*Journal of Tropical Forest Science* 36(3): 280–289 (2024)
https://doi.org/10.26525/jtfs2024.36.3.280
ISSN: 0128-1283, eISSN: 2521-9847


# FLEXURAL PROPERTIES OF AÇAÍ PALM WOOD: A POTENTIAL RESOURCE FOR AMAZON TRADITIONAL PEOPLE

**Balboni BM[1, 2, *], de Araújo Braga B[3, 4], de Sousa JTR[3], Moutinho VHP[3] & Erasmus J[2]**

[1]*Department of Forest Sciences, University of São Paulo, Piracicaba, Brazil. CEP 13418-900*
[2]*Department of Forest and Wood Science, Stellenbosch University, Matieland 7602, South Africa*
[3]*Institute of Biodiversity and Forests, Federal University of Western Pará, Santarém, Pará, Brazil. CEP 68035-110*
[4]*Department of Forest Engineering and Technology, Federal University of Paraná, Curitiba, Paraná, Brazil. CEP 80210-170*

**bruno.balboni@alumni.usp.br*

*Submitted August 2023; accepted December 2023*

Açaí berry is the main product from *Euterpe oleracea*, a palm tree largely found in the Amazon forest. The management of açaí areas involves the selective thinning of stems, a waste that accumulates in the area without any use. We aimed to assess the flexural properties of the peripheral zone of *E. oleracea* stems and their relationships with density and anatomical features. Açaí palm wood has properties similar to Amazon timbers, such as *Hymenaea courbaril* and shows strong correlation of density and fibre percentage with flexural properties. *Euterpe oleracea* palm wood has percentage of fibre tissue (46.99%) and bundle diameter (0.83 mm) similar to *Cocos nucifera*, but density (0.95 g cm-3) and flexural properties (strength = 151.6 MPa, stiffness = 16.89 GPa) superior to other palm woods, such as *C. nucifera* and *Elaeis guineensis.* Due to the stem peripheral zone thickness, açaí palm wood has the same limitations as bamboos have and, thus, can be used as a local substitute for imported bamboo products. According to its properties, açaí palm wood can be used for handicrafts, doors, frames, furniture, and structural purposes. By aligning with the ecological and social sustainability trend seen in our society, açaí palm wood products can generate deluxe items with high added value and serve as an additional income source for traditional Amazon people dependent on açaí berry management.

Keywords: Residue, forest management, *Euterpe oleracea*, community forestry

## INTRODUCTION

Açaí berry is a fruit originally from the Amazon region which has gained commercial importance in recent years. Parallel to its consumption increase, there is a growing increase of management residue (stems) whose properties have not been fully assessed. After açaí berry received the status of superfruit, there was a sharp increase in its global demand (Cymerys et al. 2011). The high antioxidant content of açaí berries is highly desired by the health food industry (Proestos 2018), resulting in its commercialisation as a superfood in the United States and Europe (Cymerys et al. 2011). This fruit is produced by a palm tree of the genus *Euterpe* and is obtained mainly in natural forests managed by traditional people within the Amazon Rainforest (Rodrigues et al. 2015), and from plantations, in other cases. There are three species of açaí palm trees: the single-stemmed, *E. edulis* and *E. precatoria* and the multi-stemmed, *E. oleracea* (Schauss 2010, Ferreira 2011). *Euterpe edulis* represents the genus in the Atlantic Forest, whereas *E. precatoria* and *E. oleracea* are the prevailing species in the western and eastern parts of the Amazon Rainforest respectively. While *E. precatoria* is naturally found on drylands, *E. oleracea* occurs mainly in flooded areas (Cymerys et al. 2011).

To meet the increased demand for açaí berry, two strategies were adopted to increase production, i.e. the plantation of orchards, using varieties developed to support non-flooded areas, and the management of natural productive areas (Homma et al. 2006). Due to the existence of vast areas with native *E. oleracea* and the prompt resource availability, the management of natural forest areas remains the main source of açaí berry, making the State of Pará (eastern Amazon) the biggest açaí berry producer in Brazil, with more than 95% of the Brazilian production in 2018 (Tavares et al. 2020). The management of natural *E. oleracea* areas includes the reduction of the number of stems in each palm clump (one individual with many stems) to minimise competition between stems from the same or other clumps (Queiroz & Mochiutti 2012). This technique can double the fruit productivity (Santos et al. 2012) and increase palm heart production up to 60% (Nogueira & Homma 2014) but generates a considerable amount of waste (stems).

These residues usually accumulate in the productive areas and are timidly used as poles in rural communities as well as to build rustic houses (Bentes-Gama et al. 2005), a trend that, according to our observations, did not change over the past decades. However, this waste has high potential for the manufacture of value-added products (Balboni et al. 2019). While the centre core of *E. oleracea* stems has light and weak material with low durability, the peripheral zone displays higher density and mechanical properties. In our previous study, we evaluated the compressive strength and its relationships with other material features, such as fibre cross-section proportion, fibre length and density (Balboni et al. 2019), but static bending is probably the major stress that products made using the peripheral zone of *E. oleracea* stems will be subjected to. Besides its strength and stiffness, a better understanding of the microstructure (i.e. proportion and diameter of vascular bundles) influences on its bending properties will help the decision on how this material can be used and how to add value to this underused residue. In this study, it was hypothesised that, likewise under compression, açaí palm wood has comparable flexural properties to Amazon timbers of similar density. It was also expected that the anatomical features of açaí palm wood have an influence akin to that observed in previous studies focused on compressive tests.

## MATERIALS AND METHODS

The material for this study was collected from the Tapajós National Forest, Brazilian Amazon (3° 31´ S, 55° 04´ W). From 10 different palm clumps, a central stem was harvested, aiming to obtain the oldest and straightest stem from each clump. The basal portion of the stems, between 0.30 and 1.5 m in height, was processed using a surface planer, to create a flat surface parallel to the grain direction, and then by a circular saw, in order to take slats tangentially from the periphery of the stems (Figure 1). The dimensions of the slats were approximately 6.5 mm × 20 mm × 1200 mm. To test our hypotheses, specimens were manufactured from these slats and tested under bending and their density and anatomical features were assessed.

Between 6 and 12 slats were produced from each stem and stacked for air drying, forming a batch of açaí palm wood. Following the sampling strategy of the Brazilian timber standard NBR7190 (ABNT 1997), we visually selected

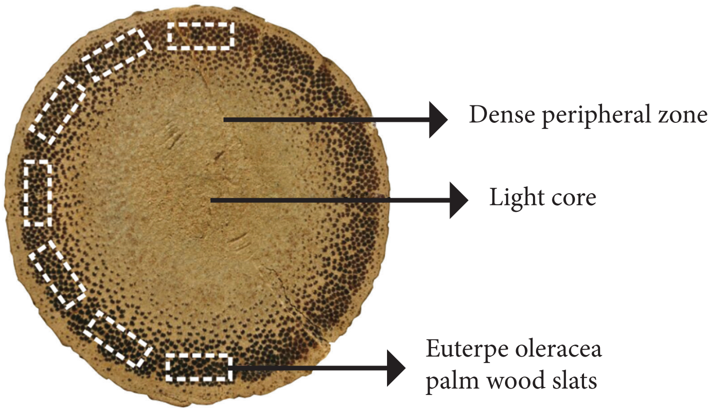


**Figure 1** Cross-section of a *Euterpe oleracea* stem (diameter = 200 mm) showing both density portions and, on its left, a diagram showing the position of the palm wood slats; source: modified from Balboni et al. (2019)

slats representative of the batch within all the range of vascular bundles sizes and frequencies. From each slat, a test specimen of 120 mm in length was prepared using a circular table saw. Altogether, we obtained 45 test specimens, from which we assessed the mechanical properties, density, and some anatomical characteristics. The terminology palm wood, as found in literature, will be adopted to refer to the peripheral zone of the palm tree stem, although it is of common knowledge that palm trees do not have cambial meristem and, thereby, do not actually produce wood (Evert & Eichhorn 2013).

Before the mechanical tests, samples were stored in an acclimatisation room with an average temperature of 25 °C and 60% air relative humidity, to reach a target moisture content (MC) of 12%. The density at 12% MC ($\rho_{12\%}$) was obtained by the gravimetric method where the mass was determined using a semi-analytical scale with a precision of 0.01 g and the volume was measured using a pair of digital callipers with a precision of 0.1 mm.

The samples were tested under static bending in order to assess the moduli of elasticity and rupture. The three-point bending tests were set up with a Universal testing machine (300 kN of capacity) using a 90-mm span, which was calculated using the span to height ratio prescribed by the ASTM—D143 standard (ASTM 2009). In order to compare *E. oleracea* palm wood with materials of different densities, we calculated the specific bending strength and stiffness, i.e. the ratios of strength/density and stiffness/density respectively. Specific properties were presented in boxplot graphs.

After the bending tests were concluded, sections close to the centre of the original samples were taken to represent the rupture zone. Then the cross-section surfaces were sanded and polished under water (Barbosa et al. 2021), using sandpaper from 80 to 200 mesh, to obtain a flat surface with good visibility of the fibre bundles. Digital images of the cross-sections of each sample were captured with a resolution of 300 dpi. With these images, the two variables, i.e. diameter of the fibrous portion of the bundles and percentage of fibrous tissue in the cross-section, were measured with the free ImageJ software. The area of 80 vascular bundles per sample was measured and the theoretical value of the diameter of each bundle was calculated considering a perfect circumference. We adopted the term bundle diameter to refer to the theoretical diameter of the fibrous portion of the vascular bundles, calculated through the equation of the circle area equation (equation 1).

$$Ø = 2\sqrt{\frac{A_b}{\pi}} \quad (1)$$

where, $A_b$ = vascular bundle cross-section area ($mm^2$) and Ø = vascular bundle diameter (mm)

For the measurement of the percentage of fibrous tissue in the cross-section, 5 $mm^2$ grids were plotted on the cross-section images (Figure 2). A set of three vertically oriented grids (15 $mm^2$) was considered one sampling area (one plot) due to the decrease of bundle distribution when approaching the centre of the stem. From approximately

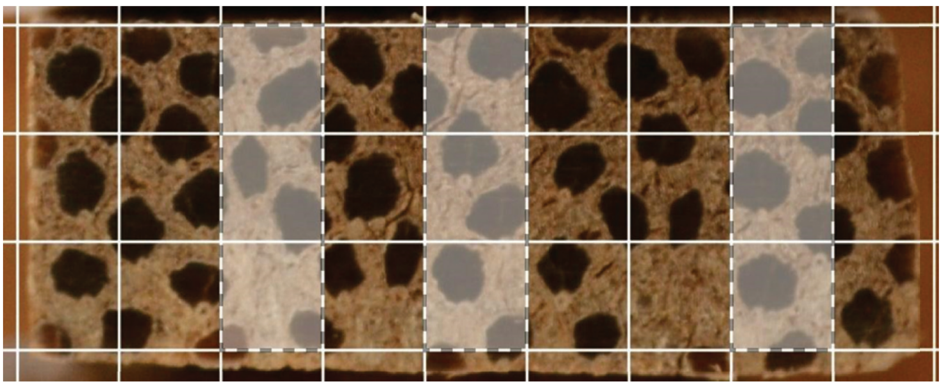

**Figure 2** Cross-section of *Euterpe oleracea* bending test specimens; grids of 5mm²; faded area represents the total sampled area, i.e. nine grids of 5 mm² area

eight plots per sample, three were randomly selected to measure the fibrous area of the material. The percentage value of the fibrous tissue in the cross-section of the samples was calculated using equation 2.

$$FP = 100 \frac{\sum_{i=1}^{n} Af_i}{\sum_{i=1}^{n} Ag_i} \quad (2)$$

where, FP = percentage of fibrous tissue in the cross section, Af = sum of fibrous area of the bundles on each plot ($mm^2$), Ag = sample area of each plot ($mm^2$), n = number of plots

We have summarised the palm wood properties in Table 1. The Pearson correlation test was applied to evaluate the relationship between the analysed variables which followed a normal distribution. The evaluation was carried out using Shapiro-Wilk test at $\alpha = 0.05$. As bundle diameter was the only variable that was not normally distributed, its correlation with other variables was evaluated through the Spearman correlation test, also at $\alpha = 0.05$. Variables whose correlation with both bending properties was significant ($\alpha = 0.05$) were used to generate linear models in order to better understand their influence on the mechanical properties and to compare this influence with other materials. Although there were correlations with p-values < α, none of the linear models with bundle diameter were significant, so we did not use them for further analysis. On the other hand, models with the other variables assessed were significant and were graphically explored. Models from the literature were used to compare *E. oleracea* to other species, the data for softwoods and hardwoods were extracted from Kretschmann (2010) and *Elaeis guineensis*, from Srivaro et al. (2018). We also built multiple regression models to understand the additive influence of density and fibre proportion on bending strength and stiffness. For statistical analysis and graphing, the software R (2022) was used.

## RESULTS AND DISCUSSION

The peripheral zone of *E. oleracea* showed high coefficient of variation for bundle diameter (Table 1), indicating that this characteristic was more heterogeneous than the percentage of fibrous tissue. Density, on the other hand, was the most uniform characteristic in *E. oleracea*. When considering the minimum values of strength, stiffness, density and percentage of fibre, we noted that mechanical properties reduced abruptly when the amount of fibrous tissue decreased, and consequently the density decreased, providing greater heterogeneity to the sample.

Bundle diameter was the only variable with negative correlation to the other variables, but the correlation with fibre proportion was not significant (p-value = 0.079). Although these correlations were not strong, *E. oleracea* palm wood which had smaller bundles also had better properties, namely, higher density, bending strength and stiffness. Density and the anatomical features assessed had a higher influence on static bending (Table 2) than that reported by Balboni et al. (2019) for parallel compression. Density had a strong influence on stiffness in static bending while in compression, the correlation was not significant. Although $\rho_{12\%}$ affected compressive strength, the effect was higher on bending strength than on compressive strength. Fibre proportion and $\rho_{12\%}$ had strong correlation with both moduli of rupture and elasticity on static bending, i.e.

**Table 1** Descriptive statistics of the variables assessed on the stem peripheral zone of *Euterpe oleracea*

| Variable | Unit | Mean (SD) | Median | Minimum | Maximum | CV% |
|---|---|---|---|---|---|---|
| Ø | mm | | 0.75 | 0.43 | 1.33 | 33.00 |
| FP | % | 46.99 (10.56) | 48.39 | 20.55 | 68.32 | 23.00 |
| $\rho_{12\%}$ | g $cm^{-3}$ | 0.95 (0.13) | 0.98 | 0.60 | 1.14 | 13.43 |
| $f_M$ | MPa | 151.60 (45.26) | 160.15 | 25.25 | 221.46 | 29.86 |
| $E_{M0}$ | GPa | 16.89 (4.34) | 17.49 | 4.66 | 22.88 | 25.71 |

Ø = bundle diameter, FP = proportion of fibre tissue, $\rho_{12\%}$ = density at 12% moisture content, $f_M$ = bending strength, $E_{M0}$ = bending stiffness, SD = standard deviation, CV% = coefficient of variation

**Table 2** Pearson (or Spearman) correlation index between the *Euterpe oleracea* palm wood variables

| Variable | Ø (mm) | FP (%) | $\rho_{12\%}$ (g cm$^{-3}$) | $f_M$ (MPa) |
|---|---|---|---|---|
| FP (%) | -0.26* | | | |
| $\rho_{12\%}$ (g.cm$^{-3}$) | **-0.31*** | **0.84** | | |
| $f_M$ (MPa) | **-0.30*** | **0.86** | **0.86** | |
| $E_{M0}$ (GPa) | **-0.35*** | **0.89** | **0.87** | **0.95** |

Ø = bundle diameter, FP = proportion of fibre tissue, $\rho_{12\%}$ = density, $f_M$ = bending strength, $E_{M0}$ = bending stiffness; bold values represent significant correlation (α = 0.05), *Spearman correlation

higher than those for compressive strength and stiffness. The bundle diameter had an opposite influence on bending and compressive stresses. Bundle diameter has a positive correlation with compression strength (Balboni et al. 2019) but negative correlation with bending stiffness. While larger vascular bundles are desirable for compression, smaller bundles take preference in the case of static bending.

The percentage of fibre and the bundle diameter on the peripheral zone are similar to values reported by Balboni et al. (2019) for the same species, i.e. 43.05% and 0.83 mm respectively, as well as for *Cocos nucifera*, 43.5% and 0.87 mm (Fathi & Frühwald 2014). Compared to *C. nucifera* peripheral zone, *E. oleracea* is 58.3% denser, 76.3% stronger and 55.5% stiffer (UNIDO 1985). Palm wood from *Elaeis guineensis*, commonly known as oil palm, has a density value, 0.297 g cm$^{-3}$ (Szymona et al. 2014), considerably lower than that of *E. oleracea*. Mechanical properties of *E. guineensis* on static bending also follow the same trend, with 6.4 MPa and 4.45 GPa for the moduli of rupture and elasticity respectively (Szymona et al. 2014). Srivaro et al. (2018) reported better mechanical properties for *E. guineensis* than Szymona et al. (2014), but they were still inferior to *E. oleracea*. The lower density of *E. guineensis* palm wood found by Szymona et al. (2014), ranging from 0.21 to 0.63 g cm$^{-3}$, could be the probable explanation for the lower mechanical properties described. For the same amount of fibre tissue, *E. oleracea* presented higher mechanical properties than *E. guineensis* (Szymona et al. 2014), although the percentage of fibre of both species overlaps only in a short range of fibre proportion (Figures 3a and b). We expected to find higher strength and stiffness in test specimens with higher fibre proportion, as fibres are the cell type responsible for mechanical support in angiosperms, such as palm trees (Evert & Eichhorn 2013).

Our results are an indication that *E. oleracea* is a material with superior mechanical properties in relation to other studied palm trees. This material might have similar properties with bamboos, as the stems from palm trees and bamboos share the same anatomical constitution, whereby their vascular bundles are immersed in the parenchymatous ground tissue (Evert & Eichhorn 2013). Although the giant bamboo (*Dendrocalamus giganteus*) is 16.69% stronger than *E. oleracea* peripheral zone (Nogueira 2013), bamboos present nodal regions, which are, in this case, 38.36 % weaker than *E. oleracea*. The absence of knots gives an advantage to the açaí palm in relation to bamboos, since this defect is relevant especially for structural uses such as glued laminated products. When using bamboo, it is mandatory to consider the mechanical properties of the nodal portion or remove this portion (Anokye et al. 2016), while *E. oleracea* do not present nodal regions. The studied material is similar to the culm of the bamboo species *Bambusa blumeana* (Abd Latif et al. 1990), with comparable density (1.01 g cm$^{-3}$) and strength (156.44 MPa), although *B. blumeana* is a lot more flexible (3.26 GPa). In the same way, *E. oleracea* peripheral zone is comparable to some important Amazon timber species such as *Astronium lecointei* and *Hymenaea courbaril*, as they present similar density and mechanical properties (Andrade 2015).

The positive relation between density and mechanical properties commonly reported for wood is also clearly present in the peripheral zone of *E. oleracea* (Figure 4a and b). Lower values of $\rho_{12\%}$ suggest moduli of rupture and elasticity inferior to those found in softwoods and hardwoods. However, based on the angular coefficient, the influence of density

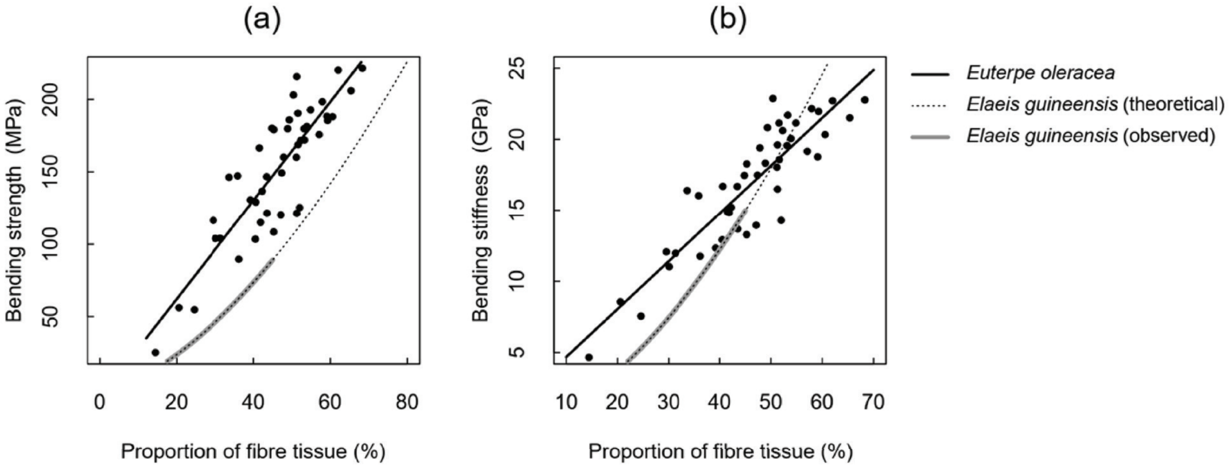


**Figure 3** Relationship of the proportion of fibre tissue (FP) on the cross section with (a) bending strength ($f_M$) and (b) bending stiffness ($E_{M0}$) on *Euterpe oleracea* palm wood; $f_M$ = -5.8331 + 3.4030 (FP), $R^2$ = 0.74, p-value = 1.755 × $10^{-14}$; $E_{M0}$ = 1.32325 + 0.33647 [FP], $R^2$ = 0.79, p-value = 2.2 × $10^{-16}$; data for *Elaeis guineensis* was taken from Srivaro et al. (2018)

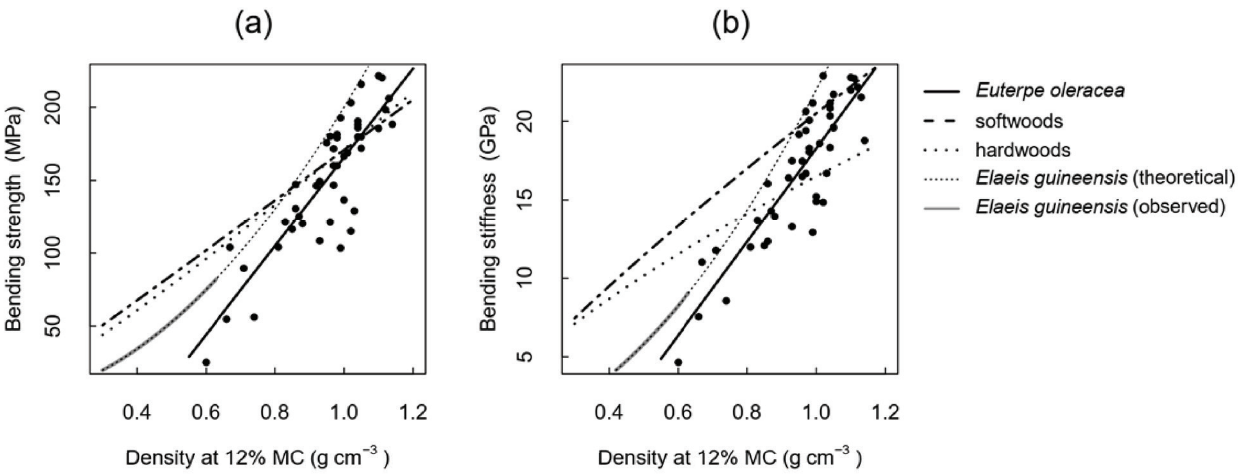


**Figure 4** Relationship of density at 12% moisture content ($\rho_{12\%}$) with (a) bending strength ($f_M$) and (b) bending stiffness ($E_{M0}$) on *Euterpe oleracea* palm wood; *Euterpe oleracea* linear models: $f_M$ = -138.218 + 303.929 ($\rho_{12\%}$), $R^2$ = 0.73, p-value = 3.778 × $10^{-14}$; $E_{M0}$ = -11.48681 + 29.75781 ($\rho_{12\%}$), $R^2$ = 0.76, p-value = 2.5 × $10^{-15}$; data for softwoods and hardwoods were from Kretschmann (2010) and *Elaeis guineensis*, from Srivaro et al. (2018).

on the strength and stiffness of the peripheral zone *of E. oleracea* is stronger than in woods. At higher densities, these properties are even above those found in timbers, although they are considerably lower at densities below 0.7 g $cm^{-3}$. When comparing our results to Balboni et al. (2019), we observed that the relationship of density with strength and stiffness of *E. oleracea* peripheral zone is closer to hardwoods in compression parallel to grain than in static bending.

*Elaeis guineensis* palm wood has superior values of bending strength ($f_M$) and bending stiffness ($E_{M0}$) than *E. oleracea* for the same density (Srivaro et al. 2018). Nevertheless, only the larger density values of *E. guineensis* reached the range observed for *E. oleracea.* The former might be more mechanically efficient for the same mass, but it never reached the strength and stiffness of the latter. In both strength and stiffness cases the influence of density was lower on *E. guineensis* than on *E. oleracea* (Figures 4a and b). Both curves (bending strength and bending stiffness) for *E. guineensis* are exponential, but at higher density values, this trend changes, and the curve above the observed data may not be representative of the material.

An interesting way to compare materials of distinct densities is through specific strength and stiffness (Figure 5a and b). The peripheral zone of *E. oleracea* was 54.9% less strong than the bamboo *Phyllostachys pubescens* (Berndsen et al. 2013) but had specific strength slightly superior to the amazon timbers *Astronium lecointei* and *H. courbaril* (Andrade 2015) and *C. nucifera* (UNIDO 1985), but a lot higher than *E. guineensis.* The açaí palm peripheral zone is as stiff as *P. pubescens* and, moreover, slightly stiffer than the dense Amazon timbers *A. lecointei* and *H. courbaril* (Andrade 2015).

The level of influence of density and fibre proportion on bending strength and stiffness is similar (Table 3). Since density and fibre proportion are strongly correlated (Table 2), the influence of both variables on the mechanical properties assessed is also connected. However, when we added density and fibre proportion as independent variables, the linear models returned higher coefficients of determination for prediction of both bending strength and bending stiffness. These results indicate that $\rho_{12\%}$ and proportion of fibre tissue have a small cumulative effect on their influence on both bending properties, which means that they are not completely dependent. The way density and fibre proportion affect both bending properties can be very useful, mainly for application of non-destructive methods. In addition, the practice of visual selection based on characteristics of bundles would also facilitate the selection by açaí producers when working with this species: peripheral zones with higher percentages of fibres on the cross-section (darker colour) will consequently be the stiffest and strongest.

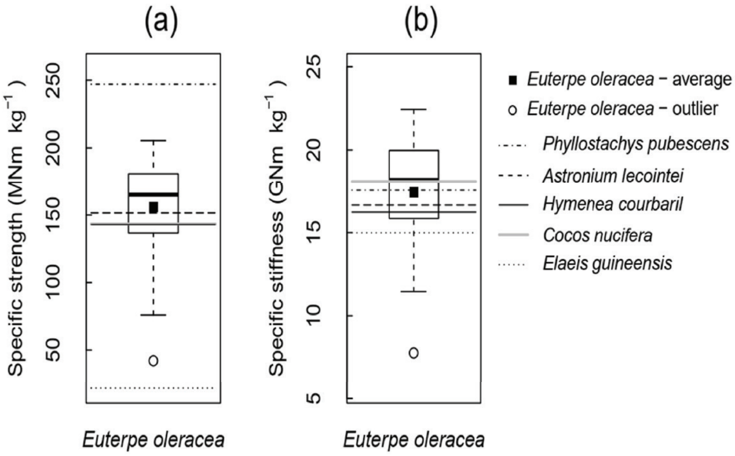


**Figure 5** Specific bending strength (a) and stiffness (b) of *Euterpe oleracea* palm wood; horizontal bars represent the median and the black square, the mean, while the boxes represent the second and third quartiles; source: *Elaeis guineensis* (Szymona et al. 2014), *Cocos nucifera* (UNIDO 1985), *Phyllostachys pubescens* (Berndsen et al. 2013), *Astronium lecointei* and *Hymenaea courbaril* (ITTO www.tropicaltimber.info/pt-br/)

**Table 3** Coefficient of determination ($R^2$) from the linear models built with dependent and independent variables

| Dependent variable | Independent variable | | |
|---|---|---|---|
| | $\rho_{12\%}$ (g cm$^{-3}$) | FP (%) | $\rho_{12\%}$ and FP |
| $f_M$ (MPa) | 0.7397 | 0.7488 | 0.8048[1] |
| $E_{M0}$ (GPa) | 0.7650 | 0.7905 | 0.8397[2] |

[1]$f_M$ = -87.6983 + 158.6358 ($\rho_{12\%}$) + 1.9028 (FP), [2]$E_{M0}$ = -6.2269 + 14.6304 ($\rho_{12\%}$) + 0.1981 (FP); FP = proportion of fibre tissue, $\rho_{12\%}$ = density, $f_M$ = bending strength, $E_{M0}$ = bending stiffness

The fact that density has a stronger influence on *E. oleracea* bending properties when compared to wood, the most studied lignocellulosic material, indicates that selecting the densest palm wood is advisable. Due to the dimensional limitation of the dense peripheral zone of stems, *E. oleracea* palm wood would be more suitable for the manufacture of glued laminated products, following the same strategy adopted to widen the application of bamboo products. Evaluating the adhesion and gluing properties is of major importance to understand the feasibility of producing these engineered glued laminated products. Preliminary studies of the adhesion strength of *E. oleracea* palm wood indicate that this material has strong bonding properties with the adhesive resorcinol formaldehyde (Batista et al. 2022). More studies are necessary to evaluate the gluing adhesion and the interaction of *E. oleracea* palm wood with other types of adhesives, especially those with no formaldehyde emissions. Also, the machining and finishing characteristics of this new material are very important to generate value-added products.

The supply chain of *E. oleracea* palm wood, considering all the processes involved, such as harvesting, drying, primary and secondary processing, and gluing, must be assessed for economic viability. Bamboos, for example, have already suffered some production obstacles due to their silica content. However, the use of tungsten double-disc circular saws by bamboo processing companies in China has solved this problem (Orthey 2015), and today bamboo has many applications worldwide. The development of a production line might turn *E. oleracea* into a local substitute for important bamboo products, such as cutting boards, cutlery, handicrafts, and packaging. Figure 6 shows a prototype of a cutting board made using glue-laminated açaí palm wood, whose unique pattern can be explored as exclusive to this material. Products made of açaí palm wood may be associated with the appropriate use of the Amazon Forest as a local product manufactured by small communities, in contrast with imported industrialised bamboo products. If proper management is conducted, *E. oleracea* palm wood products can align with the ecological and social sustainability trend in our society (Pereira et al. 2018) and serve as a source of deluxe items with very high added value. It would be a way of increasing the income of small producers of açaí fruit and palm heart, giving a proper destination of the stems, which are residues resulting from the açaí palm tree management. It is crucial that the small producers receive technical support from the government, universities or NGOs and organise themselves into cooperatives and have an official ecological and social certification. Studies quantifying the amount of açaí palm residues are essential to have an estimate of the volume of waste produced, as well as to avoid the risk of overexploiting the species, as what happened in managed areas of *E. oleracea* in Colombia for the production of palm heart (Vallejo et al. 2014).

**Figure 6** Prototype of a cutting board made with glued açaí palm wood; source: Batista et al. (2022)

The possible applications of *E. oleracea* palm wood are not restricted to handicrafts and other small items. Following the same principle of bamboo products, açaí palm wood slats can be glued side to side to form glued laminated products such as the one presented in Balboni et al. (2019). This sort of process is used to decrease variation and to generate products with standard sections for the construction industry (Sharma et al. 2015). *Euterpe oleracea* palm wood can also be adopted for the manufacturing of laminated and scrimber products for structural purposes such as the bamboo products described by Sharma et al. (2015). There is also the possibility to combine layers in different fibre orientations and produce cross-laminated panels for furniture and flooring applications, such as those made using bamboo, sugar palm wood and coconut palm wood.

Spindleless and centerless veneer lathes, currently applied for peeling logs with small diameters, can be used for producing *E. oleracea* veneer. These thin layers will probably have interesting aesthetics, and can be applied for decorative purposes, for example, in furniture or flooring. As spindleless and centreless veneering are already being used in the Amazon for peeling young *Schyzolobium amazonicum* trees (de Melo et al. 2014), testing it on *E. oleracea* stems would not be a big challenge.

## CONCLUSION

The present study shows that, under bending stresses, *E. oleracea* palm wood behaves like timbers of the same density. Açaí palm wood and Amazon timbers having about the same density have similar average flexural properties (i.e. strength and stiffness).

Anatomical features of *E. oleracea* have lower influence on bending strength compared to compression. The bundle diameter also has opposite effects on bending and compression strength. In compression, large bundles result in higher strength, while in bending, the palm wood with the smaller bundles has higher strength. Thus, the second hypothesis is rejected. When selecting palm wood raw material, the final use should be considered, since a specific anatomical characteristic may return higher or lower strength, depending on the stresses the material will be subjected to.

The good mechanical properties of this material and the fact that it comes from a residue can be an opportunity for the traditional people managing açaí berry or palm heart to increase their income. There are already similar products in the market, made with bamboo and other palm woods, so it is not necessary to create a new product niche. The ecological and social sustainability of the products and production chain can increase value, especially if they are certified. It will probably be necessary, however, for them to establish cooperatives to explore products from *E. oleracea* stems. Manufacturing palm wood products can be a stimulus for them to get organised, which is already an advantage by itself as the organisation of small producers will also be beneficial for them to secure better prices for açaí berry which is highly appreciated in the market.

## REFERENCES


Abd Latif M, Wan Tarmeze WA & Fauzidah A. 1990. Anatomical features and mechanical properties of three Malaysian bamboos. *Journal of Tropical Forest Science* 2: 227–234.

ABNT (Associação Brasileira De Normas Técnicas). 1997. *NBR-7190: Projeto de Estruturas de Madeira.* ABNT, Rio de Janeiro.

Andrade A. 2015. *Pisos de Madeira: Características de Espécies Brasileiras.* Associação Nacional Dos Produtores de Pisos de Madeira, Vila Boyes.

Anokye R, Bakar ES, Ratnansingam J & Awang K. 2016. Bamboo properties and suitability as a replacement for wood. *Pertanika Journal of Scholarly Research Reviews* 2: 64–80. https://doi.org/10.13140/RG.2.1.1939.3048

ASTM (American Society For Testing And Materials). 2009. Standard methods of testing small clear specimens of timber: D143-09. ASTM, West Conshohocken.

Balboni BM, de Sousa JTR, Ferreira MA, de Aguiar RR, & Macedo AB. 2019. Residue of açaí berry (*Euterpe oleracea*) management as a source of lignocellulosic material. *European Journal of Wood and Wood Products* 77: 509–516. https://doi.org/10.1007/s00107-019-01417-8

Barbosa ACF, Gerolamo CS, Lima AC, Angyalossy V & Pace MR. 2021. Polishing entire stems and roots using sandpaper under water: an alternative method for macroscopic analyses. *Applications in Plant Sciences* 9: e11421. https://doi.org/10.1002/aps3.11421

Batista AS, Braga BA, Sousa JTR, Garcia JN & Balboni BM. 2022. Potencial do resíduo do manejo do açaizeiro como substituto do bambu. Pp 140–153 in Cardoso R & Quintela JB (eds) *Open Science Research VIII.* Editora Científica Digital, Guarujá. https://doi.org/10.37885/221211232

Bentes-Gama MM, Ribeiro GD, Fernandes CDF & Medeiros ID. 2005. *Açaí (Euterpe spp.): Características, Formação de Mudas e Plantio Para a Produção de Frutos*. Circular Técnica 80. Embrapa Rondônia, Porto Velho.

Berndsen RS, Klitzke RJ, Batista DC, do Nascimento EM & Ostapiv F. 2013. Resistência à flexão estática e à compressão paralela do bambu-Mossô (*Phyllostachys pubescens*). *Floresta* 43: 485–494. https://doi.org/10.5380/rf.v43i3.29319

Cymerys M, Vogt N, & Brondizio E. 2011. Palm trees and diverse other species. Pp 158–168 in Shanley P (ed) *Fruit Trees and Useful Plants in Amazonian Life*. Food and Agriculture Organization of the United Nations, Rome.

De Melo RR, Del Menezzi CHS, Pavan BE & Rodolfo F jr. 2014. Rotary peeling yield *of Schizolobium amazonicum* (Leguminosae–Caesalpinioideae). *Acta Amazônica* 44: 315–20. https://doi.org/10.1590 / 1809-4392201302926

Evert RF & Eichhorn SE. 2013. *Raven Biology of Plants*. Eighth edition. WH Freeman and Co., New York.

Fathi L & Frühwald A. 2014. The role of vascular bundles on the mechanical properties of coconut palm wood. *Wood Material Science & Engineering* 9: 214–223. https://doi.org/10.1080/17480272.2014.887774

Ferreira E. 2011. Palm trees and diverse other species. Pp 170–174 in Shanley P (ed) *Fruit Trees and Useful Plants in Amazonian Life*. Food and Agriculture Organization of the United Nations, Rome.

Homma AKO, Nogueira OL, de Menezes AJEA, De Carvalho JEU, Nicoli CML & De Matos GB. 2006. Açaí: novos desafios e tendências. *Amazônia: Ciência & Desenvolvimento* 1: 7–23.

Kretschmann DE. 2010. Mechanical properties of wood. Pp 5.1–5.46 in Ross RJ (ed) *Wood Handbook: Wood as an Engineering Material*. General Technical Report FPL-GTR-190. USDA Forest Service, Madison

Nogueira CL. 2013. Ciência do material bambu e tecnologia de sua aplicação em vigas laminadas coladas de seção transversal composta. PhD thesis, Universidade de São Paulo, São Paulo.

Nogueira OL & Homma AKO. 2014. Importância do manejo de recursos extrativos em aumentar a capacidade de suporte: o caso de açaizeiros (*Euterpe oleracea* Mart.) no estruário amazônico. Pp 168–176 in Homma AKO (ed) *Extrativismo Vegetal na Amazônia: História, Ecologia, Economia e Domesticação*. Embrapa, Brasília.

Orthey AL. 2015. Uso do bambu industrializado no Brasil e sua aplicação no design de móveis: estudo de caso da empresa Oré Brasil. MSc thesis, Universidade Federal do Paraná, Curituba.

Pereira LM, Karpouzoglou T, Frantzeskaki N & Olsson P. 2018. Designing transformative spaces for sustainability in social-ecological systems. *Ecology and Society* 23: Art. 32. https://doi.org/10.5751/ES-10607-230432

Proestos C. 2018. Superfoods: recent data on their role in the prevention of diseases. *Current Research in Nutrition and Food Science Journal* 6: 576–593. https://doi.org/10.12944/CRNFSJ.6.3.02

Queiroz JAL & Mochiutti S. 2012. *Guia Prático de Manejo de Açaizais Para Produção de Frutos*. Embrapa Amapá, Macapá.

Rodrigues ECN, Ribeiro SDCA & Da Silva FL. 2015. Influência da cadeia produtiva do açaí (*Euterpe oleracea* Mart.) na geração de renda e fortalecimento de unidades familiares de produção, Tomé Açu-PA. *Observatorio de la Economía Latinoamericana* 210: 15.

Santos JC, Sena ALS & Homma AKO. 2012. Viabilidade econômica do manejo de açaizais no estuário amazônico do Pará. Pp 351–409 in Guiducci RCN (eds) *Viabilidade Econômica de Sistemas de Produção Agropecuários*. Embrapa. Brasília.

Schauss AG. 2010. Açaí (*Euterpe oleracea* Mart.): a macro and nutrient rich palm fruit from the Amazon rain forest with demonstrated bioactivities in vitro and in vivo. Pp 479–490 in Watson DR & Preedy VR (eds) *Bioact Foods in Promoting Health: Fruits and Vegetables*. Academic Press, Oxford.

Sharma B, Gatoo A, Bock M, Mulligan H & Ramage M. 2015. Engineered bamboo: state of the art. *Construction Materials* 168 57–67. https://doi.org/10.1680/coma.14.00020

Srivaro S, Rattanarat J & Noothong P. 2018. Comparison of the anatomical characteristics and physical and mechanical properties of oil palm and bamboo trunks. *Journal of Wood Science* 64: 186–192. https://doi.org/10.1007/s10086-017-1687-3

Szymona K, Borysiuk P, H'ng SP, Chin KL & Mamiński M. 2014. Valorization of waste oil palm (*Elaeis guineensis* Jacq.) biomass through furfurylation. *Materials & Design* 53: 425–429. https://doi.org/10.1016/j.matdes.2013.07.030

Tavares GS, Homma AKO, De Menezes AJEA & Palheta MP. 2020. Análise da produção e comercialização de açaí no estado do Pará, Brasil. *International Journal of Development Research* 10: 35215–35221.

UNIDO (United Nations Industrial Development Organization). 1985. *Mechanical Properties of Coconut Palm Wood*. Technical Report. UNIDO, Vienna.

Vallejo MI, Galeano G, Bernal R & Zuidema PA. 2014. The fate of populations of *Euterpe oleracea* harvested for palm heart in Colombia. *Forest Ecology & Management* 318: 274–284. https://doi.org/10.1016/j.foreco.2014.01.028