Priviet Social Sciences Journal
E-ISSN 2798-866X
P-ISSN 2798-6314
https://doi.org/10.55942/pssj.v5i9.1275

Volume 5
Issue 9
September Edition 2025

Physical characterization of coconut fiber (cocos nucifera) and melinjo peel fiber (gnetum gnemon) for potential armor applications

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Received 27 July 2025
Revised 26 August 2025
Accepted 08 September 2025

ABSTRACT

This study aims to investigate the structural characteristics and mechanical properties of young coconut coir fiber (Cocos nucifera L.) and melinjo seed coat fiber (Gnetum gnemon) as potential raw materials for developing bio-based natural armor derived from local resources. A descriptive method with an experimental laboratory approach was employed, including morphological analysis using scanning electron microscopy (SEM) and tensile strength testing based on the ASTM D3379-02 standards. The results indicate that young coconut coir fibers possess a porous structure with a high lignin content that functions as an energy-absorbing layer, whereas melinjo fibers exhibit parallel fibril orientation and high cellulose content, contributing to tensile strength and structural stiffness. The combination of these two natural fibers demonstrates the potential of a lightweight, durable, and eco-friendly hybrid composite that mimics the protective mechanism of biological armor systems. These findings provide a scientific foundation for the development of protective materials based on local biomaterials and support sustainable innovation in defense material production.

Keywords: coconut coir fiber, gnetum fiber, natural armor, Scanning Electron Microscope (SEM), tensile strength testing.

1. INTRODUCTION

The coconut plant (*Cocos nucifera* L.) is one of the leading tropical commodities widely cultivated in the coastal regions of Indonesia. Nearly every part of this plant possesses high economic value and can be processed into products with added values. One type of waste that remains underutilized is young coconut coir, which is abundantly generated from the commercial sale of young coconut water. This waste material contains significant lignocellulosic components, including cellulose, hemicellulose, and lignin, and therefore, it exhibits considerable potential as a natural fiber biomaterial for sustainable materials technology applications.

In addition, melinjo seed peel fiber (*Gnetum gnemon*) is another abundant source of natural fiber, particularly in Papua and eastern regions of Indonesia. Melinjo fiber exhibits a dense microfibrillar structure and high cellulose content, which impart superior mechanical properties, including high tensile strength and good stiffness.

Both local fibers have distinct characteristics. Coconut coir exhibits a porous morphology, rough surface texture, and high lignin content, rendering it flexible and naturally capable of absorbing impact energy. In contrast, melinjo fiber possesses a denser and stronger structure with a dominant cellulose content, making it suitable as a structural reinforcement layer. The combination of these two fibers provides an opportunity to develop a natural hybrid composite that mimics modern armor systems by integrating a ductile energy-absorbing layer and a rigid high-strength layer within a single protective material design.

Previous studies have supported this potential. Arsyad et al. (2015) and RSC (2021) reported that coconut coir fibers exhibit high elongation and lignin contents of approximately 40–45%, supporting their role as natural energy absorbers. Wulandari et al. (2019) and Putra et al. (2021) demonstrated that melinjo peel fibers possess high tensile strength with highly aligned fibrillar structures. Furthermore, Nuraeni et al. (2022) found that combining two natural fibers with different morphologies can enhance impact resistance by up to 35%. Subekti et al. (2023) explained that the rough, lignin-rich surface of coconut coir enhances mechanical interlocking with resin matrices, thereby improving the energy-absorption capacity of composite materials.

However, comprehensive studies systematically examining the relationship between the microstructure, mechanical properties, and functional performance of young coconut coir and melinjo peel fibers in the context of natural armor remain limited. Therefore, the present study proposes a novel approach through a comparative and conceptual analysis of the structure–property–function relationships of these two types of fibers while also evaluating their potential as protective hybrid composites based on local Papuan resources. This initiative aligns with the development of green materials and circular economy strategies based on biomaterials in Indonesia.

Conceptually, the structure–property–function system of natural armor comprises microstructural aspects: coconut coir exhibits randomly oriented fibrils and high porosity, whereas melinjo fiber exhibits highly aligned fibrils with a dense structure. In terms of mechanical properties, coconut coir demonstrates high elongation and good toughness, whereas melinjo fiber exhibits high tensile strength but relatively brittle behavior. Functionally, coconut coir serves as an energy absorption layer, while melinjo fiber acts as a reinforcement layer within the armor composite. The combination of these two local fibers is expected to produce a natural hybrid armor that balances strength and toughness, which are the two primary characteristics governing the effectiveness of modern personal-protective materials.

This study has three main objectives. First, the mechanical properties (tensile strength and elongation) of young coconut coir fibers and melinjo seed peel fibers were identified and compared. Second, the relationship between the surface morphology observed by Scanning Electron Microscopy (SEM) and the mechanical behavior of both fibers was analyzed. Third, the structural and functional roles of each fiber in the design of a natural armor system based on hybrid composite materials were determined.

By comprehensively understanding the relationship between the structure, properties, and functions of natural fibers, this study is expected to contribute scientifically to the development of lightweight, strong, and environmentally friendly armor materials based on local biomaterials, while supporting national defense material self-reliance through the utilization of Indonesia's biological resources.

2. LITERATURE REVIEW

Natural fibers are categorized as lignocellulosic-based materials, whose primary components consist of cellulose, hemicellulose, and lignin. These three components play a decisive role in determining the mechanical strength, elasticity, and environmental resistance of fibers. Cellulose functions as the main structural framework, arranged in parallel microfibrils that provide high tensile strength. Hemicellulose acts as a binding agent between microfibrils, whereas lignin contributes to stiffness and resistance to biological and thermal degradation (John and Thomas, 2008; Suryawan et al., 2022).

Variations in the compositional ratios of these three components result in differences in the physical and mechanical characteristics of the fiber types. Fibers with a high cellulose content generally exhibit greater strength and stiffness, whereas those with a high lignin content demonstrate superior energy absorption capacity and greater resistance to deformation (Arsyad et al., 2015).

Coconut coir (*Cocos nucifera* L.) contains approximately 40–45% lignin and 32–36% cellulose, which renders it flexible, tough, and impact-resistant. The high lignin content enhances its ability to absorb mechanical energy, making it particularly suitable as a ductile layer in protective materials (RSC, 2021; Subekti et al., 2023). Melinjo seed peel fiber (*Gnetum gnemon*) has a dominant cellulose content exceeding 55% and a highly aligned fibrillar structure, resulting in a high elastic modulus and tensile strength, although it exhibits relatively brittle behavior (Wulandari et al., 2019; Putra et al., 2021). Therefore, this fiber has a strong potential to be utilized as a rigid reinforcement layer in composite systems.

The combination of these two fiber types provides a synergistic effect, as demonstrated by Nuraeni et al. (2022), who reported that the hybridization of ductile and stiff fibers can enhance the impact resistance of materials by up to 35% through load transfer and interlayer energy-dissipation mechanisms.

The structure–property–function approach constitutes a fundamental analytical framework for understanding the relationship between the fiber microstructure, mechanical behavior, and their applications in composite systems (Callister and Rethwisch, 2020). Structural aspects include fibril arrangement, crystallinity, porosity, and chemical composition. The property aspects include tensile strength, elastic modulus, elongation, and toughness. Functional aspects are related to application performance, such as impact absorption capability, penetration resistance, and distribution of deformation energy.

In a natural armor system, flexible fiber layers, such as coconut coir, absorb kinetic energy, whereas rigid layers, such as melinjo fibers, resist penetration and redistribute impact forces. This principle emulates the multilayer armor concept, which is widely applied in modern protective material design (Suriani et al., 2020; Hameed et al., 2021).

3. METHOD

This study employed a descriptive research method with a laboratory-based experimental approach to investigate the physical characteristics of coconut (Cocos nucifera) and melinjo peel (Gnetum gnemon) fibers as potential base materials for the development of natural fiber–based armor materials. This approach was selected because it enables a comprehensive understanding of the relationship between the microstructural features, material properties, and potential mechanical performance of both fiber types (Sugiyono, 2019).

The primary materials used in this study comprised two types of natural fibers, namely coconut fiber and melinjo stem peel fiber. Coconut fibers were obtained from young coconut husk waste collected from street vendors along Teruna Bhakti Street, Jayapura City. Melinjo fibers were sourced from raw materials used for the production of traditional *noken* bags, supplied by local communities in the Abepura Ring Road area.

Both materials first underwent a fiber separation process. The fibers were then sun-dried for four days until the moisture content decreased and the fibers reached a stable condition suitable for laboratory testing.

The analytical procedure of this study included sample preparation, followed by tensile testing and SEM analysis, and subsequent data interpretation. During the sample preparation stage, dried coconut and melinjo fibers were cut to a uniform length of approximately ±5 cm to ensure consistency during testing. The microstructure of the fibers was observed using a Scanning Electron Microscope (SEM) to examine surface texture, fiber packing density, fibril orientation, and pore distribution, which influence mechanical strength. Tensile testing was conducted in accordance with ASTM D3379-02 to determine maximum stress (σ), strain (ε), and elastic modulus (E). These parameters were used to assess the suitability of both fibers as constituent materials for natural armor.

The SEM and tensile test data were analyzed using a descriptive–quantitative approach to explain the relationships between fiber morphology, constituent material characteristics, and mechanical properties. The results of both fiber types were compared to identify the type with the greatest potential for application as a base material in protective composites. The interpretation of the results was guided by the structure–property–function framework of natural composite materials (Callister & Rethwisch, 2018). Inferential statistical testing was not employed because this study is exploratory in nature and aims to provide an in-depth description of material characteristics.

4. RESULT DISCUSSION

The research materials consisted of waste fibers from young coconut coir collected from young coconut beverage vendors and melinjo peel fibers. Both materials represent resources derived from local traditional knowledge (local wisdom–based materials).

4.1. Tensile Test Results

Mechanical testing showed that coconut coir fibers exhibited an average tensile strength of 13.846 N with an elongation value of 13.323%, whereas melinjo peel fibers demonstrated a significantly higher tensile strength of 26.837 N but with much lower elongation of only 2.542%. These differences reflect the contrasting mechanical behavior of the two fibers: coconut coir is more flexible and capable of undergoing large strain prior to fracture, whereas melinjo fiber exhibits higher strength but tends to be more brittle, with limited deformation capacity before failure. See Table 1

Table 1. Tensile strength and elongation results of coconut coir and melinjo peel fibers

Sample	Tensile Strength (N)	Elongation (%)
Coconut coir fiber	13.846	13.323
Melinjo peel fiber	26.837	2.542

These differences indicate the potential functional roles of each fiber in protective composite (armor) materials. Coconut coir fibers, with their high elongation capacity and relatively high lignin content, can effectively function as an energy absorption layer. Their ductility and energy-dissipation capacity help resist deformation and redistribute impact forces, thereby reducing penetration risk and limiting crack propagation. Conversely, melinjo peel fibers, with higher tensile strength and elastic modulus, can serve as a structural reinforcement layer, providing stiffness and resistance to tensile and compressive loads. When combined, these two fibers can form a natural hybrid composite that balances strength and toughness, a key requirement for sustainable biomaterial-based armor systems.

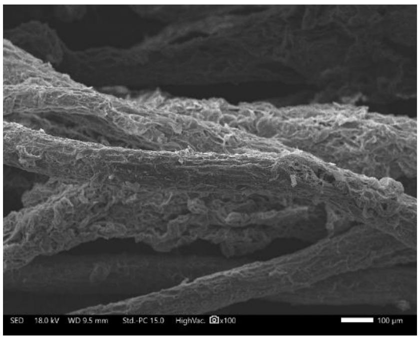
The present findings are consistent with previous studies. RSC (2021) reported that coconut coir fibers exhibit high elongation and lignin contents of approximately 45%, supporting their plastic behavior and energy dissipation capacity. Arsyad et al. (2015) reported that alkali treatment of single coconut coir fibers could increase tensile strength up to 130 MPa, with elongation at break reaching 22%, depending on the treatment conditions. Variations in the tensile strength of natural fibers are generally influenced by testing methods (single fiber versus fiber bundle), effective cross-sectional area, and chemical surface treatments.

Studies by Wulandari et al. (2019) and Putra et al. (2021) demonstrated that melinjo (*Gnetum gnemon*) fibers possess high tensile strength, making them promising candidates as natural reinforcements in composites. Alkali treatment can improve fiber strength and surface homogeneity, although brittle behavior remains dominant due to high cellulose and low lignin content. Therefore, melinjo fibers are more suitable for use as the rigid layer in composites, while coconut coir is more appropriate as an impact-resistant and energy-absorbing layer.

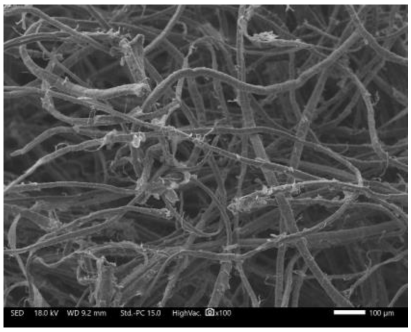
Overall, these findings confirm that the combination of coconut coir and melinjo peel fibers has strong potential to produce lightweight, strong, and environmentally friendly hybrid composites based on local Papuan fibers. A layered configuration of these two fiber types could optimize the tensile strength contribution of melinjo fibers and the energy absorption capacity of coconut coir fibers, thereby enhancing the mechanical durability and ballistic performance of the developed armor material.

4.2. Scanning Electron Microscope (SEM)

SEM analysis of coconut coir and melinjo peel fibers revealed distinct morphological differences that directly influence their mechanical properties. The surface of coconut coir fibers appeared rough and non-uniform, with remnants of lignin and hemicellulose layers that had not been completely removed. The fibrillar pattern was randomly oriented, with the presence of microvoids between the fibrillar networks. This indicates a high degree of porosity and relatively loose interfibrillar bonding. According to Arsyad et al. (2015), such a configuration allows coconut fibers to exhibit high deformability, as lignin acts as a natural flexible matrix. This observation is consistent with the tensile test results of this study, in which coconut coir fibers showed a high elongation value of 13.323%, significantly greater than that of melinjo peel fibers. See Figure 1



1.a Young coconut waste fiber



1.b Melinjo fiber (Gnetum gnemon fiber)

Figure 1. SEM images of young coconut waste fiber and melinjo fiber

In contrast, melinjo peel fibers exhibited a denser morphology with highly parallel fibril alignment. The structure appeared compact, with a high fibril density and very limited pore presence. This compact surface morphology indicates a dominant cellulose phase and strong interfibrillar bonding. This finding is in agreement with the mechanical test results, where melinjo fibers recorded a higher average tensile strength of 26.837 N but a low elongation value of 2.542%. This indicates that melinjo fibers are strong yet relatively brittle compared to coconut coir fibers.

These results are consistent with the findings of Wulandari et al. (2019) and Putra et al. (2021), which reported that alkali treatment of melinjo fibers can increase tensile strength to 35–45 MPa, but with a reduction in elongation due to the removal of lignin and hemicellulose. Furthermore, Yusril et al. (2020) emphasized that increased cellulose fibril orientation strengthens internal molecular bonding, thereby increasing tensile strength while reducing fiber flexibility.

SEM observations of coconut coir fibers support the assumption that this fiber has a high energy absorption capacity, making it a potential candidate as an energy absorption layer in protective composite systems. Conversely, melinjo peel fibers, with their dense fibril structure and high strength, are suitable as a reinforcing layer. The integration of both fiber types can result in a natural hybrid composite with a balance between toughness and strength, which is a critical characteristic for armor or personal protective materials.

Nuraeni et al. (2022) reported that combining natural fibers with different fibrillar morphologies can improve impact resistance by up to 35%. Meanwhile, Subekti et al. (2023) stated that the rough surface and high lignin content of coconut coir enhance mechanical interlocking with resin matrices, thereby increasing energy absorption capacity during impact. Additional findings by Prasetyo and Hidayat (2021) indicated that fibers with parallel fibril structures and high density possess optimal specific strength for protective applications.

The SEM analysis confirms that the porous structure and lignin-rich composition of coconut coir provide high flexibility and energy absorption, whereas the dense, highly aligned fibrils of melinjo fibers contribute to high tensile strength. Therefore, the integration of these two fiber types is highly promising for the development of lightweight, environmentally friendly natural armor materials, while supporting the sustainable utilization of local biological resources from Papua and across Indonesia.

5. CONCLUSION AND SUGESTION

The results of this study indicate that young coconut coir fibers and melinjo peel fibers exhibit distinct structural and mechanical properties that can complement each other within a composite system. Young coconut fibers, which contain high lignin content, have the potential to function as an energy-absorbing layer, whereas melinjo fibers, with their dominant cellulose content, demonstrate an effective role as a reinforcement layer. The synergy between these two fibers creates opportunities for the development of natural armor materials that are lightweight, strong, and environmentally friendly.

This study remains limited to morphological and basic mechanical analyses; therefore, further investigations involving thermal and impact testing are required to achieve a more comprehensive understanding of the overall performance of the composite material

Ethical Approval

Ethical approval was not required for this study

Informed Consent Statement

Not applicable

Authors' Contributions

WKS contributed to the conceptualization, research design, and served as the corresponding author during the manuscript submission process. MS contributed to data analysis and interpretation. YAP and RWPMC assisted responsible for the data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data Availability Statement

The data presented in this study are available on request from the corresponding author due to privacy reasons.

Funding

This research received funding from the PNBP funds of Cenderawasih University

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