SIX POTENTIAL WOODS FOR BOWS OF STRINGED INSTRUMENTS: ORGANOLEPTIC PROPERTIES, MACHINING AND COMMERCIAL AVAILABILITY[1]

SEIS MADEIRAS POTENCIAIS PARA ARCOS DE INSTRUMENTOS DE CORDA: PROPRIEDADES ORGANOLÉPTICAS, TRABALHABILIDADE E DISPONIBILIDADE COMERCIAL

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ABSTRACT – In this paper it was investigated the organoleptic properties and machining of six potential woods for bows of stringed instruments and compared the results with those mentioned for the *Caesalpinia echinata* wood, the reference for modern bows. Thirty wood stores were visited in different cities of the São Paulo state to verify the commercial availability of these woods. We concluded that despite the traditionalism of the red tones in the woods for bows, woods with yellowish tones such as *Handroanthus* spp. and *Dipteryx* spp. or brownish such as *Diplotropis* spp. with appropriate properties, may offer alternative colors and textures to the musicians. It was observed that the *Mezilaurus itauba* and *Astronium lecointei*, woods with easy machining, have no potential suitable for bows. Regarding to availability, all woods tested are relatively easy to find nowadays in the wood market. *Handroanthus* spp. and *Dipteryx* spp. showed greater potential for making bows for professional musicians. The woods of *Mezilaurus itauba* and *Astronium lecointei* did not show good potential for bows.

Keywords: *Caesalpinia echinata*; *Handroanthus*; *Dipteryx*; musical instruments.

RESUMO – Neste trabalho foram investigadas as propriedades organolépticas e a trabalhabilidade de seis madeiras potenciais para arcos de instrumentos de corda e os resultados comparados com os da madeira de *Caesalpinia echinata*, referência para arcos modernos. Foram visitadas 30 madeireiras em diferentes cidades do Estado de São Paulo para observar a disponibilidade das seis madeiras. Conclui-se que apesar do tradicionalismo dos tons de vermelhos na madeira para arcos, outras madeiras com tons amarelados como *Handroanthus* spp. e *Dipteryx* spp. ou acastanhados como *Diplotropis* spp., desde que possuam propriedades adequadas, podem oferecer alternativas de cores e texturas para os músicos. Madeiras de fácil trabalhabilidade, como *Mezilaurus itauba* e *Astronium lecointei* não são adequadas para a fabricação dos arcos. Atualmente, todas as madeiras testadas são relativamente fáceis de serem encontradas no comércio madeireiro. *Handroanthus* spp. e *Dipteryx* spp. apresentaram o maior potencial para a fabricação de arcos para músicos profissionais. As madeiras de *M. itauba* e *A. lecointei* não mostraram potencial para os arcos.

Palavras-chave: *Caesalpinia echinata*; *Handroanthus*; *Dipteryx*; instrumentos musicais.

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1 INTRODUCTION

The choice of woods for any purpose requires knowledge of their organoleptic and technological properties, machining and commercial availability. The traditional woods have had their properties checked over decades, so the comparison of these properties with the ones of alternative woods, represents an effective strategy to assess the potential of the latter.

Due to heterogeneity, orthotropy and variability of wood, even two pieces of the same tree are never absolutely similar (Burger and Richter, 1991; Araújo, 2002), so the selection of alternative woods is not a simple process.

Besides appropriate physical and mechanical properties, woods are also chosen for their organoleptic properties as color, smell and brightness. Color and smell are present mainly in the heartwood and given by pigments, tannins, resins or other organic substances. The brightness due to the reflection of light by cell walls, the texture due to the dimensions of vessels and rays and the grain related to the longitudinal orientation of cells also characterize each wood (Brunelli et al., 1997).

The machining is influenced by the structure of the wood and by its physical, mechanical and organoleptic properties as well as by the presence of crystals, silica, oils and toxic extractives that can cause difficulty in sawing and risks to health. Among these features, the grain is directly related to the finish, because woods with irregular grain will show a rough surface after sanding. The density also affects the machining: in woods with very low density, due to high frequency of axial parenchyma, it is difficult to obtain smooth surfaces because those cells tend to tear, resulting in velvety surfaces. Whereas, in the woods with high density, there is an excessive attrition and wear on cutting tools (Burger and Ricther, 1991; Williams, 1999; Hoadley, 2000).

The wood of *Caesalpinia echinata* has been used for almost 200 years in the manufacture of bows of stringed instruments (Bueno, 2002), and even nowadays there are few scientific studies to propose alternative woods (Matsunaga et al., 1996; Angyalossy et al., 2005; Alves et al., 2008a; Longui et al., 2010a, b). Considering that *C. echinata* is endangered our aims were:

1) to determine organoleptic properties and machining of six potential woods and compare them with *C. echinata*;
2) to check the availability of those woods in the woodwork supply stores, and
3) to classify the studied woods with regard to their potential for bows.

2 MATERIAL AND METHODS

2.1 Wood Species

Five planks of *Handroanthus* spp. syn *Tabebuia* (ipê) – Bignoniaceae and three planks of *Mezilaurus itauba* (itaúba) – Lauraceae, *Hymenaea* spp. (jatobá) – Fabaceae, *Dipteryx* spp. (cumaru) – Fabaceae, *Diplotropis* spp. (sucupira) – Fabaceae and *Astronium lecointei* (muiracatiara) – Anacardiaceae were bought in the wood market in São Paulo. According to Mainieri et al. (1983), these wood species have specific gravity above 950 kg m^{-3}, a density considered ideal for bows (Alves et al., 2008a; Longui et al., 2010a, b). To ensure that the samples came from different trees, only one plank was purchased in each wood store. To confirm the identification, the woods were compared with samples from the Forestry Institute Xylarium (SPSFw). Besides the above six woods, we also studied 10 samples of *Caesalpinia echinata* (pau-brasil) supplied by one of the authors.

2.2 Organoleptic Properties

It was established the organoleptic properties of the wood by visual, tactile and olfactory analyses and by comparison with data from the literature (Mainieri et al., 1983; Brunelli et al., 1997; Zenid, 2009).

2.3 Machining

The machining was based on the experience of one of the authors, a bow maker for over 20 years. For each stage of bow manufacture: sawing, planing, bending, sanding and finishing, as described by Alves et al. (2008b), a difficulty scale (levels 1 to 5) was created, with higher numbers indicating greater difficulty. The seven woods were evaluated in a comparative way, which resulted in a relative score for each stage of the process.

2.3.1 Sawing

Using A band saw, it was sawed 10 sticks (about 750 x 15 x 15 mm) for each wood in a total of 70 sticks (Figure 1).

Figure 1. Cutting *Diplotropis* spp. sticks with a band saw.

Figura 1. Corte em serra de fita das varetas de *Diplotropis* spp.

2.3.2 Planing

The sticks (Figure 2) were planed to reach the final shape and dimensions of a bow. This procedure can be performed throughout the stick manufacturing. The tools used in this stage were: planer, measurement instrument, ruler, scrapeand chisel.

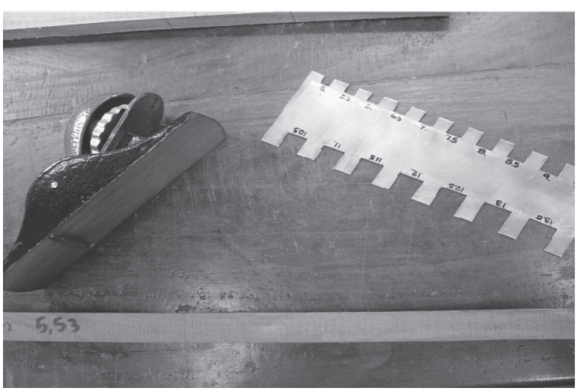

Figure 2. Planer and instrument to measure the diameter of the sticks. Photo by Erika Amano in Alves et al. (2008b).

Figura 2. Plaina e instrumento para medir o diâmetro das varetas. Foto de Erika Amano em Alves et al. (2008b).

2.3.3 Bending

This stage was performed with an alcohol lamp and a support attached to a table. The sticks were heated every 2 centimeters and forced against the support to get the curvature (Figure 3).

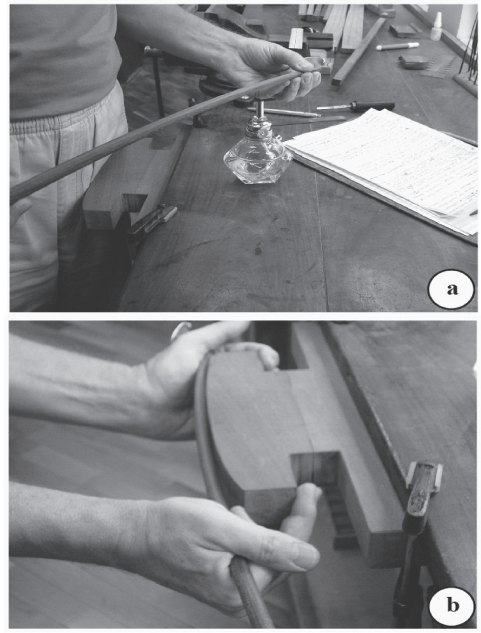

Figure 3. Curvature of sticks. a. Heating stick with an alcohol lamp. b. Stick being bent over support to obtain the curvature. Photos by Erika Amano in Alves et al. (2008b).

Figura 3. Procedimento para curvatura das varetas. a. Aquecimento da vareta com lamparina a álcool. b. Vareta sendo curvada sobre suporte. Fotos de Erika Amano em Alves et al. (2008b).

2.3.4 Sanding

Just as the planing, at various stages of manufacture and to promote the finish of the sticks, they were sanded with abrasive paper of different grit size (Figure 4). To establish the difficulty level of sanding, this stage was always performed in the longitudinal direction of the wood (parallel to the fibers).

Figure 4. Sanding the side of the stick near the head. Photo by Erika Amano in Alves et al. (2008b).

Figura 4. Lixamento da lateral da vareta próxima da ponta. Foto de Erika Amano em Alves et al. (2008b).

2.3.5 Finishing

For the finish, it was used fine abrasive paper, paintbrush, varnish and polishing cloth.

2.4 Commercial Availability

Thirty wood stores were visited: 10 in the city of São Paulo and 20 in other cities of São Paulo state. The identification of species/genus was confirmed by observation with a 10x hand lens, and comparison with literature (Mainieri et al., 1983; Mainieri and Chimelo, 1989) and with samples from wood collection of the Forestry Institute of São Paulo, whose acronym is SPSFw.

3 RESULTS

3.1 Organoleptic Properties

Table 1 shows the organoleptic properties of the seven studied species.

Table 1. Organoleptic properties of *Caesalpinia echinata* and six potential woods for bows manufacture.

Tabela 1. Propriedades organolépticas de *Caesalpinia echinata* e seis madeiras potenciais para fabricação dos arcos.

Organoleptic properties	Woods						
	Ce	Ha	Hy	Mi	Dipt	Dipl	Al
Heartwood	Orange to dark reddish	Pale brownish or yellowish with darker green or attenuated fibrous aspect, with brown streaks	Brownish red	Yellowish-green when freshly cut, becoming brownish-green to dark when exposed to light	Pale brownish or yellowish with accentuated fibrous aspect	Brownish with accentuated fibrous aspect	reddish brown with dark veins and gold hues
Odour	Indistinct	Olive	Indistinct	Pleasant	Olive	Indistinct	Indistinct
Brightness	Moderate or high	Low	Low	Moderate	Low	Absent or irregular	Moderate
Texture	Fine to medium	Medium to coarse	Medium to coarse	Fine to medium	Medium to coarse	Coarse	Medium
Grain	Straight to interlocked	Straight	Straight	Wavy to interlocked	Irregular to interlocked	Irregular to interlocked	Interlocked

Ce = *Caesalpinia echinata*; *Ha* = *Handroanthus* spp.; *Hy* = *Hymenaea* spp.; Mi = *Mezilaurus itauba*; Dipt = *Dipteryx* spp.; Dipl = *Diplotropis* spp.; Al = *Astronium lecointei*.

3.2 Machining

The values determined in each stage were added up to establish the degree of difficulty. It was noted that the wood that provided better quality sticks had greater difficulty in being worked (Table 2 and Figure 5). The six potential woods were more easily sawed, planed, bending and sanded (except *Diplotropis* spp.) than *C. echinata*, although the finishing was better in the latter.

Table 2. Machining of *Caesalpinia echinata* and six potential woods for bows manufacture. Numbers 1-5 indicate the degree of difficulty, higher numbers indicate greater difficulty.

Tabela 2. Trabalhabilidade de *Caesalpinia echinata* e seis madeiras potenciais para fabricação dos arcos. Números de 1-5 indicam o grau de dificuldade, números mais altos indicam maior dificuldade.

	Woods						
Stages	*Ce*	*Ha*	*Hy*	*Mi*	*Dipt*	*Dipl*	*Al*
Sawing	3	2	2	1	2	2	1
Planing	5	2	3	1	4	4	1
Bending	5	2	1	2	1	3	2
Sanding	3	2	1	2	3	1	2
Finishing	1	2	2	1	2	2	2

Ce = *Caesalpinia echinata*; Ha = *Handroanthus* spp.; Hy = *Hymenaea* spp.; Mi = *Mezilaurus itauba*; Dipt = *Dipteryx* spp.; Dipl = *Diplotropis* spp.; Al = *Astronium lecointei*.

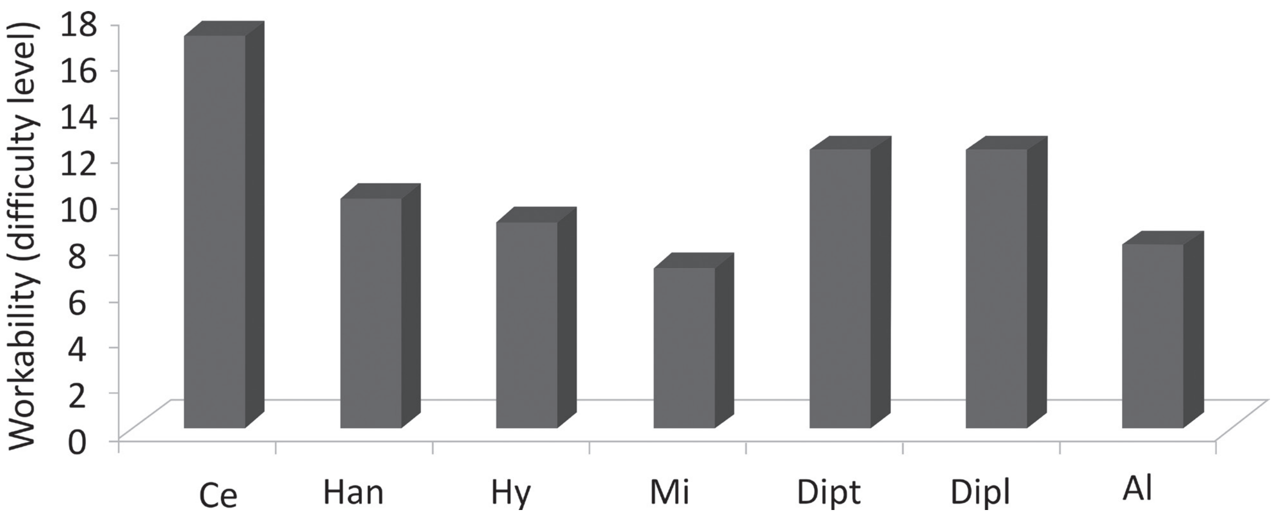

Figure 5. Sum of the degree of difficulty regarding to machining.

Figura 5. Somatória do grau de dificuldade quanto à trabalhabilidade.

M. itauba and *A. lecointei* were easier to saw (level one), while *Handroanthus* spp., *Dipteryx* spp., *Diplotropis* spp. and *Hymenaea* spp. showed the same level of difficulty of sawing (level two).

Planing varied between the potential woods: *M. itauba* and *A. lecointei* were the easiest planed (level one); *Handroanthus* spp. was level two, *Hymenaea* spp. level three, while *Dipteryx* spp. and *Diplotropis* spp. were the most difficult to be planed (level four).

Concerning bending, *Diplotropis* spp. showed difficulty level three; *Hymenaea* spp. and *Dipterix* spp. were bending easily (level one), while *Handroanthus* spp., *M. itauba* and *A. lecointei* showed level two. Comparing the potential woods with *C. echinata* (level five) they were bending easily.

C. echinata and *Dipteryx* spp. were the most difficult to be sanded (level three), *Handroanthus* spp., *M. itauba* and *A. lecointei* showed level two, the easiest were *Hymenaea* spp. and *Diplotropis* spp. (level one).

C. echinata and *M. itauba* showed the best finishing (level one) and the other woods presented level two. Comparing these woods, *Handroanthus* spp. and *Dipteryx* spp. developed raised fibers, resulting in a lower quality of finishing.

Figures 6, 7 and 8 show, by comparison, the transverse and tangential longitudinal surfaces of the studied woods.

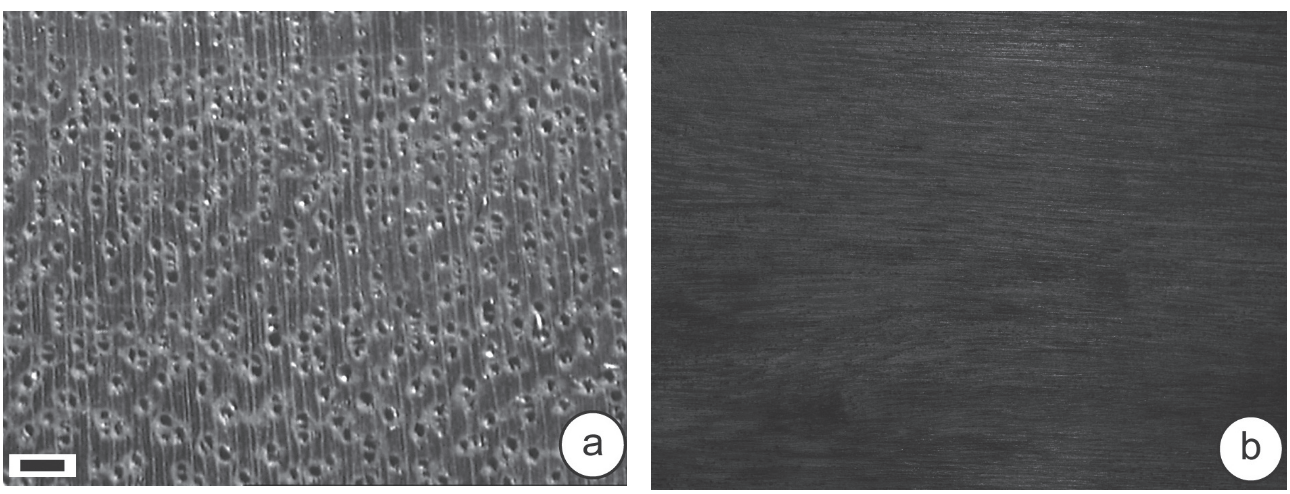

Figure 6. *Caesalpinia echinata* wood. a. Transverse surface of wood. b. Tangential longitudinal surface. Compare with figures 7 and 8 which show the images for the six potential woods for bows. Scale bar = 500 µm.

Figura 6. Madeira de *Caesalpinia echinata*. a. Superfície transversal. b. Superfície longitudinal tangencial. Compare com as figuras 7 e 8 que mostram as fotos de seis madeiras potenciais para arcos. Escala = 500 µm.

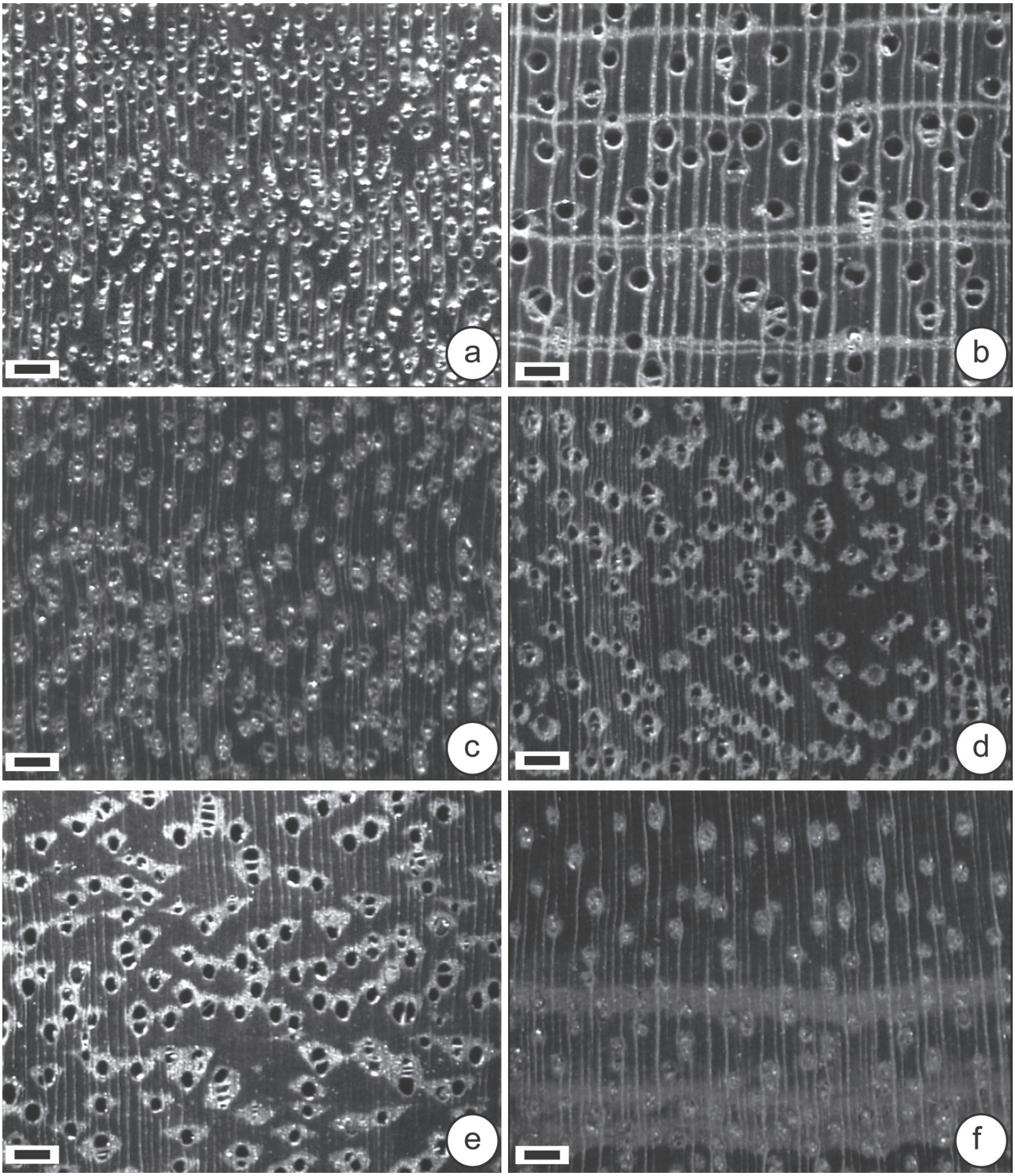

Figure 7. Transverse surface of six potential woods for bows. a. *Handroanthus* spp. b. *Hymenaea* spp. c. *Mezilaurus itauba*. d. *Dipteryx* spp. e. *Diplotropis* spp. f. *Astronium lecointei*. Observe the differences in vessel diameter, the greater abundance of axial parenchyma aliform (d, e) and the presence of axial parenchyma aliform and marginal parenchyma (b). Scale bar = 500 µm.

Figura 7. Superfície transversal de seis madeiras potenciais para arcos. a. *Handroanthus* spp. b. *Hymenaea* spp. c. *Mezilaurus itauba*. d. *Dipteryx* spp. e. *Diplotropis* spp. f. *Astronium lecointei*. Observe a diferença no diâmetro dos vasos, abundância de parênquima axial aliforme (d, e) e presença de parênquima axial aliforme e parênquima marginal (b). Escala = 500 µm.

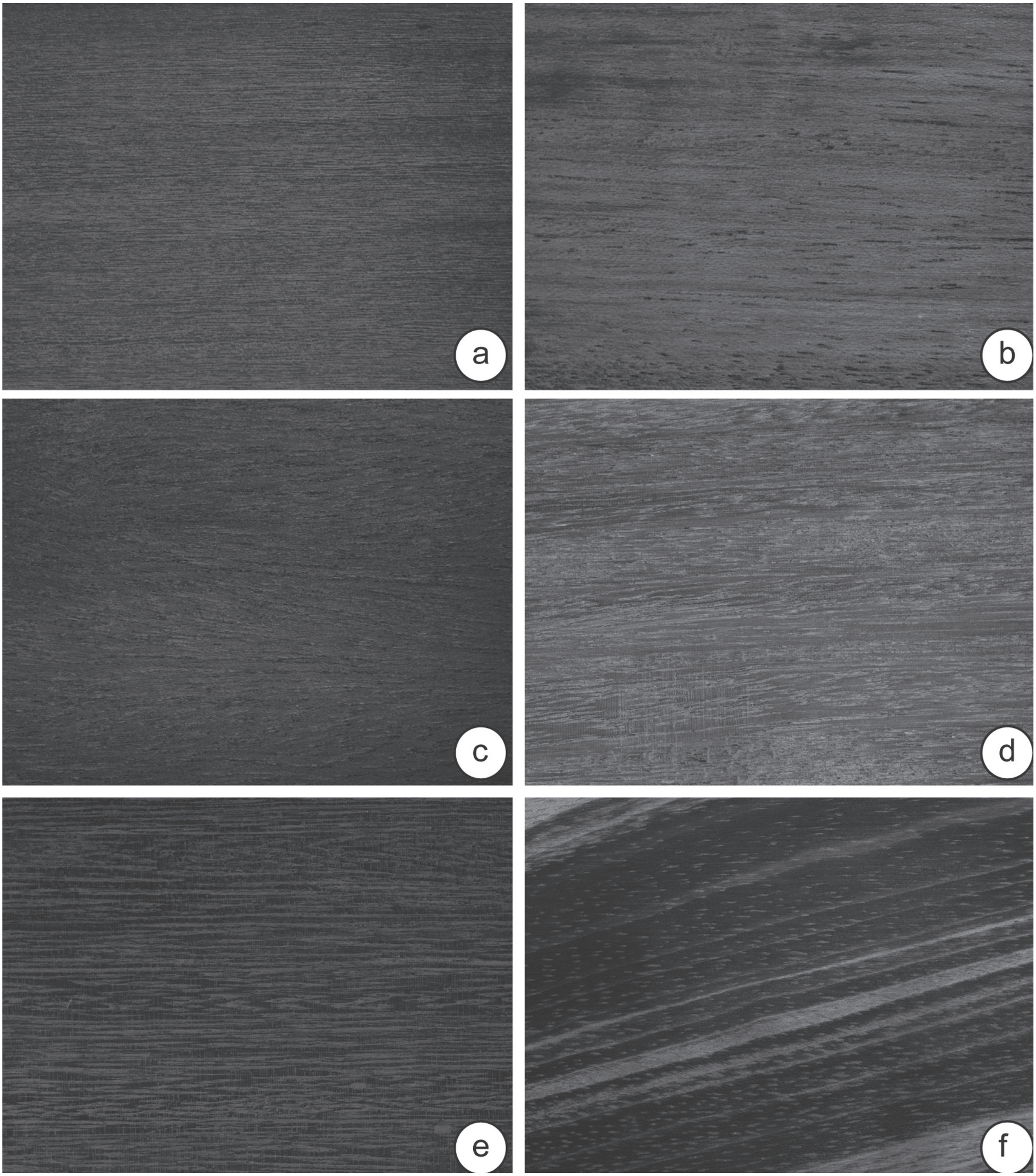

Figure 8. Tangential longitudinal surface of six potential woods for bows. Notice the different textures and quality of the sanded surface among the woods. a. *Handroanthus* spp. b. *Hymenaea* spp. c. *Mezilaurus itauba*. d. *Dipteryx* spp. e. *Diplotropis* spp. f. *Astronium lecointei*.

Figura 8. Superfície longitudinal tangencial de seis madeiras potenciais para arcos. Note a diferença na textura e qualidade da superfície lixada entre as madeiras. a. *Handroanthus* spp. b. *Hymenaea* spp. c. *Mezilaurus itauba*. d. *Dipteryx* spp. e. *Diplotropis* spp. f. *Astronium lecointei*.

3.3 Commercial availability

Based on the results of research in 30 wood stores in the São Paulo state, *M. itauba* was the most species observed, occurring in 60% stores. *Dipteryx* spp. was found in 46.6%, *Hymenaeae* spp. in 43.3% and *Handroanthus* spp. at 36.66%. The least common were *Diplotropis* spp. with 20% and *A. lecointei* with 13.3% (Figure 9).

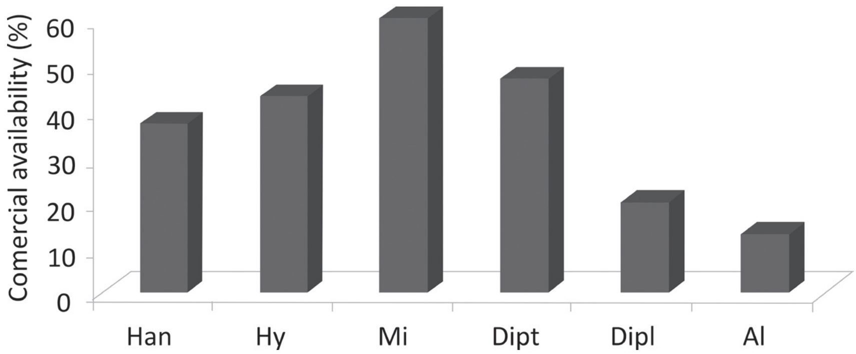

Figure 9. Commercial availability of the six potential woods for bows in 30 wood stores at São Paulo state.

Figura 9. Disponibilidade comercial de seis madeiras potenciais para arcos em 30 madeireiras do Estado de São Paulo.

4 DISCUSSION

4.1 Organoleptic properties

The reddish color of the heartwood of *C. echinata* is appreciated by musicians, who associate the wood color with bow quality. Thus, bows of other colorations are evaluated with suspicion (Alves et al., 2008a, b).

Therefore, acceptance of other colors represents one of the difficulties facing the traditionalism of reddish wood for bows. In addition to its other properties, highly suitable for the manufacture of bows, the red color of the *C. echinata* wood is also a major attraction for bow makers and musicians. However, the proposed new colors with lighter shades and yellow represent a choice.

Among the studied species, the heartwood coloration of *Hymenaea* spp. is the closest to *C. echinata*, with shades of brownish red; *Handroanthus* spp. and *Dipteryx* spp. have yellowish heartwood, *A. lecointei* present shades of red and darker stripes, which give beauty to the wood; *M. itauba* are greenish yellow when freshly cut, darkening to greenish brown some time after the cut, *Diplotropis* spp. have brownish heartwood. Besides color, it was observed attenuated fibrous aspect in *Handroanthus* spp. and *Dipteryx* spp. and accentuated fibrous aspect in *Diplotropis* spp.

In previous studies Alves et al. (2008a) and Longui et al. (2010a, b) samples of *Handroanthus* spp. was evaluated and it was concluded that this wood provided good quality bows, as confirmed by professional musicians. Therefore, it is possible to use alternative woods if they have the proper quality.

Besides color, the smell of the wood is important for bows. In *C. echinata*, smell is indistinct, but present in *M. itauba*, *Handroanthus* spp. and *Dipteryx* spp., the first ones have a pleasant smell, the other two have a smell that resembles the olive and the others have no smell. An unpleasant smell might restrict the use of wood for the bow, since it is handled near the face; however, none of the six potential woods has unpleasant smell.

4.2 Machining

4.2.1 Sawing

The difficulty level of sawing the wood is influenced by several factors: grain, wood uniformity, defects and knots, cellular composition, density, chemical constituents etc. The presence of interlocked grain and knots can explain the greater difficulty of *C. echinata*. Interlocked grain and defects in the wood make it difficult to cut, because it causes changes in the direction of the band saw, which requires constant alignment. According Kivimaa (1952) apud Lucas Filho (2004), the greater the fiber inclination, the harder is its cutting.

Matsunaga et al. (1996) found in *C. echinata* many knots and other defects such as distortion of the grain, causing low efficiency in obtaining quality sticks for bows. It was noted that from the cutting of the planks to the final dimensions of the sticks there is a loss of about 90%.

The easier cutting of *Handroanthus* spp. and *Dipteryx* spp., in comparison with *C. echinata*, can be explained by the homogeneity of these woods and less quantity of defects than *C. echinata*. Moreover, according to Alves et al. (2008a), *C. echinata* has a higher percentage of fibers and vessels with smaller diameters than *Handroanthus* spp., increasing the difficulty of cutting, considering that the fibers promote increased resistance to cutting. Silva et al. (2005) found correlations between the dimensions of the fibers and the machining in *Eucalyptus grandis*. The authors reported that fibers with thicker walls have better results because they are not crushed nor cut only partially.

In the seven woods investigated in this study, there are significant differences in the thickness of the fibers (Longui et al., 2010a), however, all the wood have fibers with very thick walls (IAWA Committee, 1989), which favors the cutting quality

Density is a property that may explain the lesser difficulty in cutting the wood of *M. itauba*, because its density was comparatively lower than *C. echinata* (Longui et al., 2010a). Néri et al. (2000) mentioned that the force required for cutting is positively correlated with wood density. Although Zenid (2009) mentions that the presence of silica in the wood of *M. itauba* might hinder its cut, this was not observed in this study.

4.2.2 Planing, sanding and finishing

The greater or lesser ease to obtain a good result in these three stages depends on many characteristics, such as grain, size and frequency of wood cells, knots, resin content, mineral abrasives etc.

C. echinata presented level five for planing which is explained by the presence of interlocked grain and knots. *Dipteryx* spp. and *Diplotropis* spp. have also irregular interlocked grain and this feature make the planing difficult (Brunelli et al., 1997), Zenid (2009). According to Gonçalves (2000), when a wood with interlocked grain is planed, the woodchips can break by shearing, causing a defect known as chipped or torn surface. According to the author, the finished long pieces are very difficult, since many wood fibers have random orientation along the trunk.

Thus, the sticks for violin bows may present many deviations in their grain. Even in *C. echinata*, the reference wood for bows, there is a wide variation in the grain, with straight grain sticks (easier to plane) and others with interlocked grain.

According to Hoadley (2000), the rays represent areas of weakness in the wood, and difficulty in obtaining a smooth surface, because their orientation rarely coincides with the worked surface; therefore, woods with more frequent and higher rays have more difficulty in planing and sanding.

Brunelli et al. (1997) and Zenid (2009) reported that the wood of *Hymenaea* spp. is easy to plane. However, in the present study, this wood had difficulty level three, despite having a straight grain. This difficulty may be due to the large vessel diameter and ray dimensions (Longui et al., 2010a). Moreover, *Hymenaea* spp. presents paratracheal axial parenchyma aliform with confluences and axial parenchyma in marginal lines (Figure 7b), characteristics that may to hamper the planing and sanding. Besides the aesthetic aspect, variations in abundance of parenchyma, size and frequency of vessels make certain regions of the wood weaker, thus more susceptible to breakage.

The final aspect of the sticks is influenced not only by the vessel's size, larger in *Hymenaea* spp. and *Diplotropis* spp. The most abundant axial parenchyma in *Dipteryx* spp. and *Diplotropis* spp. (Figures 7d and 7e) was also important in planing and sanding. The parenchyma cells, being more fragile than fibers and vessels are fragmented or detached from the wood, just as the rays, making it difficult to smooth surfaces, which explains the difficulty (level four) established for these two woods.

The density also influences the planing, which is easier for denser woods (Kollmann and Côté, 1968; Lucas Filho, 2004). In this study, the woods have the similar density (Mainieri et al., 1983); so, it can be expected that the observed differences are due to variability of the anatomical structure. Comparing the six potential woods with *C. echinata* wood, it was observed that the former presented a combination of vessels, rays and fibers with larger dimensions, and considering these anatomical features, the wood of *Handroanthus* spp. was the most similar to *C. echinata* (Figures 7a and 6a, respectively).

As mentioned previously, the anatomical features such as length and direction of the fibers, dimensions of vessels and rays directly influence the quality of planing and sanding and, consequently, the finishing. In *Hymenaea* spp. although the wood has large vessel diameter, the frequency of these cells was lower than *Diplotropis* spp., with vessels of similar diameter (Figures 8b and 8e), providing a satisfactory finish to the *Hymenaea*. The sticks of *Dipteryx* spp. become weaker due to axial parenchyma and at *Diplotropis* spp. due to the presence of large cells (Figures 8d and 8e). In *A. lecointei* there were no major difficulties during the finishing, although Slooten and Souza (1993) reported that the machining of *A. lecointei* is variable due to the darker stripes.

In addition to the orientation of the fibers, their length also influences the quality of finish, since longer fibers are more difficult to pull out when the wood is planed and to avoid the formation of holes or raised fibers (Silva et al., 2005).

Longui et al. (2010a, b) reported shorter fibers for *C. echinata* than those observed in the six potential woods. *Handroanthus* spp. and *A. lecointei* got close to this value. However, besides the length, the dimension of the contact surface between fibers in the longitudinal direction is also important. It was estimated that the larger contact area between the fibers decreases the occurrence of holes or raised fibers.

4.2.3 Bending

In this study, the sticks were heated with an alcohol lamp to soften the wood and provide the ideal curvature. According to Guimarães Júnior (2008), the softening of wood is due to physical changes in lignin and other substances that improve the conditions of rolling, especially in hardwoods. It is possible that the content of these substances in the wood influences in curvature.

Matsunaga and Minato (1998) have tested the curvature in *C. echinata* and also in three other woods – *Manilkara bidentata*, *Dialium* sp. and *Swartzia fistuloides*. The woods were bent between two steel plates at temperatures of 280 ºC and then cooled. After two weeks, the curvature was measured again: *C. echinata* showed the smallest curvature, with little difference from the three other woods analyzed, but it was the best in maintaining the curvature.

Matsunaga et al. (1996) and Matsunaga and Minato (1998) mentioned that the wood of *C. echinata* and *Swartzia fistuloides*, with a higher content of extractives than those of *Manilkara bidentata* and *Dialium* sp., showed similar softening, at a lower temperature. According to the authors, the results suggest that the extractive content influences the temperature at which the wood shows softening. Matsunaga et al. (1996) mentioned that when the woods were heated to 200 ºC, a decrease in dynamic elasticity modulus occurred due to the softening of the extractives, which restrict the free movement of hydrogen bonds between cellulose in cell walls.

In this study, due to heating, there were breaks in some of the sticks, which is due to reactions occurring in the substances present in the walls (cellulose and lignin) and in the cells lumen (extractives); the sticks have changed their rigidity, especially in regions close to the heated areas, which may increase the chance of breakage. The pattern of breakage is different in the woods: in *C. echinata* the extent of the rupture is small and the stick breaks completely, whereas in *Handroanthus* spp. and *Dipteryx* spp. there is no total disruption. When these breaks occur, the stick can be repaired, however, the bow will have a lower price. The ruptures observed in *Handroanthus* spp. and *Dipteryx* spp. were less restrictive than those which occur in *C. echinata*.

4.3 Commercial Availability

Since the 18th century, *C. echinata* wood has been used worldwide in the manufacture of bows for string instruments (Retford, 1964). However, as stated by the IBAMA (Brazilian Environment Institute) Resolution #37-N, from April 1992, the species is endangered (Rocha and Simabukuro, 2008; Gasson et al., 2009), restricting its legal commercial use after the year 2007. Therefore, studies on alternative wood species or other materials became necessary to minimize the impact on *C. echinata* wood.

For other species to be accepted for bow manufacture, studies are needed to assess their anatomical, physical, mechanical, acoustical and chemical properties, besides carrying out manufacturing bows test, as we did in the present study.

Bows with potential woods should be offered to the musicians who will test theirs quality. In this study it was not proposed to replace the *C. echinata* wood, since it has been used for centuries with great success and has recently had its quality scientifically proven (Alves et al., 2008a; Longui et al., 2010a, b). The intention is to offer alternatives, if possible for soloists or for hobbyists and beginners, at cheaper prices when compared to the *C. echinata* bows.

However, for the selection of alternative woods, it must considered that the commercial availability and provenance, i.e, trees must be removed sustainably from forests and present forestry source document. This procedure allows the exploitation of some woods for noblest applications, avoiding predatory exploitation and not repeating what happened with *C. echinata*.

In this study, it was visited a relatively small percentage of wood stores in the São Paulo state, but it was found that the six potential woods are relatively easy to find nowadays in the wood market, which enables its use in the bows manufacture.

5 CONCLUSIONS

5.1 Organoleptic Properties and Machining

Despite the traditionalism of the red tones in the woods for bows, woods with yellowish tones such as *Handroanthus* spp. and *Dipteryx* spp. or brownish such as *Diplotropis* spp. with appropriate properties, may offer alternative colors and textures to the musicians.

It was observed that the two woods that have easy machining (*M. itauba* and *A. lecointei*) have no potential suitability for bows. Among the four other potential woods, when considering the organoleptic properties associated with the machining, *Handroanthus* spp. and *Dipteryx* spp. present the greatest potential. *Diplotropis* spp. has the same difficulty level as *Dipteryx* spp., however *Handroanthus* spp. is better than *Diplotropis* spp. Thus, it was concluded that the organoleptic properties and the machining should be considered together. Furthermore, analysis of potential woods must also be made based on physical and mechanical properties that result from the variations of size and frequency of wood cells.

5.2 Commercial Availability

Regarding to availability, the two promising woods *Handroanthus* spp. and *Dipteryx* spp. or the two woods with intermediate quality *Hymenaea* spp. and *Diplotropis* spp. are relatively easy to buy nowadays in the wood market, which enables their use in the manufacture of bows.

5.3 Potential for Bows

Handroanthus spp. and *Dipteryx* spp. show greater potential for making bows for professional musicians. Bows made of *Handroanthus* spp. have been commercialized and presented to the musicians. Recently, bows made of *Dipteryx* spp. were acquired by professional musicians, which ranked as good quality bows. *Diplotropis* spp. and *Hymenaea* spp. can provide an option for amateur or beginner musicians. The studied woods of *Mezilaurus itauba* and *Astronium lecointei* do not show good potential for bows. In practice, a wood will be suitable when the bow maker manufactures a bow with ideal density, stiffness and bending, and especially when the musician produces quality music with this bow.

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