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Bamboos as the material for saxophone reed

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ABSTRACT

In this work, a material new to reed making, the bamboo, was compared with the traditionally used *Arundo donax* L. (the cane). The cross-sectional anatomy, relationship between the thickness and the reed strength, the spectral centroid, and the effect of the water extraction on the timbre were studied. The moso-bamboo has higher density of fibre inside a vascular bundle but has lower number density of the vascular bundles. For both materials, the reed thickness alone was not a good index for the reed strength. When the reed is new, the moso-bamboo gives brighter sound at the high note. After the sugar extraction by water, the spectral centroid of both materials reduced to lower frequency, indicating less bright sound. The cane seems to be more durable when the high note was compared. For the low note, the two materials perform similarly after the sugar extraction..

INSTRUCTIONS

Saxophone reed has been made of the giant reed, *Arundo donax* L. (also known as cane). In botanical classification, it belongs to the *Poaceae* family. It has been shown (Obataya and Norimoto 1999) that the water extractable sugars in the reed greatly affect the reed's frequency response and hence the tone richness of the musical instrument. Good musical performance has also been found to be associated with the anatomical characteristics of *Arundo donax* L.(Kolesik, Mills et al. 1998).

Bamboo (Obataya, Kitin et al. 2007), which also belongs to the *Poaceae* family, has similar longitudinal fibre structure and polysaccharide composition as in the cane. It is intriguing to investigate whether bamboo is suitable for making saxophone reed.

In this work, the cross-sectional anatomy of the cane and the bamboo was compared using a confocal scanning microscope. Moreover, the timbre of the alto reeds made of *Arundo donax* L. and moso-bamboo was analysed by their audio spectrogram. The timbre analysis was focused on the spectral distribution. The effect of the reed strength was studied using strength from soft to hard (100 cN to 200 cN). The effect after the water extraction of the soluble sugars in the reeds was also studied.

MATERIALS AND METHODS

Reed fabrication and cross-section measurement

Two materials for making reeds were used. For the conventionally used reed material *Arundo donax* L., reed blanks were acquired commercially (Rigotti alto reed blank, #471847) and used without further modification. The blanks were then manually shaped to an alto saxophone reed using a reed profiling machine (RPM82, UHL Technik). The reed strength was measured by a strength grading system (SGS82, UHL technik). The thickness of the reed was measured at 2 mm from the reed tip.

Three species of bamboo from two genera, *Bambusa* and *Phyllostachys*, were tested. *Bambusa oldhamii* Munro (green bamboo in Taiwanese) belongs to the genus bambusa. *Phyllostachys makinoi* Hayata (makino bamboo) and *Phyllostachys pubescens* Mazel (moso bamboo) belong to the genus *Phyllostachys*. Only moso bamboo yields reeds that have stable dimension. Reeds made of the other two species distort significantly after hydration. The spectral analysis was performed for the moso-bamboo.

Grown-up bamboo culms were acquired locally. The culms were dried under ambient temperature and humidity for one year in an office. Culm of the bamboos with diameter of 10 to 15 cm was used in this study. Straight internode was sawed and then shaped to dimension of 72 x 16 x 3 mm using a CNC milling machine. The obtained bamboo blanks were then manually shaped to reeds using the same profiling machine for the cane. The reed strength was also measured using the strength grading system.

For water-extraction of the sugars in the reeds, the reeds were immersed in RO water at the ratio of 150 mL water per reed for 96 hours with occasional agitation. Water was replaced at every 48 hours. The obtained reeds, named as the extracted reeds in this study, were then air-dried for 24 hours before use.

The observation of the reed cross-sections was performed as follows. The reed was cut with a sharp blade. If a clean cut could not be achieved, the reeds were first softened in water before cutting. The cross-section was then observed using a laser confocal scanning microscope (VK-9710K profiler, Keyence) or an inverted microscope (Olymus IX71). 10 X objective lens were used in both microscopes. For large area observation, multiple images were stitched using the program provided by the microscope manufacturer.

Audio spectrum measurement

A microphone with flat frequency response from 20 Hz to 20 kHz (Audix TR40A) was used for capturing the sound. The signal was then digitized using a sound card (MicPort Pro, CEntrance) and recorded using commercial software, Adobe Audition 3.0. Fast Fourier transform (FFT) was performed on the recorded waveform using the software. The window of the transformation (the FFT size) is 32768 points and Blackam-Haris algorithm was used.

For timbre analysis, the lowest note D (nominal fundamental *f0* = 174.6 Hz, F_3 in piano) and the highest note D (nominal fundamental frequency *f0* =698.5 Hz, F_5 in piano) were played on an alto saxophone. The mouthpiece was a Yamaha 4C. Recordings with stable sound level and period of 1 to 2 seconds were used. Noise background was subtracted. For each note, spectra from three recording were averaged and used for the analysis.

After the FFT, the fundamental and harmonics were identified and used for the calculation of the spectral centroid according to the equation:

$$\text{Spectral centroid} = \frac{\sum_k f(k) A_k}{\sum_k A_k} \qquad [1]$$

, where *f(k)* is frequency at the k^{th} rank of the harmonic and A_k is it amplitude in dB. The frequencies used in the analysis were normalized to the nominal fundamental frequency (*f0*) according to:

$$\text{normalized frequency} \quad f(k) = f_i(k) \times \frac{f0}{f_i(0)} \qquad [2]$$

, where $f_i(k)$ and $f_i(0)$ are the observed k^{th}-ranked harmonic frequency and the observed fundamental frequency, respectively. Harmonics from the fundamental to 10,000 Hz were used for the centroid calculation.

RESULTS AND DISCUSSION

Cross-sections of cane and moso-bamboo

The anatomy of the cane and the mono-bamboo was observed and compared by a laser confocal scanning microscope. Large-area and close-up views are shown in figure 1.

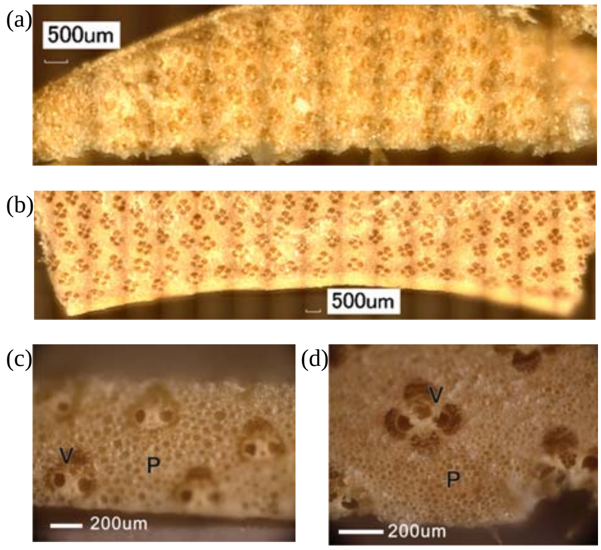


Figure 1. Cross-sections of cane ((a) and (c)) and mono-bamboo ((b) and (d)). Vascular bundles (V) and the parenchyma cells (P) are clearly seen in the close-ups. ((c) cane and (d) bamboo).

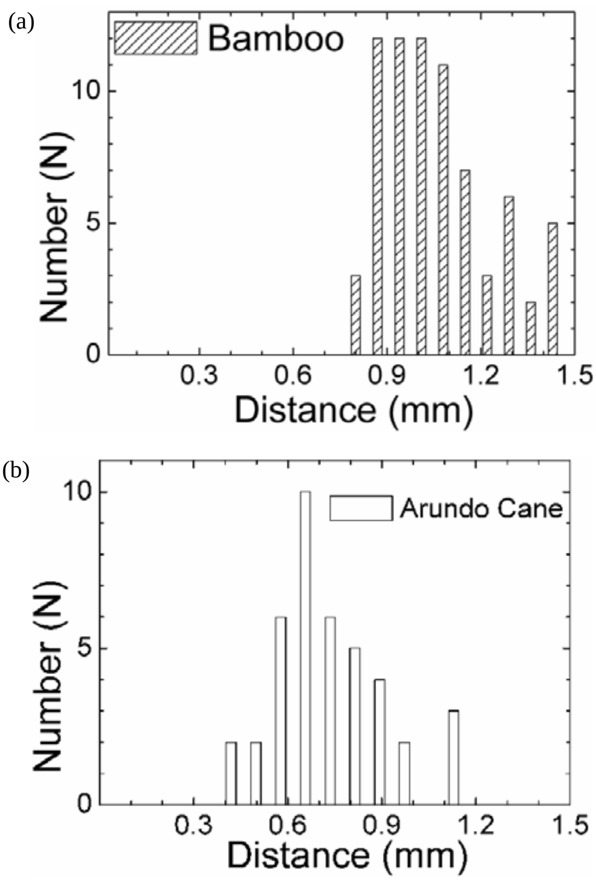


Figure 2. Histograms of the distance of the vascular bundles of the cane (a) and the mono-bamboo (b).

In figure 1(c) and 1(d), the colour of the vascular bundles of the bamboo is darker than for the cane. Fibre exists near the vascular bundle (Kolesik, Mills et al. 1998), dark colour usually indicates higher fibre density near the bundle. In addition, the bamboo clearly has higher density of the parenchyma cells. Parenchyma cells are short, round and soft cells that connect the fibre bundles. The cells are therefore conjectured to be related to the vibration characteristics and hence the timbre of the reeds. It has also been shown that the drying method for the parenchyma cell is important to the shrinkage of the cane (Obataya, Gril et al. 2004; Obataya, Gril et al. 2005).

(a)

(b)

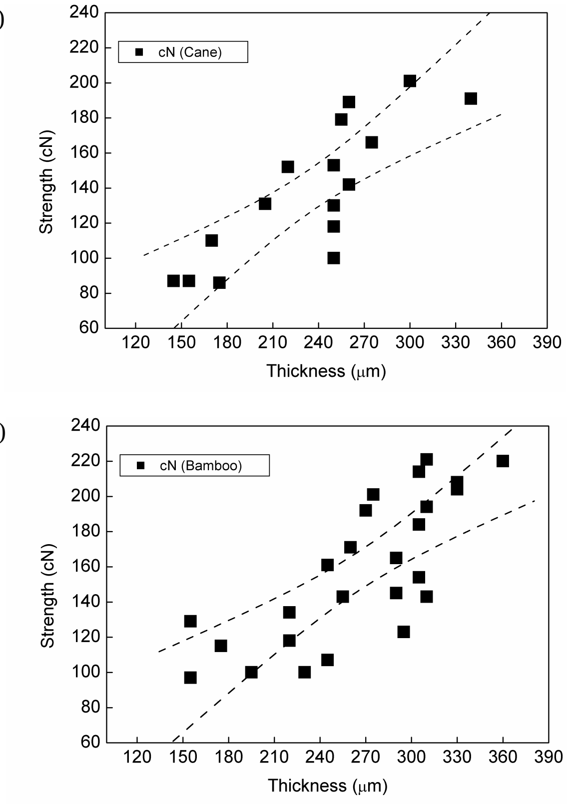


Figure 3. Relationship between the reed strength and the reed thickness for the cane (a) and the moso-bamboo (b). Linear regression was fitted. The dashed lines show the limit of 95 % confidence zones.

Using Young's moduli, Spatz et al. (Spatz, Beismann et al. 1997) has shown that the extraordinary stiffness of the cane is due to the high amount of fibre in parenchyma of the inner cortex. The high density fibre in the moso-bamboo may be an indication of its high stiffness. However, the number density of the vascular bundle may also affect the overall strength.

The large-area view of the cross-section in figure 1(a) and 1(b) are further analysed. The distance between the vascular bundles were measured and shown in histograms in figure 2. The average bundle distance for the cane and the mono-bamboo are 0.7 ± 0.2 mm and 1.1 ± 0.2, respectively. Apparently the cane has shorter average distance between the bundles and thus the higher number density. Similar to the dark bundles observed for the bamboo, the higher number density in the cane also may contribute to stronger reed strength. Because of the two competing effects, it can not be concluded that under the same dimension, which material would produce reeds with higher strength. However, because the average bundle distance in the bamboo is larger (1.1 mm) and the usual reed thickness is only 200 μm, it may be speculated that the strengths of bamboo reeds may vary to a larger extent. This effect was studied by the relationship between the reed strength and the thickness.

Reed strength and thickness

Reeds with thickness from 150 μm to 360 μm were fabricated and their strength measured. The results were fitted with linear regression and plotted in figure 3. It can be seen that the results were rather scattered, indicating that the thickness alone is not a good index for the reed strength. This can be realized by the fact that the reed thickness is significantly smaller than the average vascular bundle distance (1 mm) In addition, the 95 % confidence zones for either material do not differ substantially, suggesting that the inhomogeneous distribution of the vascular bundles in both materials is the main cause for the strength variation of such thin reeds. It is concluded that small vascular bundle distribution is crucial for consistent reed strength.

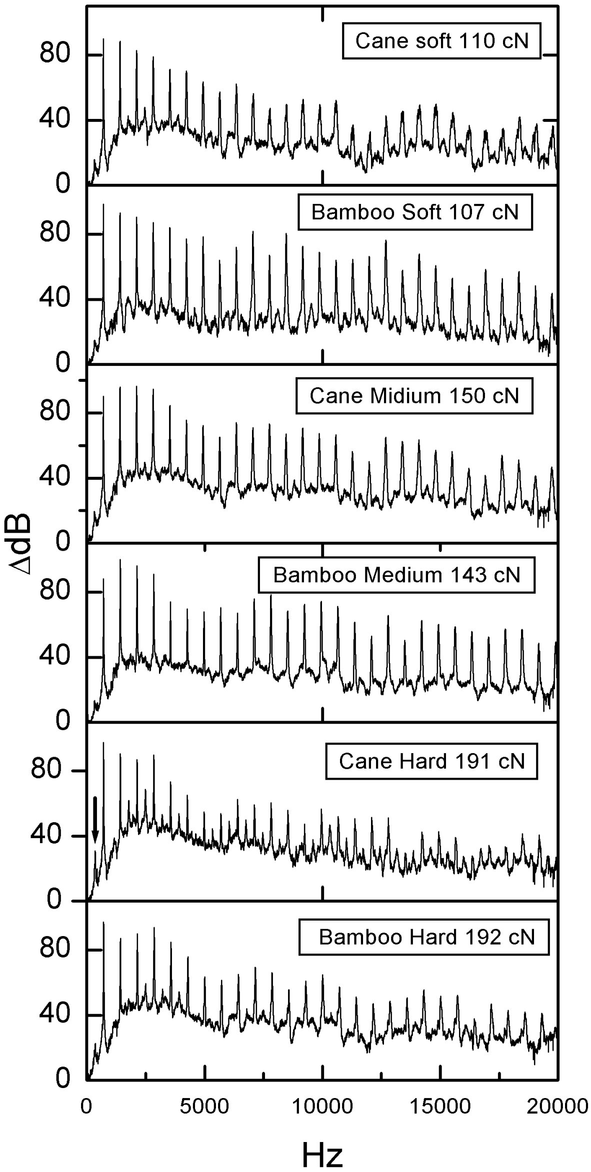


Figure 4. Typical audio spectra of cane and mono-bamboo reeds with strength from soft to hard (from the top to bottom). The note is the highest D (nominal fundamental frequency *f0* =698.5 Hz, F_5 in piano). The arrow in the second from the bottom indicates the subharmonics peak at about 350 Hz.

Typical audio spectra of cane and moso-bamboo

The typical audio spectra of the highest D (F_5) and the lowest D (F_3) using new reeds made of the cane and the moso-bamboo are shown in figure 4 and figure 5. Prominent harmonics were observed up to 20,000 Hz for both materials. In general, for the hard reeds, the high frequency harmonics are relative weaker than the harmonics below 10,000 Hz. This trend was observed for both the cane and the moso-bamboo. Also, it is observed that the high-frequency harmonics are weaker for the hard reed.

No consistent formant was observed for either material, indicating similar timbre between them. More detailed timbre analyses were compared using the spectral centroid.

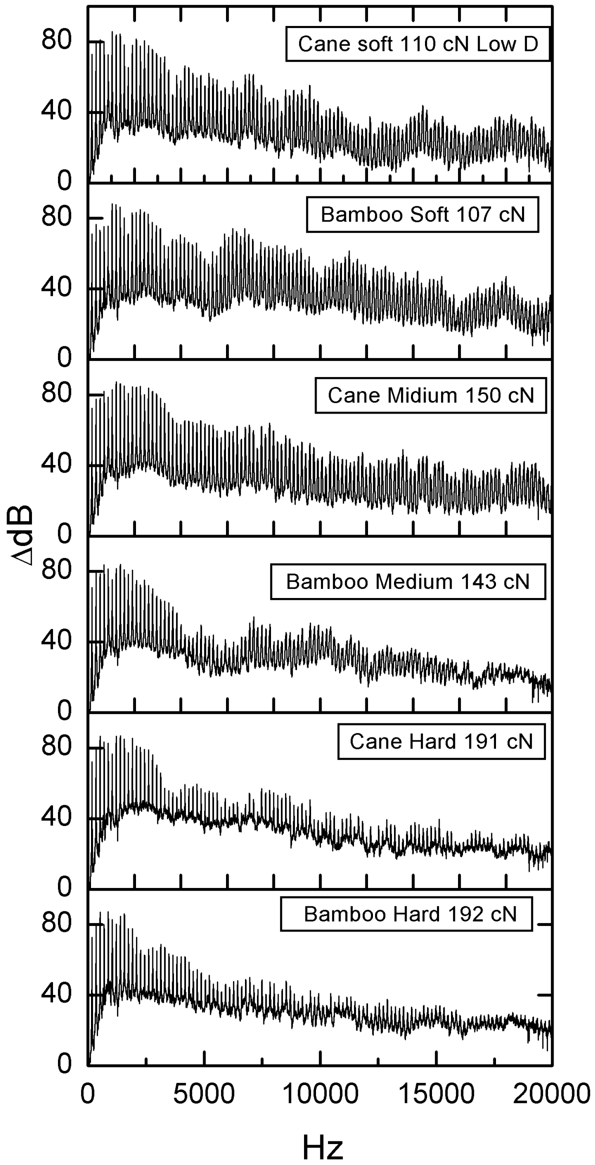


Figure 5. Typical audio spectra of cane and mono-bamboo reeds with strength from soft to hard (from the top to bottom). The note is the lowest D (nominal fundamental frequency *f0* =174.6 Hz, F_3 in piano).

An interesting observation about the spectra is the existence of the subharmonics. The subharmonics seem to be more prominent for hard cane reed, as seen in figure 4. However, currently there is no enough data to claim whether such subharmonics occurs for reeds of different strength and materials or not. Further studies will be carried out.

Spectral Centroid of new reed

Spectral centroid has been recognized to be closely related to the "brightness" of a sound (Deutsch 1999). For our analysis, harmonics below 10,000 Hz were used.

The normalized spectral centroid of the new reeds made of cane and the moso-bamboo are shown in figures 6(a) and 6(b). For both materials, the centroid for the high pitch is higher than that for the low pitch. The centroid separation is clearer for the moso-bamboo. In addition, the centroid slightly reduced to lower frequency for hard reeds although the tendency is not substantial. Two-population t-test for the cane and the bamboo under different conditions were performed to compare their difference in the centroid. The comparison is summarized in Table 1

The t-test reveals that the two materials produce similar spectral centroid when played at the low D note (p=0.69). On the contrary, when played at the high D note, the moso-bamboo produces higher centroid. The difference is significant with p = 0.02. This indicates that the moso-bamboo gives brighter tone than the cane does when played at the high note.

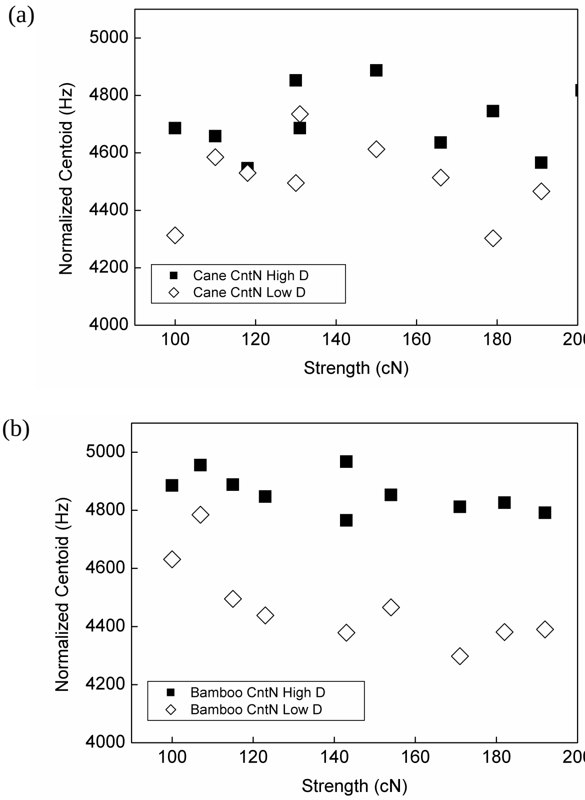


Figure 6. Spectral centroid of new reeds played with the highest D and the lowest D for the cane (a) and the moso-bamboo (b).

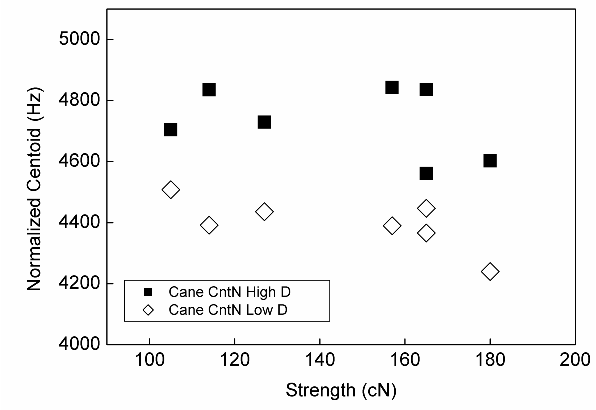
Table 1. Comparison of the spectral centroid of the two materials. P ≤ 0.05 indicates significant difference.

Normalized Centroid (Average ± SD, Hz)		**Cane**	**moso-bamboo**	**P value of t-test**
New	High D	4753 ± 112	4878 ± 68	0.02
	Low D	4511 ± 98	4484 ± 156	0.69
Extracted	High D	4727 ± 108	4762 ± 129	0.56
	Low D	4392 ± 79	4292 ± 160	0.13

Spectral centroid of extracted reeds

An important characteristic of a reed is its durability under repeated wetting by saliva. During the repeated wetting, the water-soluble sugars in the reed dissolves and the vibrational properties of the reed changes (Obataya and Norimoto 1999). We mimicked the dissolution of the sugars by soaking the reeds in water for four days to obtain the "extracted" reeds. The spectral centroids of the extracted reeds are shown in figures 7(a) and 7(b).

(a)



(b)

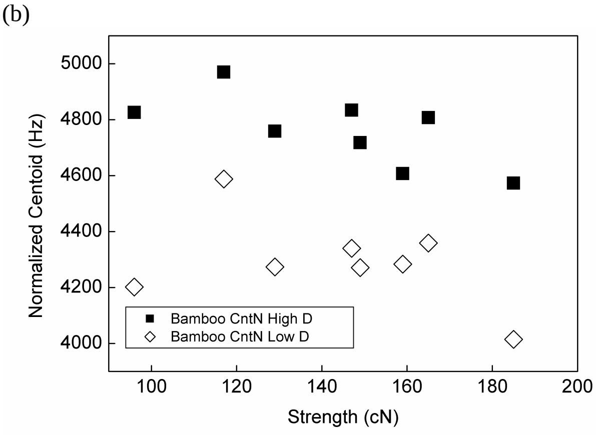


Figure 7. Spectral centroid of the extracted reeds played with the highest D and the lowest D for the cane (a) and the moso-bamboo (b).

After extraction, the two materials yield similar centroid, as shown in table 1. The difference in the high note disappears. For both materials, the spectral centroids for the high D and the low D note all differ from those of the new reeds, except for the cane that was played in the high D note (Table 2). After the extraction, the brightness of the cane played in the high D note did not change significantly although the centroid did shift to lower frequency when played in the low D note. The result suggests that when played in the high note, the cane seems more durable than the moso-bamboo.

Table 2. Centroid comparison of new and extracted reeds. P ≤ 0.05 indicates significant difference.

p-value	cane		moso-bamboo	
	High D	Low D	High D	Low D
New vs. Extracted	0.64	0.02	0.05	0.03

In summary, for the high note, the moso-bamboo gives brighter sound than does the cane when the reed is new. Nonetheless, the cane seems more durable than the moso-bamboo when played in the high note.

CONCLUSION

The anatomy of the cane and the moso-bamboo was observed and compared using laser confocal microscopy. The moso-bamboo has higher density of fibre inside a vascular bundle but has lower number density of the bundles.

For both materials, the reed thickness alone was not a good index for the reed strength.

The timber analysis focusing on the spectral centroid for the cane and the moso-bamboo were conducted. When the reed is new, the moso-bamboo gives brighter sound at the high note. After the sugar extraction by the water, the spectral centroid of both materials reduced to lower frequency, indicating less bright sound. The cane seems more durable when the high note was compared. For the low note, the two materials perform similarly after the sugar extraction.

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