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Morphological and Structural Characterization of Pineapple Leaf Fibers: Implications for Eco-Friendly Textile Applications

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Abstract: Natural fibers from pineapple leaves (Ananas comosus L.) are a potential renewable resource, but their characteristics are highly dependent on their geographical origin. This study aimed to characterize the physico-mechanical properties and morphology of pineapple leaf fibers (PALF) sourced from local farmers in Kediri, East Java. Characterization was conducted at an accredited testing institution using SNI standards, covering fineness, bundle tenacity, and Scanning Electron Microscopy (SEM) observations. The results revealed that the fibers exhibited an average fineness of 33.7 dtex and a tenacity of 23.20 g/tex. Morphological analysis showed a course, multi-cellular, and dense fiber structure. Based on these findings, it is concluded that these PALF demonstrate greater potential for applications in technical textiles and as reinforcement in bio-composite materials rather than as a raw material for apparel yarn.

Keywords: Eco-friendly; Mechanical decortication; Pineapple leaf fiber; Tensile strength; Textile applications

Introduction

The global textile industry's shift toward sustainability has intensified the demand for renewable and biodegradable alternatives to synthetic polymers (Jahandideh et al., 2021; Jain, 2021; Liu et al., 2024; Patti & Acierno, 2022). Among these, pineapple leaf fiber (PALF), derived from Ananas comosus, has emerged as a highly attractive candidate due to its biodegradability and favorable mechanical properties for both textiles and bio composites (Dissanayake & Samarasinghe, 2024; Rahman, 2019 Rahman, 2024, Rahman, 2024; Yusuf & Ojedokun, 2024). However, the properties of PALF are significantly influenced by geographic origin and cultivar, highlighting the critical need for region-specific data to ensure reliable industrial process design (Mulyati et al., 2023). While the literature confirms that PALF exhibits competitive mechanical performance, a notable gap persists between its generalized potential and the standardized, actionable data required for consistent industrial adoption, largely due to cultivar diversity and varied processing practices (Dissanayake & Samarasinghe, 2024; Todkar, 2019).

A primary barrier to widespread adoption is the significant variation in PALF properties across different cultivars, which obscures its true performance potential if the fiber is treated as a uniform material (Gaba, 2021; Hapsari et al., 2023; Johny, 2023; Lee et al., 2020; Pisupati et al., 2021). Furthermore, many studies employ chemical or enzymatic retting to enhance fiber quality, a practice that can undermine the sustainable principles of using PALF. In contrast, mechanical decortication is recognized as a scalable and environmentally benign approach. Yet, standardized baseline data for mechanically processed PALF, particularly for specific commercial varieties, remain limited (Johny, 2023; Rahman, 2024, Rahman, 2024). The Queen variety, a commercially important cultivar in Indonesia, is thus a prime candidate for establishing such a baseline, aligning with calls in the literature for green extraction

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pathways that retain the fiber's intrinsic properties (Hapsari et al., 2023; Mulyati et al., 2023).

The novelty of this study lies in its direct response to this knowledge gap by providing the first systematic characterization of PALF from the Queen cultivar, extracted exclusively via mechanical decortication. This focused approach isolates the inherent properties of the fiber, generating the foundational data essential for reliable industrial modeling and quality control (Fikri et al., 2024; Gundara et al., 2023; Yanti et al., 2025). Previous reviews have consistently underscored the need for such cultivar-specific, standardized baselines to facilitate accurate morphology-property correlations and predictive modeling in PALF-reinforced applications (Abu et al., 2023; Dissanayake & Samarasinghe, 2024; Rahman, 2024b).

Therefore, the objective of this study is to establish a clear relationship between the microscopic structure and the macroscopic physico-mechanical properties of mechanically processed Queen variety PALF. By focusing on a commercially significant variety sourced from local farming communities in Kediri, East Java, this research contributes vital, actionable data for process optimization and material selection in eco-friendly textile and bio composite applications. The outcomes are anticipated to support the integration of PALF as a sustainable reinforcement material and guide the development of standardized green processing protocols.

Method

Materials

The raw material used was natural fiber extracted from pineapple leaves (Ananas comosus L.). The fibers were sourced from the Mukti Bedali Farmer's Group, located in Bedali Village, Ngancar District, Kediri Regency, East Java, Indonesia. Based on the characterization, these pineapple fibers exhibit an average fineness of 33.70 dtex and a bundle tenacity of 23.20 g/tex. Prior to further characterization, all fiber samples were conditioned in a standard atmosphere (27 ± 2 °C and 65 ± 2% relative humidity) for 24 hours.

Fiber Characterization

All testing and characterization of the fiber samples were performed at the Center for Standardization and Textile Industry Services (BBPJIT) in Bandung, Indonesia, a government-accredited testing institution.

Fiber Fineness

Fiber fineness was determined using the gravimetric method in accordance with the SNI 08-1111-1989 standard. Five replications were conducted to obtain the average fineness value in dtex.

Bundle Tensile Properties

The tensile properties, including bundle tenacity and elongation at break, were tested following the SNI 08-1112-1989 standard. It is noted that these tests were conducted on fiber bundles, not on single fibers. This standard was chosen for its relevance in domestic industrial quality control applications. However, the authors acknowledge that the use of an older standard is a methodological limitation, and future studies could employ international standards for single-fiber testing (e.g., ISO 5079) for broader data comparability.

Surface Morphology

The surface morphology and cross-sectional shape of the pineapple fibers were observed using Scanning Electron Microscopy (SEM) for qualitative visual analysis.

Results and Discussion

Results

The physico-mechanical properties of the mechanically extracted pineapple leaf fibers (PALF) were characterized in accordance with Indonesian National Standards (SNI). The primary findings are summarized in Table 1. The fibers exhibited an average fineness of 33.70 dtex, with a standard deviation of 5.79. Regarding the mechanical properties, the bundle tenacity was determined to be 23.20 g/tex, and the elongation at break was 5.90%. The surface morphology and cross-sectional structure of the fibers were qualitatively analyzed using Scanning Electron Microscopy (SEM), with representative micrographs presented in Figure 1.

Table 1. Physico-Mechanical Properties of Pineapple Leaf Fiber (Experimental Results)

Test Type	Test Result	Test Method
Fiber Fineness, dtex	33.70	SNI 08-1111-1989
Bundle Tensile Strength		SNI 08-1112-1989
a) Tensile strength, g/tex	23.20	
b) Elongation	5.90%	

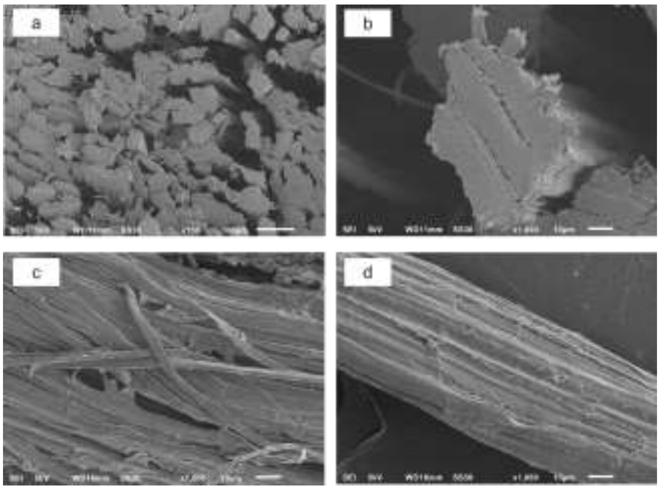

Figure 1. SEM micrographs of pineapple leaf fiber (PALF): (a) Cross-section showing a dense packing of multi-cellular filaments; (b) Detailed cross-section of a single fiber bundle; (c) Longitudinal view showing multiple elementary fibrils; (d) Detailed longitudinal surface morphology with characteristic striations

Discussion

Fiber Fineness and Potential Applications

The measured fineness of 33.70 dtex positions the pineapple leaf fiber (PALF) from the Queen cultivar as a relatively coarse natural fiber, particularly when compared to fine apparel-grade fibers (Alam et al., 2022; Zolkifflee et al., 2024). This classification is consistent with literature that frames PALF as a reinforcement-oriented material rather than a soft textile fiber for clothing (Lee et al., 2020b; Aznar, 2019). Its fineness typically falls within a range suitable for technical applications where properties such as stiffness, dimensional stability, and efficient load transfer are prioritized over tactile softness (Esan et al., 2023; Johny, 2023).

Consequently, the inherent coarseness of this fiber makes it a highly suitable candidate for specific industrial segments. These include reinforcement in bio composites, where its high modulus contributes to structural integrity, and in technical textiles such as geotextiles, upholstery, and carpets, where durability is paramount (Johny, 2023; Marques et al., 2024; Palanisamy et al., 2024). The effort to valorize agricultural waste like pineapple leaves is part of a broader research trend in sustainable materials, which also includes developing value-added products like biodegradable plastics and films from other biomass sources (Ihsan & Ratnawulan, 2023; Rahmah et al., 2025; Santi et al., 2024).This interpretation, based on fineness, logically directs the subsequent analysis toward the fiber's mechanical and morphological characteristics to fully validate its performance potential in these demanding applications (Geng et al., 2022; Singha et al., 2020; Surajarusarn et al., 2019).

Mechanical Properties and Comparison

The bundle tenacity of 23.20 g/tex measured for the Queen PALF represents a robust strength level for an untreated natural fiber, positioning it favorably for reinforcement applications. When combined with its relatively low elongation at a break of 5.90%, the results indicate a material that is both strong and rigid. This balance is a highly desirable trait for reinforcing fibers in bio composites, where the primary role is to bear load and prevent deformation of the matrix material (Harigovindan et al., 2024; Mustafa et al., 2024).

To contextualize this performance, the tenacity of this PALF is significantly higher than that of coir fiber (typically <18 g/tex) and is competitive with other widely used lignocellulosic fibers such as jute and kenaf (Fu et al., 2023; Sayeed, 2023). This respectable strength validates its suitability for integration into polymer matrices. Indeed, numerous studies demonstrate that PALF can effectively enhance the tensile and flexural performance when incorporated into epoxy, polypropylene, and polyester matrices, confirming its role as a viable structural reinforcement (Fikri et al., 2024; Gundara et al., 2023). The mechanical profile observed in this study thus strongly supports the conclusion that this Queen PALF is best utilized in technical applications where its rigidity and load-bearing capacity can be fully leveraged.

Morphological Analysis

The SEM micrographs presented in Figure 1 provide a clear visualization of the fiber's architecture. The cross-sectional analysis is particularly insightful, revealing a dense, multi-cellular structure composed of irregularly shaped fibrils packed tightly together with minimal voids (Wang et al., 2023). The longitudinal views complement this by showing a surface with characteristic parallel striations, confirming that the fiber is a composite bundle of smaller, well-aligned elementary fibrils. Furthermore, the use of advanced imaging techniques like SEM to correlate such microscopic structures with macroscopic properties is a powerful pedagogical approach for developing scientific inquiry skills in students.

This dense and highly oriented internal structure is fundamental to the fiber's mechanical performance. It facilitates efficient stress transfer among the fibrils when a tensile load is applied, which directly contributes to the respectable bundle tenacity of 23.20 g/tex observed in this study. This relationship, where an organized microstructure dictates macroscopic mechanical performance, is a well-documented principle for lignocellulosic fibers and is also a key factor in the development of other bio-based materials, such as bioplastic films where polymer chain arrangement determines strength (Nakagaito et al., 2024; Rahmah et al., 2025; Sadeghi et al., 2024; Santi et al., 2024).

The functional implication of this morphology is its suitability for reinforcement applications. The observed surface geometry and internal packing are known to play a crucial role in promoting mechanical interlocking at the fiber–matrix interface in composites. This is a key factor for achieving effective reinforcement and efficient load transfer from the matrix to the fiber (Yusof et al., 2023). Thus, the morphological evidence strongly supports the conclusion that this Queen PALF is structurally well-suited for use as a high-performance reinforcement material in sustainable composites.

Conclusion

This study successfully established a physico-mechanical and morphological baseline for pineapple leaf fibers (PALF) from the Queen cultivar, sourced from Kediri, East Java, and processed via a purely mechanical decortication route. The fibers exhibited a mean fineness of 33.70 dtex and a robust bundle tenacity of 23.20 g/tex. Qualitative SEM analysis revealed a coarse surface and a dense, multi-cellular cross-section. These characteristics collectively support the conclusion that this PALF is a viable reinforcement candidate for eco-friendly technical textiles and bio composites, rather than a primary raw material for fine apparel yarns. The findings provide a critical, cultivar-specific data point for a commercially significant variety under a green processing pathway, addressing a noted gap in literature. Based on these results, future research should be prioritized in several key directions. Extending the characterization to single-fiber testing is essential for more precise structure-property correlations. Multi-scale characterization, including XRD for crystallinity and FTIR for surface chemistry, would provide a deeper understanding of cultivar-driven performance variations. Finally, investigations into interfacial strength within specific green polymer matrices are necessary to translate this foundational data into predictive models for industrial deployment. Pursuing these research trajectories will accelerate the adoption of PALF as a standardized, sustainable material.

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Author Contributions

Conceptualization, [A.D.]; methodology, [A.D.], [N.I.] and [F.D.]; formal analysis, [A.D.]; investigation, [A.D.], [F.D.], [S.P.] and [N.I.]; resources, [S.P.]; writing—original draft preparation, [A.D.]; writing—review and editing, [S.P.] and [N.I.]; supervision, [A.D.]; funding acquisition, [S.P.]. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest

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