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ACOUSTIC AND PERFORMANCE-BASED IPE WOOD SELECTION FOR VIOLIN BOWS

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ABSTRACT

Pernambuco wood is the most used material for making professional violin bows. Since the 18th century, it has been known as the best wood for this purpose. However, it is classified as an endangered species. Some researchers looking for alternative woods for bow making have pointed out that ipe wood may have desirable features for making violin bows. Therefore, the objective of this research was to define an evaluation method that could guide selection steps in order to find suitable wood for violin bows testing it in practice. To carry out this research, ipe wood samples were selected from lumber companies and analyzed. Afterward, five violin bows were made and evaluated by professional violinists using a 6-point scale questionnaire. As a result, ipe bows were highly rated by professional violinists, with mean scores spanning 4.21 to 5.10, suggesting a positive level of acceptance. Furthermore, there was a coherence between the scores given by musicians and the estimated potential quality of wood which also had a larger proportion of fibers and lower apparent density, in conformity with other studies. It was concluded that the method adopted worked to find ipe wood suitable for violin bows with characteristics needed to produce professional violin bows even among piles of discarded wood at lumber companies.

Keywords: Bow making, *Handroanthus spp.,* violin bow, wood technology, wood acoustics, musical performance evaluation.

INTRODUCTION

The adoption of European music by the non-European world has raised the demand for bows since the 1950s, especially in the Asiatic market, leading to a significant increase in the value of violin bows (Huber 1995). The bow is a curved rod made of pernambuco wood, on which a bundle of horsehair is stretched and covered with a thin layer of rosin, used to vibrate strings of musical instruments like violin, viola, cello and double bass (Lehmann 2006). Pernambuco wood (*Paubrasilia echinata* Lam.) is known as a great material for bow making. For more than 200 years, bows made of pernambuco are traditional because this wood brings

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together some fundamental aspects that can be handcrafted into a bow that combines lightness, strength, and elasticity required for playing musical instruments (Boyden 2002). Finding the main raw material for bows is a challenging task for bow makers due to restrictions on pernambuco trade, because the species is CITES listed (CITES 2022), and is classified as endangered to extinction (MMA Brasil 2014).

Ipe wood may be a viable alternative for making musical instrument bows (Longui *et al*. 2010a). The ipe wood (*Handroanthus* spp.) is a hardwood tree, belonging to *Bignoniaceae* family that occurs naturally in Latin America (Pace *et al*. 2015). It is popularly known as *verdecillo, amapá prieta, pau-d'arco, ipe-amarelo, ipe-una, piúna, yellow oak*, *guayacán polvillo*, *groenhart*, *pui*, *lapacho, courtés, guayacan, ébène verte, arcwood*, and *bastard lignum* vitae (Guzmán *et al*. 2010). This wood is used in floorboards (Mainieri and Chimelo 1989), carpentry, heavy constructions, external structures, high quality furniture, sports articles, toys, and musical instruments (Andrade 2015).

In a study related to potential Brazilian wood species for bows, six types of wood were analysed: ipe (*Handroanthus* spp.), itaúba (*Mezilaurus itauba* (Meissner) Taubert ex Mez), jatobá (*Hymenaea* spp.), cumarú (*Dipteryx* spp.), sucupira (*Diplotropis* spp.) and muiracatiara (*Astronium lecointei* Ducke), comparing them with pernambuco wood (*Paubrasilia echinata* Lam.). Among them, ipe and cumarú woods - although they did not have the traditional reddish color - were the ones with the greatest number of similarities in relation to three fundamental properties: density, speed of sound propagation, and elasticity. However, due to variations in the size of anatomical and structural elements of wood, in practice, the authors concluded that only ipe wood presented promising results (Longui *et al*. 2010b).

In another study, the potential of ipe wood (*Handroanthus* spp.) was compared with *maçaranduba* (*Manilkara* spp.) for bow making, it was concluded that ipe presented potentially better properties than those found in maçaranduba when compared to the ones of pernambuco wood. Between the two genera analyzed, the highest values of modulus of elasticity (MOE), modulus of rupture (MOR*),* and the higher velocity of sound propagation were highlighted in ipe wood. Only density measurements were higher for maçaranduba wood. However, the authors stated that density alone does not guarantee good quality wood for bows (Longui *et al*. 2010a). Within the same wood species, it is normal for property variations to occur (Portal-Cahuana *et al*. 2019). Therefore, to predict whether it will be suitable for making good bows is a hard task and a matter of great importance to a professional bow maker. It was pointed out that the initial selection of wood for this purpose should be guided by these features: right orientation; fine texture; absence of deformations and firmness (Angyalossy *et al*. 2005). Radially-sawn wood should also be a concern when selecting it due to shear strength which is also an important property for bows because, although not directly related to performance, it helps to prevent bow tip rupture (Matsunaga 2000).

The evaluation of pernambuco wood quality made by bow makers is related to density and bending strength although other factors may be associated with potential quality for bows (Schimleck *et al*. 2009). According to another study on wood for bows, samples of pernambuco wood classified by bow makers into potential quality levels were analyzed anatomically, physically, and chemically. Afterward, the collected data was submitted to Principal Component Analysis (PCA) and it was possible to conclude that samples classified as the best had the following characteristics: MOE values at static bending tests above 180000 $kgf \cdot cm^{-2}$ (17650 MPa); values of MOR at static bending tests above 2000 $kgf \cdot cm^{-2}$ (196 MPa); velocity of sound propagation estimated by stress waves above 4300 $m \cdot s^{-1}$; velocity of sound propagation estimated by ultrasound waves above 5300 $m \cdot s^{-1}$; lower frequencies of vessels and rays, higher percentage of fibers; density above 1000 $kg \cdot m^{-3}$ (Alves *et al*. 2008). The acoustic and mechanical properties of wood are closely correlated. Non-destructive acoustic methods, such as analyzing the speed of sound or stress waves through a vibrational behavior of wood samples are capable to predict properties like stiffness to estimate wood's potential quality for applications like musical instruments. These non-destructive techniques usually show a strong direct correlation with destructive testing methods, without damaging the material (Bucur, 2006). Most wood for bows is sold according to the speed of sound propagation and its price is proportional to the measured speed and the concern in measuring it is due to the relationship between the acoustic properties of the material and the specific elastic modulus $E \cdot \rho^{-1}$ (Hori *et al*. 2002). This is done by an ultrasonic pulse through the longitudinal section of the wood using a device called an Elasticity Tester (Alves *et al*. 2008). By analyzing wood sound propagation velocity and wood density, it is possible to estimate dynamic MOE in (Pa) by the Equation 1:

$$MOE_{dyn} = v^2 \cdot \rho^{-1} \quad (1)$$

Where: v = velocity of sound propagation ($m \cdot s^{-1}$), ρ = density ($kg \cdot m^{-3}$) (Mclennan 1990).

Using this data obtained by non-destructive methods, it is possible to establish a performance index (*PI*) of the wood according to Wegst *et al*. (2007) by the Equation 2:

$$PI = \left(MOE_{dyn}\right)^{1/2} \cdot \rho^{-1} \quad (2)$$

Where: ρ = density ($kg \cdot m^{-3}$).

The Equation 2 could be used to rank a set of rough wood rods for bows by an important parameter: the estimated elasticity per unit of mass distributed in the volume, thus, improving the selection process before transforming wood into bows for string instruments.

As a violin bow quality strongly depends on wood properties (Macedo *et al*. 2020), in this study a selection method was applied based on previous studies about bow wood quality and related properties. Physical analysis and anatomical identification were performed, and bows were made from selected wood. Afterward, bows were submitted to professional violinists who stated which bow would be preferred in their opinion through a blind test. The data is compared to confirm whether the method of non-destructive wood selection and analysis of PI is effective in practice for finding wood with quality potential for bows compared to the destructive method and the blind test.

MATERIALS AND METHODS

The wood used in this study was purchased as ipe wood from lumber companies and suppliers of decks and wood floors in *Pinhais* city, in *Paraná* state in southern Brazil. During the selection of wood samples, the following criteria were observed: 1. Visual observation of the lumber ends to verify the orientation of growth rings, aiming to identify radially-sawn boards; 2. Visual observation of the fiber alignment in order to obtain wood with a straight grain and fine texture; 3. Visual observation to avoid knots, cracks, or other defects in wood; 4. Sensitive analysis of board mass, seeking to obtain wood with a density greater than 1000 $kg \cdot m^{-3}$; 5. Analysis of sound propagation in the boards with the Elasticity Tester *Lucchimeter,* looking for wood with measurements above 5000 $m \cdot s^{-1}$.

Five wood samples were chosen and identified with the letters A, B, C, D, and E, samples of 1000 mm *x* 90 mm *x* 20 mm for each board were used for making bows. For laboratory analysis, other 700 mm x 90 mm x 20 mm of the same board segment were reserved. Analysis was performed in the laboratory for the determination of density, MOE, MOR, moisture content, and sound velocity by Stress Wave Timer (SWT) and by ultrasonic waves. Wood anatomy analysis was performed in laboratory to confirm the genus analyzed and to compare wood sample structures. Static bending tests were carried out, with samples of 20 mm x 20 mm x 300 mm using an Emic Universal Testing Machine (DL-30) following the COPANT 555-1973 (COPANT 1973) standard, to obtain MOE and MOR data. The moisture content (MC %) of the samples was obtained through maintenance and drying in an oven at 103 ºC (± 2 ºC) until constant weight was reached. Its value, calculated in relation to the dry basis, was obtained by the Equation 3:

$$MC_{db} = \left(W_i - W_f\right) \cdot W_f^{-1} \cdot 100 \quad (3)$$

Where: W_i is the initial weight; W_f is the final weight.

Anatomical analysis of samples was performed using histology slides. They were made in cross, radial, and tangential sections. Maceration was also done to measure wood fibers, which were then analyzed under a microscope to get qualitative and quantitative data about the characteristics of ipe wood samples used.

Violin bows were handmade with ipe wood in a standardized way, following the shape and measurements currently used for violin bows made with pernambuco wood and based on Tourte’s model (Dell’Olio 2009).

To perform the blind test, the participant should be blindfolded. Individual, disposable non-toxic and anti-allergic face masks were used covering participant's eyes that in a preliminary test showed ease of adaptation, effectiveness, safety, and hygiene. All musicians were willing to participate in the tests and were conscious that the objective was to better understand wood quality for bows and that it was an anonymous questionnaire inspired by studies of Caussé (2001) and Fritz (2014). Each participant was invited to express his assessment and preference about the bows and it was neither possible to visualize which bow was being played nor the wood it was made from. Figure 1 depicts the research flowchart. In total, there were sixteen violinist participants who had 14 to 42 years of violin practice at the time. All musicians worked as professional violinists in professional orchestras.

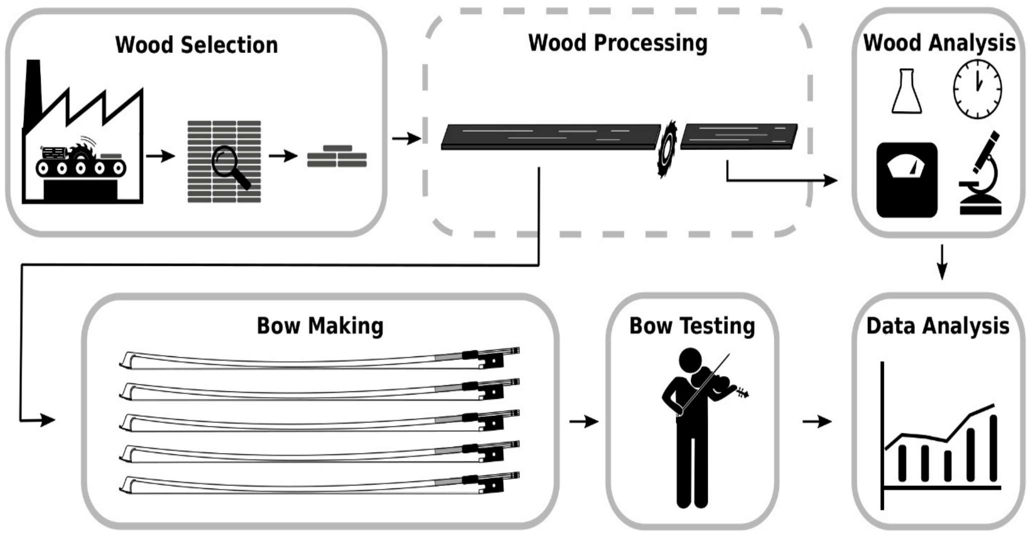

Figure 1: Research Flowchart.

To carry out the tests, a professional violin was used. The string set used was Pirastro brand, Tônica model, medium tension. The same instrument was made available to all participants with the same configuration, aiming to standardize the tests. The rosin (resin for violin bow) used was Hill brand, dark type. The shoulder rest used was Wolf brand, Forte Secondo model, and the chinrest was Teka type. The quality score was registered by means of forms, in a verbal consultation, using a Likert-type scale from 1 to 6 (Robson 1993), without central position, using semantic differential related to degrees of satisfaction perceived by musicians in five different criteria based on preview studies on violin bows (Caussé *et al*. 2001), aiming at a qualitative analysis. Five criteria were adopted: Weight, Weight Balance, the compliance between Stiffness and Flexibility, Playability and Sound Response, with mark 1 meaning totally dissatisfied and mark 6 totally satisfied. Musicians were also asked which bow would be their choice if they could keep one of the five bow samples.

Data was subjected to statistical analysis to determine whether there was a distinction between the wood samples analyzed. Shapiro Wilk's test was performed. When data abnormality was identified non-parametric analysis was performed by Kruskal-Wallis one-factor ANOVA and post-hoc multiple comparison method Dwass-Steel-Critchlow-Fligner (DSCF) test. Correlation tests were also performed by Kendall Tau-B correlation method for non-parametric data to indicate relations between anatomical features and bows scores.

RESULTS AND DISCUSSION

Wood anatomy

After anatomical analysis, all samples were identified as belonging to the genus *Handroanthus*. (Inside-Wood 2004, Wheeler 2011). According to the list of macroscopic characteristics of hardwoods (IAWA 1989), the following characteristics were observed in samples A, B, C, D and E (Figure 2): 1. Growth ring boundaries distinct; 5. Wood diffuse-porous; 13. Simple perforation plates; 22. Intervessel pits alternate; 42. Mean tangential diameter of vessel lumina 100-200 μm; 47, 5 to 20 vessels per square millimeter; 66. Non-septate fibers present; 70. Fibers very thick-walled; 72. Mean fiber lengths 900 to 1600 µm (samples: C, B, E); 73. ≥ 1600 µm (samples A e D); 74. Mean = 1310, SD = ± 323,58, Range = 687 to 2062, n = 150; 80. Axial parenchyma aliform; 82. Axial parenchyma winged-aliform; 83. Axial parenchyma confluent; 84. Axial parenchyma unilateral paratracheal; 91. Two cells per parenchyma strand; 92. (3 - 4) cells per parenchyma strand; 97. Ray width 1 to 3 cells (predominantly two cells); 104. All ray cells procumbent; 115, 4 - 12 Rays per millimeter; 118. All rays storied.

Figure 2: Microphotography of ipe samples in cross-section. Scale bar: 1000 μm.

In analysis comparing samples fibers, we verify that samples A and D had the lowest proportion of fibers. Samples A and D, are statistically different from samples B, C, and E by the multiple comparison DSCF test on fiber length data (Table 1).

Table 1: Multiple Comparison DSCF - Fiber Length.

Ipe Sample		W	p
A	B	- 9,42	< 0,001
A	C	- 9,42	< 0,001
A	D	- 4,58	0,010
A	E	- 9,33	< 0,001
B	C	- 5,28	0,002
B	D	9,14	< 0,001
B	E	4,84	0,006
C	D	9,31	< 0,001
C	E	7,88	< 0,001
D	E	- 8,31	< 0,001

Physical, mechanical and acoustic properties

Samples selected were analyzed and after static bending tests, each sample presented the properties described in Table 2. Samples A and D were denser, however, they were different in properties. Samples D and E had the highest values of MOE and MOR in static bending tests.

Table 2: Physical, mechanical and acoustic properties by method.

Destructive					Non-destructive			
Sample	Properties				SWT		Ultrasound	
	Density*	MOE	MOR	MC	Speed	MOE_{dyn}	Speed	MOE_{dyn}
	(kg/m³)	(MPa)	(MPa)	(%)	($m\cdot s^{-1}$)	(MPa)	($m\cdot s^{-1}$)	(Mpa)
A	1169	18210	196	13	4118	19820	5145	30944
B	1032	18768	202	14	4590	21743	5616	32548
C	1019	18392	214	11	5000	25475	5290	28515
D	1167	21147	230	11	4375	22337	5300	32781
E	1100	20922	219	12	4375	21054	5221	29118

*Apparent density at 12 % of moisture content.

Sound propagation speed measurements by SWT, had a range of 4118 to 5000 $m\cdot s^{-1}$ and followed the order C, B, E, D and A. Measurements by ultrasonic meter had a range of 5145 to 5616 $m\cdot s^{-1}$ and followed the order B, D, C, E and A, from the highest to the smallest (Table 2). Acoustic measurements of wood are essential for analyzing wood for musical instrument bows (Wegst 2006), as they can be obtained through both destructive and non-destructive methods, facilitating the prediction of additional properties.

Table 3 shows the performance index of samples by method. It is possible to observe that SWT non-destructive method and the destructive method were classified in the same order, while the ultrasonic meter changed the order of samples B and C, compared to SWT and the destructive method. This is explained because ultrasound waves are less suitable for estimating MOE_{dyn} compared to the stress wave method. Despite this, ultrasound devices are most used due to their ease of use on site (Baar *et al.* 2015). Samples D and E, had a small change by the ultrasound method. Sample A had the least potential. Samples C and B were evaluated with the best potential for bows among the five analyzed.

Table 3: Comparison of Performance Index classified by method in descending order.

Destructive		Non-destructive			
Sample	PI	Sample	PI SWT	Sample	PI Ultrasound
	$(MOE)^{½}\cdot\rho^{-1}$		$(MOE_{dyn})^{½}\cdot\rho^{-1}$		$(MOE_{dyn})^{½}\cdot\rho^{-1}$
C	0,133	C	0,156	B	0,174
B	0,132	B	0,142	C	0,165
E	0,131	E	0,131	D	0,155
D	0,124	D	0,128	E	0,155
A	0,115	A	0,120	A	0,150

The equation for calculating sound velocity in wood takes into account the wood density. Hence, the lower the density and at the same time the higher the MOE, the higher the wave velocity. This leads to the conclusion that increasing density should decrease the sound propagation speed. Therefore, even though stiffness and density in wood are not independent, density singly, without considering cellular structures or arrangement, does not define stiffness completely (Baar *et al*. 2012, Longui 2009, Schimleck *et al*. 2011). Interlocked grain, size or high number of pith rays, and other complex microscopic structures like microfibril angle, may also influence the sound propagation speed (Hori *et al.* 2002).

Bows features

Built bows are shown in Figure 3. Bows were made aiming to obtain the greatest possible similarity between the artifacts using reference average values considered by the literature as usual for measurements of thickness, weight, length, center of mass, and camber for violin bows.

Figure 3: Finished bows made of ipe wood.

As a result, percussion center varied subtly depending on mass distribution, probably due to density variations, even though their measurements are considered normal for physical characteristics of violin bows according to Kun and Regh (1994). Bows' shape similarities as well as physical characteristics are described in Table 4.

Table 4: Physical and geometric characteristics of bows.

Sample	Mass	Center of Mass[1]	Center of Percussion[2]	Wood length	Total length
	(g)	(mm)	(mm)	(mm)	(mm)
A	61,6	185	447	727	741,5
B	60,6	183	439	727	741,5
C	59,4	187	447	727	741,5
D	60,9	184	450	727	741,5
E	59,6	183	442	727	741,5

[1]Measured from the transition between frog's ferrule and the hair. [2]Measured by pivoting the bow from frog's thumb notch.

Bows evaluated has a Center of Mass range variation of 4 mm and Center of Percussion range variation of 11 mm. The range of bows mass variation was 2,2 g.

Sensorial bow evaluation

Non-parametric multiple comparison analysis (DSCF) performed with scores related to criteria including Weight, Weight Balance and Playability showed that there is a statistically significant difference only for sample A in relation to C. There was a tendency to assign higher marks to the lightest bow among the five, which was 59,4 g as shown in Table 5. In the Weight Balance criterion, the bow made from sample A had the worst evaluation among bow samples. Coincidentally, bow A is the heaviest bow among others with 61,6 g. When dealing with such a small quantity of wood as that of a violin bow, whose rod weighs around 36 g to 38 g on average, along 70 cm small fluctuations in physical properties may be meaningful. Bows sample C and E, were the lightest ones with 59,4 g and 59,6 g respectively.

Table 5: Bow sample overall average in descending order with scores means by criterion and respective coefficient of variation.

Sample	C	B	E	D	A
Score mean	5,10 (0,03)	4,78 (0,01)	4,76 (0,04)	4,61 (0,06)	4,21 (0,07)
Weight	5,37 (0,13)	4,68 (0,24)	4,93 (0,17)	4,93 (0,09)	4,31 (0,26)
Weight Balance	5,12 (0,20)	4,75 (0,18)	5,06 (0,18)	4,81 (0,17)	3,75 (0,38)
Stiffness & Flexibility	4,93 (0,25)	4,75 (0,21)	4,56 (0,21)	4,18 (0,23)	4,31 (0,25)
Playability	5,19 (0,20)	4,88 (0,22)	4,69 (0,24)	4,38 (0,23)	4,31 (0,18)
Sound Response	4,93 (0,21)	4,87 (0,23)	4,81 (0,21)	4,68 (0,21)	4,56 (0,22)

The scores assigned to bows under Stiffness & Flexibility and Sound Response criteria singly did not show a significant difference. The overall average scores related to bow quality by musicians can be considered satisfactory on a 6-point scale range and were ordered identically to the *PI* destructive analysis.

The aim of the initial selection was to find suitable wood for bow making, according to the characteristics listed in related studies (Alves *et al.* 2008, Angyalossy *et al.* 2005), thus, properties and characteristics suggested as selection criteria for pernambuco wood with potential quality for violin bows provided guidelines to select ipe wood samples. However, it did not make the selection process a simple or an easy task. Due to the level of specificity required, few boards presented basic characteristics recommended in proportion to the amount of wood analyzed in lumber companies. Some wood samples in this study came from spoiled pieces during the milling process and sometimes boards presented the expected sound propagation speed, although the fiber alignment and growth ring orientation was inappropriate.

The quality performance of bows made with ipe wood in this research (Table 5), to a certain extent, was determined by the properties of wood and the way its configuration was defined, as pointed by Wegst *et al.* (2007), because bows with high degrees of satisfaction were also made from wood with high potential quality measured through *PI* in laboratory tests. However, the ultrasonic non-destructive analysis by *lucchimeter* did not assess the potential of samples in the same order, and it was less precise in characterizing the quality of wood, though it was faster than the laboratorial analysis and did help to identify wood with acoustic properties within desired range of speed of sound propagation (Table 3). Bow sample C had the best evaluation in technical aspects, however, when musicians were asked if they could keep one bow for them, bow sample B was the favorite one. In individual criteria the bow of sample C was the one that obtained the highest score, but in practice the bow of sample B stood out among the violinists, even though bow sample B did not have the best average score given by musicians themselves. Musicians ranked their favorite bows in the following order, from most to least preferred: B, C, E, D, A. When asked why they favored one bow over others, they cited ease of control, sound quality, and responsiveness. Notably, bow sample B, the most preferred, also had the least coefficient of variation between criterion means evaluated by them (Table 5). It is worth noting that the coefficient of variation between bow means followed this same order. This means that even if we have similar bows from the perspective of physical properties, little differences in performance might be quite significant from musicians' perspective, which justifies a careful search for high-quality wood for this purpose. One cannot ignore the importance and complexity of acoustical interactions between bow and violin realized through their handling by the violinist (Gough 2011).

Using the Kendall's Tau-B rank correlation method for non-parametric analysis, stiffness and flexibility criteria scores had a moderate positive relationship with scores attributed to the perceived playability, which had a weak negative correlation with fiber length related to bows evaluated as best in musicians' opinion (Figure 4). Also Playability and Sound Response are moderately and positively correlated. The weight criteria was weakly correlated with Sound Response, however, Weight Balance was positively moderately correlated with Playability and Sound Response.

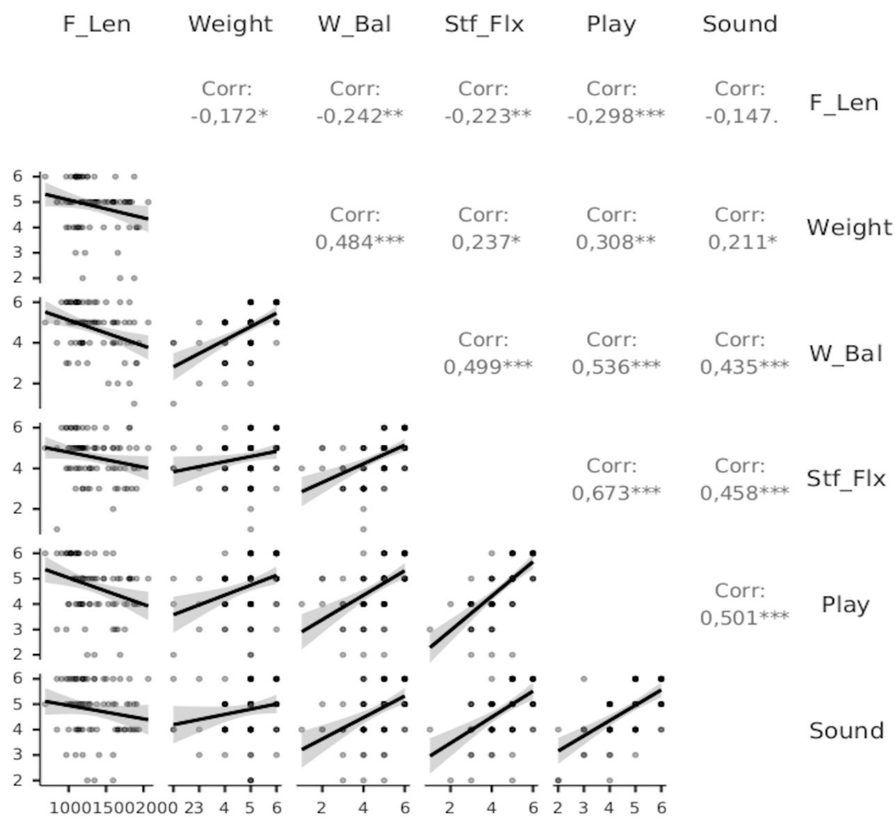

Figure 4: Correlation array and chart with fiber length and bow scores by criterion. F_Len: Fiber Length; W_Bal: Weight Balance; Stf_Flx: Stiffness & Flexibility; Play: Playability; Sound: Sound Response; Corr: Kendall's correlation coefficient; * p-value < 0,05; ** p-value < 0,01; *** p-value < 0,001.

The findings of Longui (2009) on wood for violin bows concluded that fiber features were those that most contributed to variations in apparent density, and that, in most cases, it was not possible to correlate density and sound propagation speed. In our study, we also observed that longer fiber length was linked to greater density.

In this regard, although complex laboratory analysis might not be feasible when selecting wood for bows, it's possible to say that the approach of a bow maker before a high-density wood (with appropriate stiffness, *i.e.*, high MOE value), should aim at the resiliency of the rod. The mass of the bow is to be a consequence, not an objective. Otherwise, the bow will become excessively thin, because, according to Schimleck *et al.* (2011), very high-density wood could result in thin bows due to weight requirements which may not perform well. To confirm this assertion, bow sample D had the highest MOE value of all (Table 2), the Weight criteria evaluated by musicians was good, as well as Weight Balance (Table 5), however, scores to the criteria Stiffness & Flexibility was the worst of all, affecting also Playability. Hence, if this bow sample D was thicker, it could perform better, at the expense of lightness. Therefore, to estimate the potential wood quality for bows it's highly recommended not only to determine the sound propagation speed, but also to measure the lumber mass at the same volume and shape, in order to compare the apparent density and sound velocity of wood samples more quickly. Using that criteria it's possible to rank in a more precise way a quantity of wood whose purpose is bow making by means of PI. It is important to consider that ultrasound measurements have a positive correlation with moisture content in wood (Simpson 1998), so ranking wood should be done in the same environment with the wood at the same equilibrium moisture content.

CONCLUSIONS

Following parameters for pernambuco wood, ipe wood was suitable for making professional violin bows and its performance was considered satisfactory after evaluation by professional violinists. Bow samples with values of density above 1160 kg·m^{-3} were the least appreciated by musicians. Bows rated as best had density between 1000 kg·m^{-3} to 1100 kg·m^{-3}. In addition, the method used for selecting wood for bow making succeeded and the main aspects evaluated during the selection of ipe wood for violin bows in this research were: wood integrity; fiber alignment, radially-sawn wood, sound propagation speed, and wood density. Also ranking wood sample quality by performance index using the ultrasonic method was faster though less accurate than the Stress Wave Timer and destructive methods, which better aligned with violinists' perceived bow quality. This evaluation method highlights the existence of ipe wood with potential for bows in the wood stock of some lumber companies, or even among discarded piles, which may have high commercial value as a wood product. The results reinforce the potential of ipe wood for violin bows while actions on the sustainable use of pernambuco wood are developed.

Authorship contribution

I. M. F.: Data curation, investigation, formal analysis, writing - original draft. T. C. F.: Conceptualization, supervision, writing - review & editing. S. N.: Conceptualization, resources, supervision, writing - review & editing. J. L. M. M.: Conceptualization, resources, supervision, writing - review & editing.

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