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STRUCTURE AND MECHANICAL BEHAVIOUR OF RAPHIA LEAF CUTICLES FROM CONTRASTING AGROECOLOGICAL REGIONS OF CAMEROON

Structure et comportement mécanique des cuticules de feuilles de raphia issues de
régions agroécologiques contrastées du Cameroun

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1. RÉSUMÉ / ABSTRACT

Résumé

Raffia leaf cuticles constitute a renewable lignocellulosic resource traditionally used in handicrafts but remain poorly documented for engineering applications. This study investigates the influence of agroecological origin and anatomical position on the physical, hygroscopic, structural and tensile properties of raffia leaf cuticles collected from three contrasting regions of Cameroon. The cuticles exhibited thicknesses of 16.8-40.0 μm , densities of 1.16-1.64 g/cm^3 and grammages of 26.0-59.5 g/m^2 , whereas moisture regain and water absorption remained relatively stable at approximately 18 wt% and 13.2-15.9

wt%, respectively. X-ray diffraction revealed crystallinity indices ranging from 33.5 to 61.9%, which were consistent with tensile strengths of 112-280 MPa and Young's moduli of 1.6-5.3 GPa. The southern specimens displayed the highest crystallinity and stiffness, whereas western samples were thicker and heavier. These results indicate that raffia cuticles possess a combination of moderate hygroscopic stability and mechanical performance that merits further investigation as a reinforcement for lightweight textile structures and bio-based composites.

Abstract

This study demonstrates that the physical, hygroscopic, structural and tensile properties of raffia leaf cuticles are governed jointly by agroecological origin and anatomical position within the leaflet. Although pronounced differences were observed in thickness (16.8-40.0 μm), density (1.16-1.64 g/cm^3), crystallinity (33.5-61.9%) and tensile behaviour (112-280 MPa; 1.6-5.3 GPa), hygroscopic properties remained comparatively stable. The higher crystallinity measured for the southern cuticles was associated with greater stiffness, whereas the western samples exhibited larger thicknesses and grammages. These observations provide a first quantitative assessment of the variability of raffia cuticles and identify characteristics that may be advantageous for lightweight textile reinforcements and bio-based composite preforms. Nevertheless, the present work remains limited to material-scale characterisation. Future research should therefore investigate fibre extraction reproducibility, spinning behaviour, yarn architecture, weaving performance, durability under environmental ageing and fibre-matrix interactions to establish the suitability of raffia cuticles for structural textile and composite applications.

Keywords: Raffia leaf cuticle; Agroecological variability; Crystallinity; Tensile properties; Bio-based textile reinforcement

2. INTRODUCTION

The depletion of fossil resources and the environmental impacts associated with synthetic fibers have increased interest in plant-based fibers, which are renewable and biodegradable. To date, most research has focused on industrially cultivated plants such as flax, hemp, jute, and sisal, particularly in Europe and Asia. However, tropical regions are home to many fiber-producing plants that remain largely underexploited. Among them, raffia stands out for its multifunctionality. Its nuts provide edible and cosmetic oil, while its petioles and leaves are used as construction materials. In addition, the leaf epidermis or cuticle can be cut into strips that can be regarded as natural fibers [1]. These fibers are traditionally used to produce mats, handicrafts, and local textiles [2].

Despite this potential, scientific knowledge of the raffia leaf cuticle remains fragmented. Very few studies have systematically characterized its microstructure or its physical and mechanical properties. Elanga et al. [1] demonstrated that the fibrous cuticle of *Raphia hookeri* is 100% biodegradable and exhibits a layered structure consisting of an outer scaly envelope and an inner honeycomb-like core. They also showed that it contains partially crystalline cellulose, as confirmed by Fourier Transform Infrared Spectroscopy with Attenuated Total Reflectance (FTIR-ATR) and X-ray Diffraction (XRD). However, these studies remain limited, as they do not consider either the position along the leaflet or the influence of the harvesting site, both of which may significantly affect the physical and mechanical properties of plant fibers.

This knowledge gap hinders the valorization of this fiber and limits the availability of reliable technical data for artisans, manufacturers, and designers. To address this limitation, the present study aims to characterize the textile potential of the raffia leaf cuticle by investigating the effects of its position along the leaflet and the

harvesting site on its morphological, hygroscopic, and mechanical properties, with the objective of providing a solid scientific basis for its local and industrial valorization.

3. MATERIALS AND METHODS

3.1 Harvesting of leaves and cuticle extraction

Raffia palm (*Raphia* spp.) leaf spears (Fig. 1a) were collected from three Cameroonian agroecological zones exhibiting contrasting climatic conditions: Meyomadjoum (South, humid equatorial climate), Pouma (Littoral, tropical monsoon climate) and Mbouda (West, tropical highland climate).

Following harvesting, the leaflets were manually detached from the rachis, and the lamina was separated from the central midrib using a stainless-steel knife. The laminae were then immersed in fresh water, renewed periodically, for 14 ± 2 °C to promote the controlled biodegradation of the parenchymatous tissues. The cuticle was subsequently recovered by longitudinal peeling (Fig. 1b), thoroughly rinsed with distilled water to remove residual organic matter, and air-dried until a constant mass was reached. Prior to characterisation (Fig. 1c), the samples were conditioned at 25 ± 2 °C and $65 \pm 5\%$ relative humidity. Finally, six sample batches were defined according to their geographical origin and the surface analysed (Table 1).



Fig. 1. Extraction process of Raffia leaf cuticles: (a) stripping the Raffia spear; (b) manual peeling of the cuticles after 14 days of retting in fresh water; (c) extracted fibrous cuticles.

Table 1 - Sample batch coding

Code	Meaning
CE-L	Outer surface cuticle of raffia leaf (Littoral Cameroon)
CE-W	Outer surface cuticle of raffia leaf (West Cameroon)
CE-S	Outer surface cuticle of raffia leaf (South Cameroon)
CR-L	Folded surface cuticle of raffia leaf (Littoral Cameroon)
CR-W	Folded surface cuticle of raffia leaf (West Cameroon)
CR-S	Folded surface cuticle of raffia leaf (Littoral Cameroon)

3.2 Determination of the physical properties of the cuticles

The geometrical dimensions were measured on ten specimens per batch using an optical microscope ($\times 40$) coupled with ImageJ software after calibration with a stage micrometer. The areal density was determined according to ISO 3801 using specimens measuring 50 ± 0.2 mm $\times$ 10 ± 0.1 mm and weighed with a precision balance (0.001 g). The areal mass was calculated as the ratio of the conditioned mass to the projected surface area. The apparent density was measured in accordance with ASTM D2320-98 using an ethanol pycnometer.

After initial weighing (0.31 ± 0.01 g), the specimens were fully immersed in ethanol to minimise swelling, and the displaced volume was used to calculate the apparent density.

3.3 Determination of the hygroscopic properties of the cuticles

The hygroscopic behaviour was assessed using two complementary methods. Moisture regain was determined in accordance with ASTM D570. Oven-dried specimens were conditioned for 24 h in a climatic chamber maintained at 91% relative humidity and 26 ± 1 °C, before being weighed with an accuracy of 0.001 g. Water absorption was measured following NF EN ISO 1097-6 after complete immersion in distilled water for a predetermined period. The specimens were then surface-dried and immediately weighed. Moisture uptake was calculated from the relative mass increase.

3.3 Determination of the structural properties of the cuticles

The crystalline structure was characterised by X-ray diffraction using an ARL EQUINOX 100 diffractometer (Thermo Fisher Scientific, USA) equipped with a Cu K α radiation source operating at 30 kV and 10 mA. Diffraction patterns were recorded over a 2θ range of 20–50°, with a 0.02° step size, a wavelength of 0.154 nm, and a scanning speed of 3° min⁻¹. The crystallinity index was subsequently calculated according to the procedure described in ASTM E915.

3.4 Determination of the mechanical properties of the cuticles

The tensile properties were determined in accordance with NF T25-501-2 using an LDW-5 electromechanical testing machine equipped with a 1 kN load cell. Ten specimens per batch, measuring 50 mm in length, 0.6 ± 0.03 mm in width and 0.6 ± 0.03 mm in thickness, were conditioned at 25 ± 2 °C and 65% relative humidity before testing. The gauge length was fixed at 30 mm (Fig. 2a), and the tests were carried out at a displacement speed of 2 mm min⁻¹ until failure (Fig. 2b, c). Young's modulus was determined by linear regression within the 0.2–0.6% strain interval. Tensile strength was taken as the maximum engineering stress, whereas the strain at break was calculated from the relative elongation. Finally, toughness was determined by dividing the area under the force-displacement curve, calculated by the trapezoidal integration method in OriginPro 2024, by the specimen cross-sectional area, following the procedure reported in the literature [3].

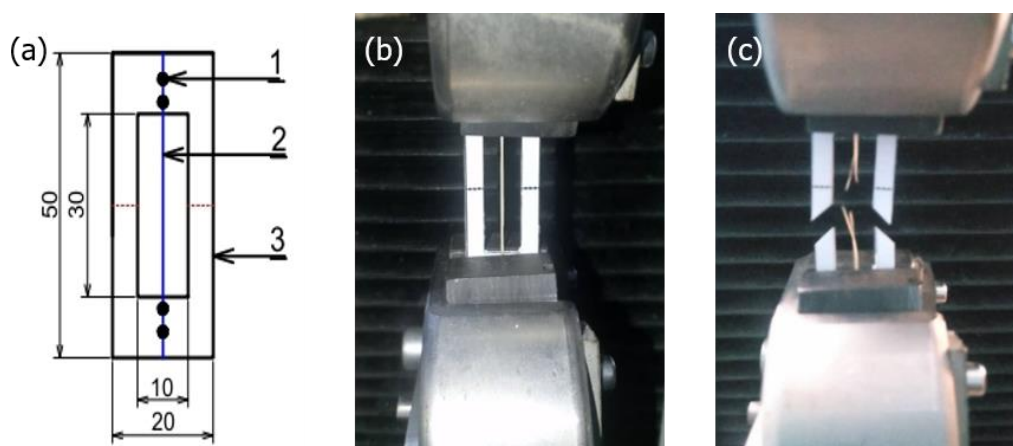


Fig. 2. (a) test specimen, (b) test specimen clamped in the jaws of the tensile testing machine, and (c) cuticle cut away after tensile testing. 1 - adhesive applied, 2 - cuticle, 3 - paper frame.

4. RÉSULTS AND DISCUSSION

4.1. Physical properties of the cuticles

The physical properties of the cuticles vary markedly with both the agroecological zone and their anatomical position within the leaflet (Table 2). Thickness ranges from 16.8 to 40.0 μm ($\times 2.4$), with the highest values recorded for CE-W and CR-W. This trend is accompanied by an increase in areal density from 26.0 to 59.5 g/m^2 and apparent density from 1.16 to 1.64 g/cm^3 (+41%). Overall, the folded cuticles (CR) are denser than the outer cuticles (CE), whereas specimens from the Western Highlands exhibit the most massive structures. These variations probably reflect morphological adaptations to local environmental conditions and provide a range of reinforcements suitable for both technical textiles and lightweight composites.

Table 2 — Physical properties of *Raffia* leaf fibrous cuticles as a function of the harvesting région in Cameroon and thier position along the young leaflet.

Cuticle Type	Thickness (μm)	Cross-sectional area (mm^2)	Areal Density (g/m^2)	Density (g/cm^3)	Moisture Content (wt%)	24h Water Absorption
CE-L	21.3 $\pm$ 3.2	0.014 $\pm$ 0.002	26.5 $\pm$ 1	1.25 $\pm$ 0.06	1.7 $\pm$ 0.1	13.6 $\pm$ 0.2
CE-W	39.8 $\pm$ 1.5	0.026 $\pm$ 0.001	46 $\pm$ 0.1	1.16 $\pm$ 0.06	4.9 $\pm$ 0.3	14.3 $\pm$ 0.8
CE-S	19.4 $\pm$ 3.4	0.013 $\pm$ 0.002	26 $\pm$ 0.1	1.34 $\pm$ 0.07	4.6 $\pm$ 0.3	13.2 $\pm$ 1.1
CR-L	20.4 $\pm$ 2.1	0.013 $\pm$ 0.001	29 $\pm$ 1.2	1.42 $\pm$ 0.07	5.4 $\pm$ 0.3	15.9 $\pm$ 1.2
CR-W	40 $\pm$ 0.9	0.026 $\pm$ 0.001	59.5 $\pm$ 6	1.49 $\pm$ 0.07	2.3 $\pm$ 0.1	15.2 $\pm$ 1.1
CR-S	16.8 $\pm$ 4	0.011 $\pm$ 0.003	27.5 $\pm$ 1	1.64 $\pm$ 0.08	4.6 $\pm$ 0.3	13.6 $\pm$ 1

4.2. Hygroscopic properties of the cuticles

Despite the pronounced morphological differences, the hygroscopic behaviour remains remarkably stable (Tables 2 and 3). Moisture regain ranges only from 17.7 to 18.5 wt%, while 24 h water absorption varies slightly between 13.2 and 15.9 wt%. This limited variability suggests that moisture exchange is governed primarily by the chemical composition of the lignocellulosic matrix rather than by cuticle geometry. Such stability is advantageous for textile applications, where moisture regulation enhances physiological comfort, and for bio-based composites exposed to moderate humidity fluctuations [4], [5].

Tableau 3 - Hygroscopic, structural, and mechanical properties of *Raffia* leaf fibrous cuticles according to the harvesting région and thier position along the young leaflet.

Cuticle Type	24h Moisture regain (wt%)	Crystallinity Index (%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Toughness (J/cm^2)
CE-L	18.5 $\pm$ 0.9	39.5	244.9 $\pm$ 80	4.0 $\pm$ 0.9	8.3 $\pm$ 1.4	11.2 $\pm$ 2.2
CE-W	18.2 $\pm$ 0.8	33.5	112.6 $\pm$ 24	1.6 $\pm$ 0.5	9.9 $\pm$ 2	12.7 $\pm$ 2.3
CE-S	18.3 $\pm$ 0.9	34.1	112.6 $\pm$ 24	4.4 $\pm$ 1.0	6.1 $\pm$ 1.4	4.8 $\pm$ 1.2
CR-L	18.5 $\pm$ 0.6	41.6	273.0 $\pm$ 50	4.1 $\pm$ 0.6	8.9 $\pm$ 2.1	12.2 $\pm$ 2.1
CR-W	18.4 $\pm$ 0.4	37.7	219.3 $\pm$ 48	2.8 $\pm$ 0.4	8.2 $\pm$ 1.8	8.8 $\pm$ 1.6
CR-S	17.7 $\pm$ 0.7	61.9	279.6 $\pm$ 57	5.3 $\pm$ 1.3	6.2 $\pm$ 1.7	9.9 $\pm$ 1.8

4.3. Crystalline structure of the cuticles

The crystalline organisation is strongly influenced by both the geographical origin and the cuticle side examined (Table 3). The crystallinity index ranges from 33.5 to 61.9% (+85%), with the highest value recorded for CR-S, compared with 33.5–41.6% for the remaining batches. This hierarchy probably reflects a more ordered arrangement of cellulose microfibrils in the folded cuticles from the Southern region. It is consistent with their superior stiffness and suggests a more efficient load-transfer architecture. Conversely, the lower

crystallinity of CE-W and CE-S may promote greater flexibility, a desirable feature for certain apparel textile applications.

4.4 Mechanical properties of the cuticles

Mechanical performance closely reflects the underlying structural organisation (Table 3). Tensile strength ranges from 112.6 to 279.6 MPa ($\times 2.5$), while Young's modulus varies from 1.6 to 5.3 GPa ($\times 3.3$), with the highest values recorded for CR-S and CR-L. Meanwhile, elongation at break remains moderate (6.1-9.9%), whereas toughness reaches 4.8-12.7 J/cm² ($\times 2.6$), indicating a favourable balance between stiffness and energy absorption. The folded-face cuticles (CR), characterised by higher crystallinity, also exhibit superior mechanical performance, suggesting that they contribute preferentially to the structural reinforcement of the leaflet. Conversely, the outer-face cuticles (CE), with lower crystallinity, appear more compliant. A clear agroecological effect is also observed. Specimens collected from the humid equatorial region of southern Cameroon exhibit the highest crystallinity, stiffness and tensile strength, whereas those from the western highlands display the greatest thicknesses and areal densities. Combined with their low areal weight and moderate water absorption, these characteristics place raffia cuticles among lignocellulosic materials of interest for textile applications [6], [7], [8], [9] and highlight their potential as precursors for the development of bio-based yarns and woven fabrics.

4.5. Preliminary analysis of the mechanical behaviour of cuticle-based yarns

Preliminary observations demonstrate that the cuticles can be assembled into yarns through a conventional twisting process (Fig. 3a, b). The resulting yarns exhibit diameters ranging from 418 to 553 μm , which gradually decrease as the twist angle increases (Fig. 3c), indicating progressive compaction of the fibre assembly. The tensile curves (Fig. 3d) reveal an almost linear elastic response up to the maximum load, followed by a gradual failure governed by interfacial sliding and fibrillation. Such a damage mechanism promotes progressive energy dissipation and suggests promising potential for flexible technical textiles as well as continuous reinforcements for bio-based composite materials.

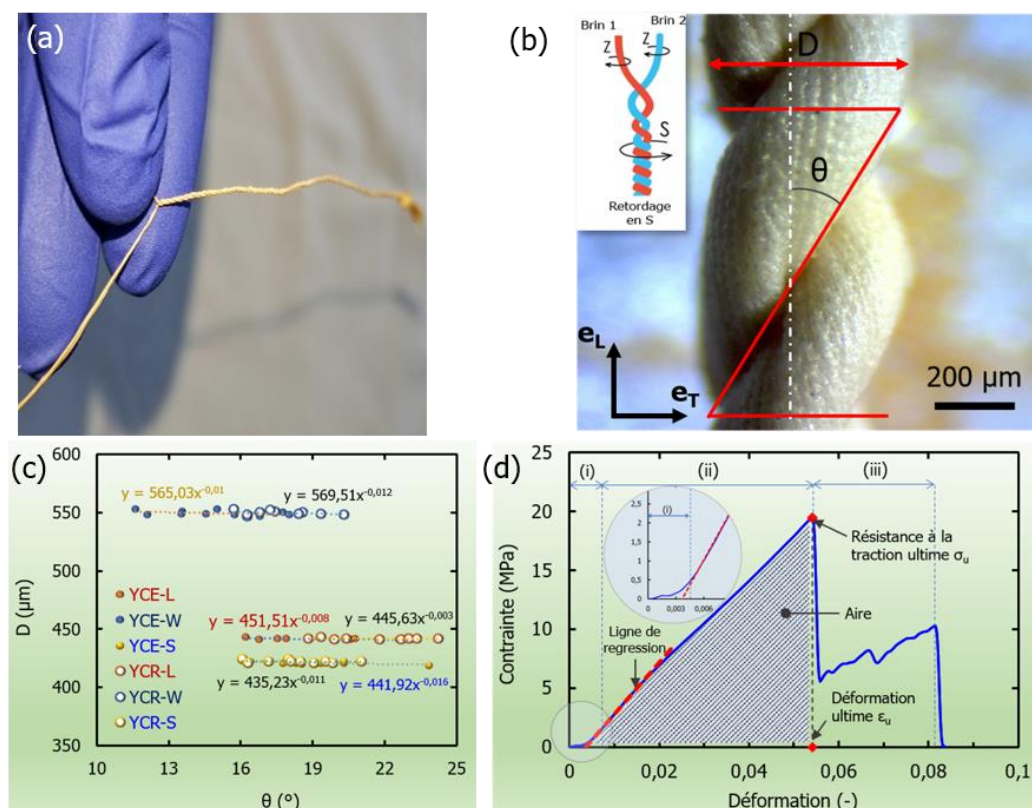


Fig. 3. (a) manual spinning; (b) optical micrograph showing the Z-twist and the twist angle (θ); (c) Relationship between wire diameter and twist angle and (d) Typical tensile behaviour of a cuticle-based wire.

5. CONCLUSION

This study demonstrates that the physical, hygroscopic, structural and tensile properties of raffia leaf cuticles are governed jointly by agroecological origin and anatomical position within the leaflet. Although pronounced differences were observed in thickness (16.8-40.0 μm), density (1.16-1.64 g/cm^3), crystallinity (33.5-61.9%) and tensile behaviour (112-280 MPa; 1.6-5.3 GPa), hygroscopic properties remained comparatively stable. The higher crystallinity measured for the southern cuticles was associated with greater stiffness, whereas the western samples exhibited larger thicknesses and grammages. These observations provide a first quantitative assessment of the variability of raffia cuticles and identify characteristics that may be advantageous for lightweight textile reinforcements and bio-based composite preforms. Nevertheless, the present work remains limited to material-scale characterisation. Future research should therefore investigate fibre extraction reproducibility, spinning behaviour, yarn architecture, weaving performance, durability under environmental ageing and fibre-matrix interactions to establish the suitability of raffia cuticles for structural textile and composite applications.

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