slooten and Souza (1987) and was conducted at the Forest Products Laboratory of the Brazilian Forest Service. The specimens were 30 cm in length, 2 cm in height, and 0.3 cm in width. These parts were subjected to forced vibration to determine their natural frequency of vibration (fr). From

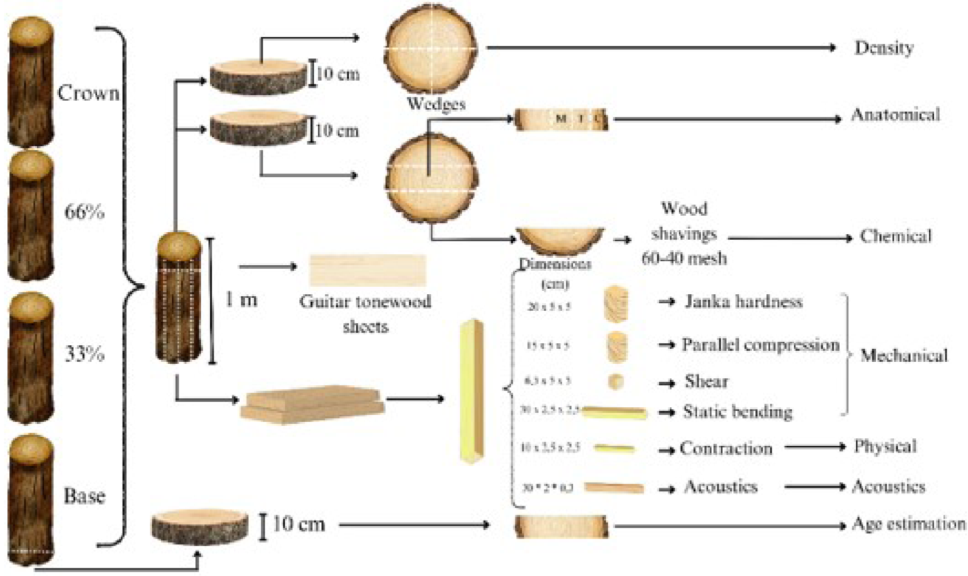


Figure 1: Scheme for obtaining test specimen samples for technological characterization of *Araucaria angustifolia* wood.

this variable, the logarithmic decay (DL) was calculated according to the equation 1 proposed by Hearmon (1968).

$$DL = \frac{\pi}{\sqrt{3}} \times \frac{\Delta f}{f_r} \quad (1)$$

Where: DL = Logarithmic decay; fr = Resonance frequency; Δf = Differential of resonance points.

The speed of sound was determined by using the Metriguard model 239A stress *wave timer*.

Technological characterization of *A. angustifolia* wood

Anatomical characterization of wood

The macroscopic characterization of the material was conducted using a Dino-Lite model AM4113ZT (R4) digital microscope, after surface sanding. For microscopic analysis, permanent slides were prepared using a Leica model SM2010R sliding microtome, from the samples, transverse, tangential longitudinal, and radial longitudinal sections were obtained. The slides were assembled following the methodology proposed by Coradin & Muñiz (1991). Additionally, wood maceration samples were prepared according to Franklin (1945).

Microscopic analyses were performed using the Modulo Leica Measure V6.1 application, and the anatomical description adhered to the standards established by the IAWA Committee (1989).

Chemical analysis

The material, previously classified in 40-60 mesh sieves, was subjected to air conditioning under conditions of 20°± 3° and 65% ± 3% relative humidity. The chemical analyses were conducted following the standards methodologies outlined in Table 1.

Table 1: Analyses carried out to characterize the structural chemical composition of *Araucaria angustifolia* wood.

Analytics	Standard
Material soluble in 1% sodium hydroxide	NBR 7990 (ABNT, 2010)
Total extractives (Ethanol-toluene, ethanol, and water)	NBR 14660 (ABNT, 2004)
Ash content	TAPPI T413 om-06 (TAPPI, 1993)
Lignin content	TAPPI T222 om-08 (TAPPI, 2000)
Holocellulose content	Due to the difference in components, total extractive content, lignin, and ash

Physical and mechanical properties

The basic density of wood was determined according to the methodology proposed in the COPANT 30:1-004 standard (1971). For the dimensional stability analysis, the radial, tangential, and longitudinal dimensions of the material were measured under saturated and oven-dry conditions. After obtaining these values, the following were calculated: maximum linear shrinkage; volumetric shrinkage and anisotropic coefficient, according to COPANT 30:1-005 (1971).

The mechanical property tests were conducted using a universal testing machine (EMIC), following the standards presented in Table 2.

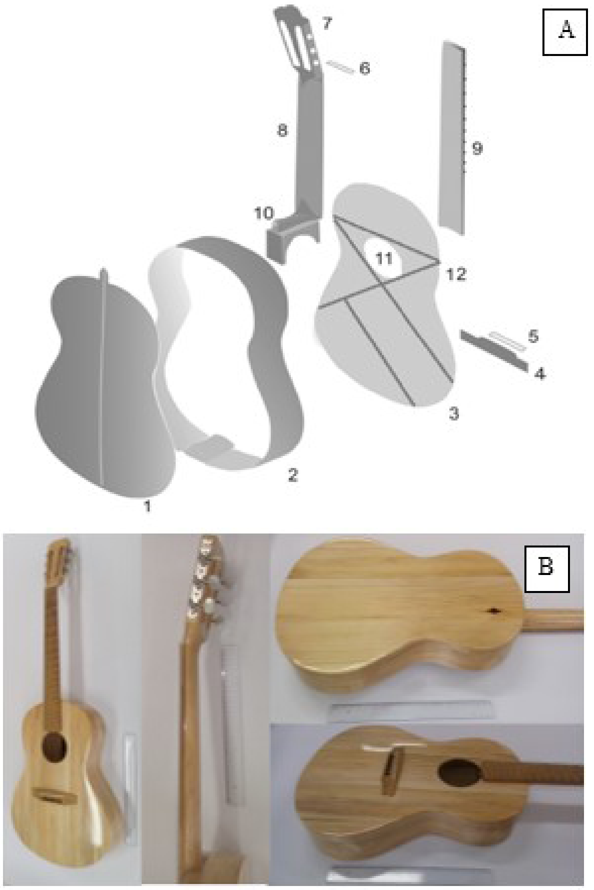
Guitar production

To produce the guitar, the services of a luthier were contracted, and the instrument was assembled according to Figure 2. *A. angustifolia* wood was used for the back,

Table 2: Dimensions of the test specimens and respective standards for determining the mechanical properties of *Araucaria angustifolia* wood

Analysis	Dimension (cm)	Standard
Static bending (MOE and MOR)	2.5 x 2.5 x 30	ASTM - D143 – 94 (1995)
Janka hardness	5 x 5 x 15	ABNT NBR 7190 (1994)
Compression parallel to the grain (MOE and MOR)	5 x 5 x 20	ABNT NBR 7190 (1994)
Shear strength (parallel to the grain)	5 x 5 x 6.5	ABNT NBR 7190 (1994)

sides, top, saddle, nut, headstock, and neck. However, the fingerboard and bridge were made from *Apuleia leiocarpa* (Vogel) JF Macbr wood. – Garapeira, as these components require wood with a higher density (Fiedler *et al*. 2013).



A: Source: Zaczéski *et al*. (2017) Adapted by the Authors.

Figure 2: A: Description of the parts of a guitar: 1- Bottom, 2- Sides, 3- Top, 4- Bridge, 5- Saddle, 6- Nut, 7- Headstock, 8- Neck, 9- Scale, 10- Heel, 11 - Mouthpiece. 12- Harmonic Fan (X bracing Martin). B: Guitar made from *A. angustifolia* wood.

Questionnaire to evaluate the musical instrument

The sound evaluation of the instrument was conducted by professional musicians. A total of 32 professional musicians were contacted and invited to a public audition, followed by the administration of a questionnaire specifically developed for this study (Table 3).

Table 3: A questionnaire to evaluate the musical instrument

Name:
Training:
Music experience:
Professional performance:

1. What is the quality of the sound produced?

Bad ( ); Regular ( ); Good ( ); Very good ( ); Great ( );

2. How is the timbre produced in relation to other musical instruments?

Bad ( ); Regular ( ); Good ( ); Very good ( ); Great ( );

3. How is the playability?

Bad ( ); Regular ( ); Good ( ); Very good ( ); Great ( );

4. How is the volume produced?

Bad ( ); Regular ( ); Good ( ); Very good ( ); Great ( );

5. How is the sound sustaining?

Bad ( ); Regular ( ); Good ( ); Very good ( ); Great ( );

6. Is the sound produced more...?

Record ( ); Acute ( ); Average ( ); Excellent ( ); Other________

7. What is your opinion about the instrument?

8. Do you have any suggestions to contribute?

Statistical analysis

For this study, a completely randomized design was considered; all variables were subjected to normality and homogeneity tests, using the Scott-Knott and Bartlett tests, respectively. Subsequently, the Pearson Correlation analysis was performed between the acoustic and technological properties of the woody material. Additionally, a questionnaire regarding the musical instrument was administered to musicians, and the responses were analyzed using descriptive statistics.

RESULTS

Age estimation

The age of the trees used in this present study was determined by counting the growth rings, yielding an average age of 48 years (Figure 3).

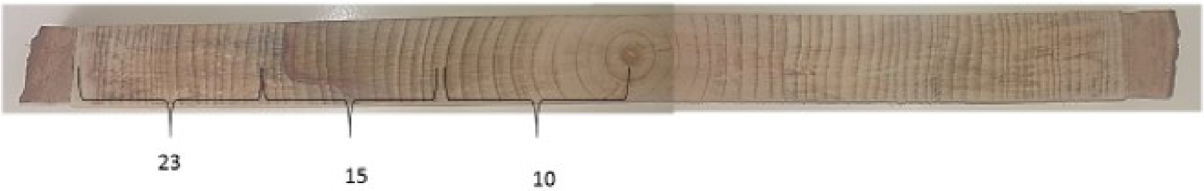


Figure 3: Tree age estimation.

Acoustic properties of wood

The acoustic variables analyzed included resonance frequency, logarithmic decay, and sound speed (Table 4).

Table 4: Results of the acoustic variables analyzed for *Araucaria angustifolia* in comparison to other species common in the manufacture of guitars.

	F (Hz)	Dlog(s)	$V(m \cdot s^{-1})$
Araucaria angustifolia	199.10	0.019	4657.13
Picea abies[1]	187	0.021	4977
Picea sitchensis[2]	251	-	5100
Acer platanoides[1]	148	0.026	3928
Dalbergia nigra[2]	237	-	4400

Where: F = Frequency, Dlog = Logarithmic decay, and V = speed of sound propagation. Source: [1] Slooten and Souza (1987), [2] Bessa (2000).

Technological characterization of *A. angustifolia* wood

Anatomical characterization of wood

Macroscopic features: Distinct growth rings, with a smooth transition from earlywood to latewood. It features light-colored wood, with the heartwood displaying a brownish hue, moderate luster, straight grain, and fine texture (Figure 4A).

Microscopic features: The wood exhibits distinct growth rings, characterized by a gradual transition between earlywood and latewood, which is distinguished by the increase in the thickness of the tracheid walls (Figure 4B). The axial tracheids have alternating areolate, uniseriate, or biseriate pits (Figure 4F). The rays are homogeneous, composed of procumbent cells, and are predominantly unicellular (Figure 4C).

The quantitative results of the anatomical elements for *A. angustifolia*, along with the values found for species traditionally used in guitar production, are presented in Table 5.

The correlation between the acoustic properties of *A. angustifolia* wood and its anatomical characteristics is presented in the following analysis (Table 6).

Regarding the correlation between anatomical and acoustic properties of the wood, the diameter of tracheid pits showed strong negative correlations with logarithmic decay and frequency (−0.93 and −0.68, respectively), indicating an inversely proportional relationship between these variables.

Another anatomical characteristic that presented significant correlations with acoustic properties was the diameter of the cross-field pits, which showed a similar behavior, with a strong negative correlation with frequency (−0.66) and a strong positive correlation with sound velocity (0.93).

Chemical characterization of wood

Table 7 presents the results of the chemical analyses conducted on *A. angustifolia* wood, along with

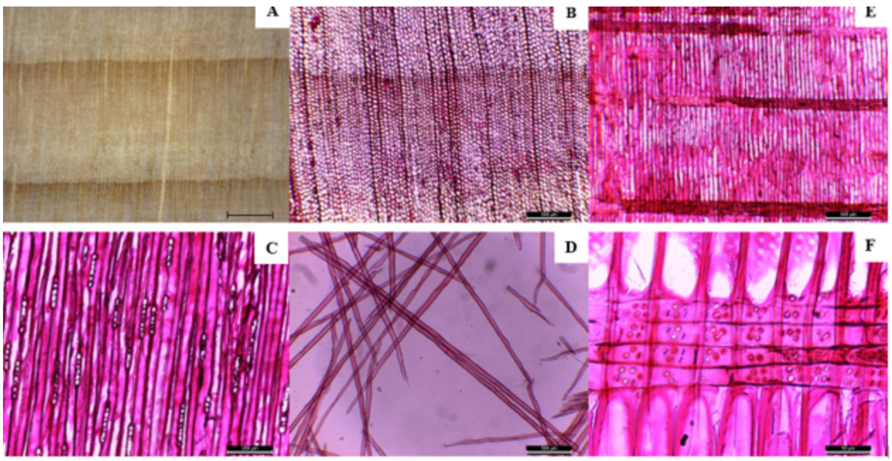


Figure 4: A: Macroscopic image (scale bar: 1 mm); B: transverse section (4×, scale bar: 500 μm); C: radial section (4×, scale bar: 500 μm); D: tangential section (10×, scale bar: 200 μm); E: macerated material, tracheid (4×, scale bar: 500 μm); F: points of crossing field pits (40×, scale bar: 50 μm).

Table 5: Anatomical characteristics of the *A. angustifolia* species and those traditionally used in the manufacture of musical instruments.

Species	W	L (μm)	DL (μm)	EP (μm)	Radius/ linear mm	Cell/Radius	Height. Radius (μm)	Width. Radius (μm)
Gymnosperms								
Araucaria angustifolia	4886.1	48.3	34.9	6.7	0-9	1-19	123.1	20.17
Picea abies[2]	3700	38.5	32.3	3.1	-	-	-	-
Picea sitchensis[1]	2720.8	38.1	27.9	5.1	8-17	2-13	201.7	16.3
Pinus silvestris[1]	2430.9	42.2	31.2	5.5	8-20	2-13	203.6	20.8
Angiosperms								
Acer saccharum[3]	-	11.1	8.42	1.33	-	-	-	-
Acer nigrum[3]	-	10.2	7.8	1.22	-	-	-	-
Dalbergia nigra[1]	1187.5	19.6	10.6	4.5	-	-	-	-

Where: Tracheid length (W), Tracheid width (L), Lumen diameter (DL), Tracheid wall thickness (EP), Radii per mm (Radius/mm), Cells per radius (Cel/radius), Height of the radii (Alt. radius), and Width of the radii (Width. radius). Prepared by the authors (2024). Source: ¹ Bessa (2000), ² Sarén et al. (2001), ³ Woodrum et al. (2003).

values from literature reviews for species traditionally used in the construction of acoustic guitars.

Table 8 presents the correlation values between the acoustic and chemical properties of the material. The acoustic variable sound velocity showed a moderate to strong negative correlation with ethanol-soluble extractives (−0.591), a moderate positive correlation with water-soluble extractives (0.454), and a moderate positive correlation with lignin, exhibiting logarithmic decay (0.410).

It is observed that sound velocity is influenced differently by the nature of the extractives present in the wood, with ethanol-soluble extractives showing a moderate negative correlation. In contrast, water-soluble extractives exhibit a moderate positive correlation, suggesting that non-polar extractives tend to impair the propagation of sound waves.

Lignin, in turn, has a minimal influence on sound velocity; however, it presents a moderate positive correlation with logarithmic decay, indicating a direct role in damping and dissipating vibrational energy.

Physical properties of wood

The physical properties determined for the *A. angustifolia* species are presented in Table 9.

Table 10 presents the Pearson correlation values between the acoustic and physical properties of *A. angustifolia* wood.

According to the results, logarithmic decay showed a moderate negative correlation with the density of *A. angustifolia* wood (−0.457), indicating that higher density is associated with lower damping capacity, favoring the maintenance of vibrational energy.

A similar relationship was observed between density and frequency (−0.504), which may be explained by the greater mass of the wood influencing the vibration behavior of the material.

Mechanical properties of wood

The mechanical properties of *A. angustifolia* wood are presented in Table 11.

Table 12 presents the Pearson correlation values between the acoustic and mechanical properties of *A. angustifolia* wood.

Radial hardness (HRd), tangential hardness (HTg), and axial hardness (HAx); shear strength (τ); compression modulus of elasticity (CMOE) and compression modulus of rupture (CMOR); flexural modulus of elasticity (FMOE) and flexural modulus of rupture (FMOR); DLog: logarithmic decay; F: frequency; V: sound velocity.

Significant correlations were observed among the studied variables. Sound velocity showed negative correlations with radial and axial hardness (−0.489 and −0.628, respectively), while logarithmic decay presented a positive correlation with tangential hardness (0.454).

Table 6: Correlation between the anatomical and acoustic variables of *Araucaria angustifolia* wood.

	W	L	DL	EP	Radius/mm	Cel/radius	Alt. radius	Radius width	Diam. Point. Traq.	Diam. Point. Cam Cruz.
DLog	0.29	0.14	0.21	-0.13	-0.02	0.16	0.05	-0.20	-0.93	-0.07
F	-0.24	0.04	-0.05	0.25	-0.18	-0.28	-0.34	-0.27	-0.68	-0.66
V	0.02	0.03	-0.03	0.16	0.04	-0.13	-0.23	-0.27	0.31	0.93

W: Length of tracheids, L: Width of tracheids, DL: Lumen diameter, EP: Wall thickness, Radius/mm: Radius per linear millimeter, Cel/radius: number of cells per radius, Width. radius: Radius width, Diam. Point. Traq: Diameter of the Pitting of the Tracheids, Diam. Point. Cam. Cruz.: Diameter cross-field pitting. DLog: Logarithmic Decay, F = frequency, V = speed of sound.

Table 7: Chemical characteristics of *Araucaria angustifolia* wood compared to species traditionally used for musical instruments.

Species	Ashes (%)	H20 (%)	Total Ext. (%)	Ethanol (%)	Lig (%)	Holocellulose (%)	Cell (%)
Araucaria angustifolia	0.35	1.51	4.77	0.65	30.84	64.5	-
Picea abies[2]	-	-	5.63	-	27.90	-	62.20
Picea sitchensis[1]	0.20	3.80	3.00	2.50	-	-	-
Pinus silvestris[1]	0.30	1.00	4.20	2.30	-	-	-
Dalbergia nigra[1]	0.20	1.30	4.00	6.20	-	-	-

Being, Ashes, Solubility in water (H20), total extractives (total Ext.), ethanol (Et), lignin (Lig), and cellulose (Cel): source: [1]BESSA (2000), [2]TIMELL (1986).

Descriptive evaluation of the guitar

Several scientific studies aim to evaluate the potential and quality of wood properties for musical instrument production (Bennet, 2017; Costa, 2017; Flores, 2015; Guilhon *et al*., 2021). However, few studies focus on assessing instrument quality from the perspective of musicians.

Figure 5 presents a compilation of responses from musicians in a public audition featuring a guitar made from *A. angustifolia* wood.

The guitar produced was predominantly rated between good and very good, followed by excellent and fair, with no responses classifying it as bad. Some musicians noted that certain notes did not fully reach lower or higher tones. However, the overall structure of the guitar and the quality of the sound produced were deemed satisfactory by most participants.

The most remarkable aspect, according to the evaluators, was that the guitar was almost entirely made from *A. angustifolia*, giving it a distinctive and visually appealing appearance that was significantly different from conventional guitars. Regarding sound quality, responses ranged predominantly between good and very good, with a similar trend observed for timbre.

In terms of playability, musicians noted that the neck felt slightly heavy and/or thick, as well as narrow. However, this criterion is highly dependent on the musician's preferred guitar style, indicating that future evaluations could benefit from testing different instrument models suited to various musical genres. Despite this, 78% of the participants rated playability as good or very good.

For volume, more than 50% of the ratings fell between 'good' and 'very good'. During discussions, it was noted that volume is closely related to the size of the resonance box. Traditional guitar models generally have a slightly larger resonance chamber, suggesting that increasing their dimensions could enhance projection. Regarding sustainability, 68% of the evaluations rated it good and very good. However, the tonal response varied between medium and high.

Table 8: Statistical correlation of chemical variables.

	Ashes	Sol.NaOH	Eth. Tol	Eth	H2O	Ext. Totals	Lig	holo	DLog	F	V
DLog	-0.014	0.055	0.261	-0.083	-0.056	0.130	0.410	-0.341	1,000		
F	-0.175	-0.215	-0.243	-0.123	0.206	-0.073	-0.213	0.239	-0.091	1,000	
V	0.106	0.333	0.221	-0.591	0.454	0.309	-0.005	0.173	-0.056	0.040	1,000

Ash content (ASH), Solubility in NaOH (Sol. NaOH), Solubility in ethanol-toluene (Et. Tol), Solubility in ethanol (Et), Solubility in water (H20), Total extractives (Ext. Total), Percentage of lignin (LIG.), Percentage of holocellulose (HOLO), Logarithmic decay (DLog), Resonance frequency, Sound speed.

Table 9: Physical properties of *A. angustifolia* wood and species traditionally used for musical instruments.

Species	βrd (%)	βtg (%)	βlg (%)	CVol (%)	θ (%)	D ($kg.m^{-3}$)
Araucaria angustifolia	4.8	6.8	0.4	12.8	1.4	430
Picea abies[2]	3.6	7.8	-	12.2	2.1	430
Picea sitchensis[1]	4.2	10.2	1.7	16.8	2.2	450
Pinus silvestris[1]	4.7	8.9	0.6	14.6	1.9	480
Acer pseudoplatanus[2]	3.0	8.0	-	11.5	2.7	590
Acer saccharum[2]	4.8	9.9	-	14.7	2.1	560
Acer nigrum[2]	4.0	8.0	-	-	2.0	570
Dalbergia nigra[1]	2.9	5.7	0.2	9.0	2.0	830

Where: βrd: Radial Expansion; βtg: Tangential Expansion; βlg: Longitudinal Expansion; CVol: Volumetric Expansion; θ: Anisotropy coefficient; D: Basic density. Source: [1] BESSA (2000); [2]SLOOTEN and SOUZA (1987).

Table 10: Pearson correlations between the physical and acoustic variables of *Araucaria angustifolia* wood.

	βrd	βtg	αlg	CVol	D	θ	DLog	F	V
DLog	-0.179	-0.307	-0.071	-0.110	-0.457	-0.118	1,000		
F	-0.075	-0.309	0.280	-0.370	-0.504	-0.068	-0.091	1,000	
V	-0.110	-0.078	0.163	0.296	-0.092	0.079	-0.056	0.040	1,000

Where: βrd: Radial contraction; βtg: Tangential contraction; βlg: Longitudinal contraction; CVol: Volumetric contraction; θ: anisotropy coefficient; D: Basic density; DLog: Logarithmic decay; F: Resonance frequency; V: Speed of sound.

Table 11: Mechanical variables of *Araucaria angustifolia* wood in comparison with traditional species used in musical instruments.

Species	CMOR (MPa)	MOE (MPa)	MOR (MPa)	Cis (MPa)	Janka hardness (MPa)
Araucaria angustifolia	32.61	10469.69	80.83	10.41	33.52
Picea abies[1]	42.16	10787.32	64.72	6.5	20.39
Picea sitchensis[1]	38.83	10787.32	70.70	7.94	22.75
Pinus silvestris[1]	32.22	-	58.61	-	-
Acer pseudoplatanus[2]	56.87	9218.25	109.83	8.80	-
Acer saccharum[1]	54.23	12650.58	109.54	18.04	64.62
Acer nigrum[1]	45.20	10983.45	90.22	12.25	50.99
Dalbergia nigra[1]	63.15	11669.92	135.63	13.63	-

CMOR: Compressive force at modulus of rupture, MOE: Modulus of elasticity, MOR: Modulus of rupture, Cis: Shear stress. Prepared by the authors (2024). Source: ¹ SLOOTEN and SOUZA (1987). ² MADERSKI et al. (2015).

Table 12: Pearson correlation analysis between mechanical and acoustic variables for *Araucaria angustifolia* wood.

	Cis	Hrd	Htg	Hax	FMOE	FMOR	CMOE	CMOR
DLog	0.001	0.389	0.454	0.244	-0.153	-0.151	-0.315	-0.353
F	0.004	0.219	0.255	0.220	0.171	0.068	0.184	0.332
V	-0.078	-0.489	-0.336	-0.628	-0.058	-0.169	0.350	0.281

Overall, *A. angustifolia* wood was approved by the evaluators for guitar production, particularly given the species' cultural significance in the region. The main suggestions included experimenting with different resonance box shapes, modifying the neck design, and testing the guitar with alternative string types.

DISCUSSION

Technological characterization of A. angustifolia wood

Acoustic properties of wood

Given the values found in the present study for *A. angustifolia*, Flores (2015) reported the sound speed values of 5900 $m \cdot s^{-1}$. and 4900 $m \cdot s^{-1}$ for the same species, with the latter being very close to the values found in this study.

When compared to species traditionally used in the manufacture of musical instruments, *A. angustifolia* exhibits values analogous to those reported by Slooten and Souza (1987) in their study of wood from *Picea abies* and *Acer platanoides* (Table 4). Bessa (2000), in her research with *Picea sitchensis* and *Dalbergia nigra*, found higher values (Table 4) than those determined for *A. angustifolia* in this study.

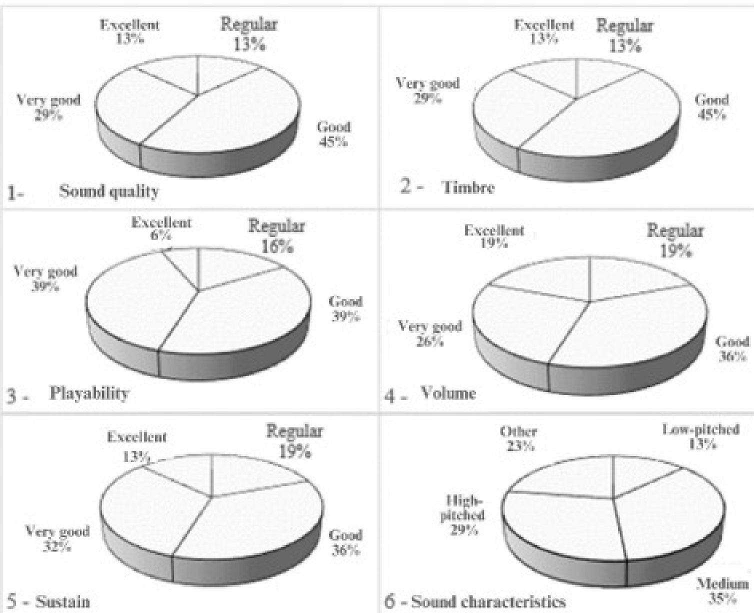


Figure 5: Graphs of the questionnaire responses from musicians. 1: How would you rate the quality of the sound produced? 2: How does the timbre compare to other musical instruments? 3: How is the playability? 4: How is the volume output? 5: How is the sustain of the sound? 6: How would you describe the tonal characteristics of the instrument?

As portrayed by Slooten and Souza (1987), the production of the soundboard is involved. The wood should have a resonance frequency above 170 Hz and a logarithmic decay below 0.021. Regarding sound speed, higher values indicate greater acoustic quality. Therefore, the wood of *A. angustifolia* proves to be satisfactory for this purpose.

Wegst (2006) developed his research on the characteristics of desirable wood for musical instruments. In this, he compared the speed of sound and the density of wood to determine the usefulness of each species, noting that the top requires wood with a lower density compared to the sides. As stated above, *A. angustifolia* emerges as a promising species to produce acoustic guitar soundboards.

Anatomical characterization of wood

Longui (2009) emphasizes the importance of the cell wall in sound propagation, as it is through this structure that sound is transmitted. Therefore, the present study found values consistent with those reported by Mattos *et al*. (2006), who characterized *Araucaria angustifolia*, reporting a cell wall thickness of 7.3 μm. It is noteworthy that *A. angustifolia* wood exhibited greater cell wall thickness compared to species traditionally used for musical instruments, such as *Picea abies* (Sarén *et al*., 2001), *Picea sitchensis*, and *Pinus sylvestris* (Bessa, 2000).

According to Brancheriau *et al*. (2006), species with narrower, more uniform rays and lower ray density exhibit better acoustic properties. The values found in this study for the mean ray height and ray frequency in *A. angustifolia* were lower than those reported by Bessa (2000) for *Picea sitchensis* and *Pinus sylvestris*.

Another influential factor in sound propagation is the presence of vessels (pores) in the wood. Wood with fewer, larger-diameter vessels tends to have higher acoustic velocity (Brancheriau *et al*., 2006; Alves *et al*., 2008; Longui, 2009). However, as *A. angustifolia* is a gymnosperm, it lacks vessels, resin canals, and axial parenchyma, which contributes to its higher acoustic velocity compared to angiosperms such as *Acer platanoides* and *Dalbergia nigra* (Bessa, 2000).

Chemical characterization of wood

Fujimoto *et al*. (2007), Salmén and Bergström (2009), and Carrasco and Azevedo Junior (2003) found a positive relationship between cellulose and lignin content in wood, while Longui (2005), Alves *et al*. (2008), and Schimleck *et al*. (2009) observed a negative relationship between extractives and lignin.

Minato *et al*. (1997) and Sakai *et al*. (1999) observed that extractive content reduces logarithmic decay, which is beneficial for the construction of musical instruments. In contrast, Longui (2009) found a positive relationship between extractive content, lignin, and sound propagation when studying *Caesalpinia echinata*.

Mattos *et al*. (2006), in their study on *A. angustifolia* wood aged 38 years, obtained results of 3.8%, 27.8%, and 68.4% for total extractives, lignin, and holocellulose, respectively—values comparable to those found in the present study.

In comparison to species traditionally used in guitar construction, *A. angustifolia* exhibited a lower extractive content than *Picea abies*; however, its lignin percentage was higher. The other species presented in the table showed lower lignin levels than those found in *A. angustifolia*.

Farvardin *et al*. (2015) reported that the content of hot water-soluble extractives in wood positively influences acoustic properties, whereas extractives soluble in ethanol and acetone exhibit an opposite effect. This finding supports the correlations observed between the chemical and acoustic properties of the wood, in this study.

Considering the guitar-making process, in which wooden sheets need to be submerged in water to ensure their malleability for shaping, the solubility of extractives in water plays a crucial role. Furthermore, according to Hilde *et al*. (2014), the removal of extractives significantly reduces the quality of the final instrument.

Physical properties of wood

The average basic density found for *A. angustifolia* wood corroborates the values reported by Melo *et al*. (2010) in their study on juvenile and adult wood of the same species at 38 years of age, with respective values of 390 kg/m^3 and 480 kg/m^3.

Regarding the volumetric shrinkage of *A. angustifolia* wood, Melo *et al*. (2010) found values of 14.22% in juvenile wood and 10.81% in adult wood, while Hillig *et al*. (2012) reported a variation between 9% and 11% in individuals aged 33 and 58 years, respectively. Both studies found values in line with those in the present research.

Regarding the anisotropy coefficient, Melo *et al*. (2010) reported a value of 1.54 for *A. angustifolia* wood, which is consistent with the value found in this study. As a reference, wood classified as excellent for applications that require dimensional stability—such as windows, furniture, and musical instruments—should have anisotropy coefficients within the range of 1.2 to 1.59.

When compared to species commonly used in musical instrument construction (Table 9), the density of *A. angustifolia* is analogous to *Picea abies*, *Picea sitchensis*, and *Pinus sylvestris*. These species have relatively low density and are recommended for guitar tops, as components such as the back, sides, and neck require higher-density wood. Furthermore, the anisotropy coefficient of *A. angustifolia*, being the lowest among all species analyzed, is a favorable attribute, making it easy to work with and less prone to warping and cracking (Pereira, 2011).

Density is a fundamental factor in selecting wood for instrument production; however, some studies indicate that density does not have a direct relationship with sound velocity. This can be explained by the fact that both low- and high-density species can exhibit high sound propagation values. Moreover, identifying direct relationships between properties is not always possible due to the complexity of wood's composition (Wang *et al*., 2003; Fernandes, 2004; Wegst, 2006; Longui, 2009).

Mechanical properties of wood

The present study reports on mechanical property values for *A. angustifolia* that align with those found by Melo *et al*. (2010). These authors, in their study on *A. angustifolia*, determined an average Janka hardness of 33.13 MPa. Additionally, in shear strength tests, they obtained an average value of 6.27 MPa, which is lower than the values found in this research.

When comparing the shear strength of *A. angustifolia* with that of *Picea abies*, *Picea sitchensis*, and *Acer pseudoplatanus* (Table 12), species already are well established in musical instrument manufacturing, the values for *A. angustifolia* were higher. The anatomical structure of the species directly influences shear strength, as it depends on the lateral cohesion of tracheids or fibers. Higher shear strength values indicate a reduced likelihood of wood chipping during machining, contributing to better workability (Longui, 2009). These results confirm that the species under study exhibits favorable characteristics to produce musical instruments.

The static bending results (Table 12) obtained in this study are comparable to values reported for other gymnosperms commonly used in musical instrument manufacturing. Melo *et al*. (2010) reported values of 42.98 MPa for the modulus of rupture (MOR) and 14,367 MPa for the modulus of elasticity (MOE) in the same species, which are consistent with the values obtained in this research.

CONCLUSIONS

The results highlight the strong potential of *Araucaria angustifolia* wood to produce musical instruments. Its technological characteristics are comparable to those of species traditionally used in the lutherie, indicating its viability as a potential raw material.

One particularly relevant finding was the strong inverse correlation between the logarithmic decay rate of sound and the diameter of tracheid pits, suggesting that finer anatomical structures may have a positive influence on acoustic performance. Additionally, the high and direct proportional correlations between sound velocity and cross-field pit characteristics reinforce the importance of specific microstructural traits in sound propagation.

However, density and mechanical properties (like the modulus of elasticity) affect sound velocity, but they do not fully explain acoustic performance, indicating that acoustic behavior is more closely linked to anatomical features than to other technological properties of the material.

According to evaluations conducted by professional musicians, *A. angustifolia* received high scores, particularly in terms of playability (78% in good and very good), sound quality (45% in very good and 29% in good), and timbre (74% in good and very good)—key attributes for the performance and acceptance of musical instruments.

For future developments, it is recommended to assess the dimensional and tonal stability of guitars made with *A. angustifolia* in response to environmental variations such as humidity and temperature. Furthermore, the influence of different string materials should be investigated, as they directly affect sustain—a parameter that received a “regular” rating in 19% of the evaluations. Another suggestion would be the production of an electroacoustic guitar made with *A. angustifolia*, aiming to address the volume characteristic, which—like sustain—also received a “regular” rating from 19% of the evaluators. Exploring the use of this wood in other types of musical instruments and construction techniques will also be essential to broaden and validate its applicability.

The findings presented here contribute to expanding the range of wood species suitable for high-value applications, opening new perspectives for the responsible use of native forest resources and promoting sustainable forest management. This also introduces a native Brazilian species into the lutherie industry.

AUTHORSHIP CONTRIBUTION

Project Idea: PDR; LSK; NDM; LMS; RS
Database: PDR; LSK; NDM; LMS; RS
Processing: PDR; LSK; NDM; LMS; RS; PHM
Analysis: PDR; LSK; NDM; LMS; RS; PHM
Writing: PDR; LSK; NDM; LMS; RS
Review: PDR; LSK; NDM; LMS; RS; PHM; CAC; TFC; ABC; MAB; RFT

DATA AVAILABILITY

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

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