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Mechanical Properties and Microstructural Analysis of Gnetum Gnemon Fibers in Traditional Papuan Noken Bags: Integrating Indigenous Knowledge with Materials Science

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Abstrak

Serat alami menjadi solusi strategis dalam pengembangan material berkelanjutan, namun tantangan utama tetap pada optimalisasi sifat mekanis dan karakteristik fungsional. Meskipun berbagai penelitian telah mengeksplorasi serat alami seperti kenaf, rami, dan bambu, serat melinjo (Gnetum gnemon L.) masih belum sepenuhnya dikaji dari perspektif rekayasa material. Kesenjangan penelitian ini mendasari pentingnya investigasi komprehensif untuk memahami potensi struktural dan mekanis serat melinjo dalam konteks pengembangan produk tekstil berkelanjutan. Penelitian bertujuan mengoptimalkan kekuatan tarik serat melinjo melalui analisis sistematis variasi pola anyaman untuk mendukung pengembangan tas noken sebagai warisan budaya Papua. Melalui pendekatan eksperimental, penelitian menguji tiga konfigurasi anyaman (1X1, 2X1, dan 2X2) menggunakan metode ekstraksi tradisional dan analisis ilmiah modern. Spesimen dikarakterisasi menggunakan *Universal Testing Machine* sesuai standar ISO 13934 dan SNI 0276:2009 untuk menganalisis properti mekanis secara komprehensif. Hasil menunjukkan anyaman 2X2 mencapai kekuatan tarik tertinggi 678,09 N, sementara anyaman 1X1 memiliki elongasi optimal 191%. Temuan ini mengungkap potensi serat melinjo dalam pengembangan tekstil fungsional berbasis kearifan lokal, membuka peluang inovasi material berkelanjutan dengan nilai budaya tinggi.

Kata kunci: gnetum gnemon l.; pola anyaman; uji tarik; material berkelanjutan

Abstract

Natural fibers have emerged as a strategic solution in sustainable material development, with the primary challenge remaining in optimizing mechanical properties and functional characteristics. Despite extensive research exploring natural fibers such as kenaf, rami, and bamboo, melinjo fibers (Gnetum gnemon L.) have not been fully investigated from a materials engineering perspective. This research gap underscores the importance of comprehensive investigation to understand the structural and mechanical potential of melinjo fibers in the context of sustainable textile product development. The research aims to optimize the tensile strength of melinjo fibers through systematic analysis of weaving pattern variations to support the development of noken bags as a Papuan cultural heritage. Using an experimental approach, the study examines three weaving configurations (1X1, 2X1, and 2X2) utilizing traditional extraction methods and modern scientific analysis. Specimens were characterized using a Universal Testing Machine in accordance with ISO 13934 and SNI 0276:2009 standards to comprehensively analyze mechanical properties. Results demonstrate that the 2X2 weave achieved the highest tensile strength of 678.09 N, while the 1X1 weave exhibited optimal elongation of 191%. These findings reveal the potential of melinjo fibers in developing functional textiles based on local wisdom, opening opportunities for sustainable material innovation with high cultural value.

Keywords: *gnetum gnemon l.; weaving patterns; tensile test; sustainable materials*

1. Introduction

The exploration of natural fibers as alternative reinforcement materials represents a critical trajectory in contemporary materials science and sustainable engineering. As industrial sectors increasingly seek environmentally conscious solutions, the investigation of plant-derived fibers has emerged as a promising avenue for developing innovative composite materials.

Addressing this challenge requires strategic utilization of plant-derived biomass and natural fiber extraction. As seen on previous research that examined other natural fiber such as: Sida Rhombifolia [1], Kenaf Fiber [2], Jute Fiber [3,4], Oil Palm [5], Bamboo [6], Enset Ventricosum [7], Sisal Fiber [8]. The intrinsic characteristics of natural fibers—including their renewable nature, low environmental impact, and potential for localized production—position them as compelling alternatives to conventional synthetic reinforcement materials [9].

The traditional manufacturing process of Noken bags incorporates diverse natural fibers, by utilizing planst bark includes the Melinjo tree (Damiyo), Ilam tree bark (Tokeipo), anyamin tree (Kepiyai), tree bark (Woge), Watu tree bark and Epiyo [10]. Among these various natural materials, Gnetum gnemon fibers, derived from the melinjo tree, demonstrate particularly promising characteristics due to their superior tensile strength properties and widespread availability throughout the Indonesian archipelago [11]. However, the optimization of Gnetum gnemon fiber tensile strength within the context of Noken bag manufacturing necessitates further comprehensive investigation, particularly regarding the correlation between weaving patterns and structural integrity.

Weaving patterns constitute a critical determinant in the mechanical properties and durability of natural fiber-based products. The variation in weaving patterns not only influences aesthetic attributes but also demonstrates direct correlation with tensile strength and product longevity [12]. This research endeavors to conduct a systematic analysis of Gnetum gnemon fiber tensile strength across different weaving pattern variations, with the objective of developing enhanced quality parameters for Noken bag production. The investigation of traditional crafting techniques through the lens of materials science not only contributes to the preservation of cultural heritage but also facilitates the development of improved manufacturing methodologies. This interdisciplinary approach, combining traditional knowledge with modern scientific analysis, presents opportunities for sustainable product development while maintaining cultural authenticity and enhancing functional performance.

Previous research on natural fiber tensile properties has demonstrated significant variability across different plant sources. Kenaf fibers have shown a wide range of tensile strengths, from 200 to 400 MPa, with elongation at break between 1.5-3.5% [13]. The processing techniques, such as the combed method, can significantly enhance the tensile strength, reaching up to 692 MPa [14]. On the other hand, research by [15] found that bamboo fibers exhibit tensile strengths averaging 150-250 MPa, with more consistent mechanical properties compared to other natural fibers. Also on the same paper, jute fibers have tensile strengths around 250-350 MPa, highlighting the importance of species-specific variations. These studies consistently emphasize the potential of natural fibers as sustainable alternatives to synthetic reinforcement materials, while also noting challenges related to mechanical performance consistency. Factors such as extraction method, fiber maturity, environmental conditions, and processing techniques have been identified as critical variables influencing the mechanical properties of natural fibers. The inherent variability observed in these studies underscores the necessity of comprehensive characterization for each specific fiber type, making the current investigation into Gnetum gnemon L. fibers particularly valuable for expanding the scientific understanding of natural fiber mechanics.

The present study represents a focused investigation into the mechanical properties of Gnetum gnemon L. fibers, addressing a significant gap in current scientific knowledge. Despite extensive research on natural fibers like hemp, jute, and bamboo, Gnetum gnemon L. remains largely unexplored from a materials science perspective. This research seek to move beyond previous studies that have narrowly focused on the plant's biological or nutritional attributes, instead providing a holistic understanding of its material potential. This study aspires to contribute meaningful insights to the fields of sustainable materials engineering, textile material, and composite material development for noken’s bag production.

2. Material and methodology

2.1 Fiber's Extraction

Gnetum gnemon fiber extraction begins with bark removal from mature trees using a machete or knife. Tree selection criteria specify a minimum diameter of 15cm, as these specimens yield superior quality fibers. The process involves manually separating outer and inner bark layers, with only the inner bark utilized for fiber extraction.

The bark undergoes softening through percussion with stone implements as seen on Fig. 1, following traditional Papua methods. This step facilitates fiber separation during subsequent drying. Manual compression removes excess moisture through mechanical dewatering, preparing the material for further processing. The desiccation process requires 48-72 hours under ambient conditions to achieve optimal moisture content of 8-12%. This specific moisture threshold prevents fungal colonization and material deterioration, resulting in light-colored fibers without mycological growth. Fiber extraction proceeds through manual separation of the dried bark material. When optimal desiccation parameters are maintained, the process encounters minimal mechanical resistance. Traditional yarn production in Papua employs hand-twisting techniques against the thigh or leg surface. However, this manual methodology presents limitations in achieving consistent results, particularly in fiber diameter and morphological uniformity. These variations in fiber thickness and configuration often create challenges in subsequent product development stages, potentially compromising final product quality.

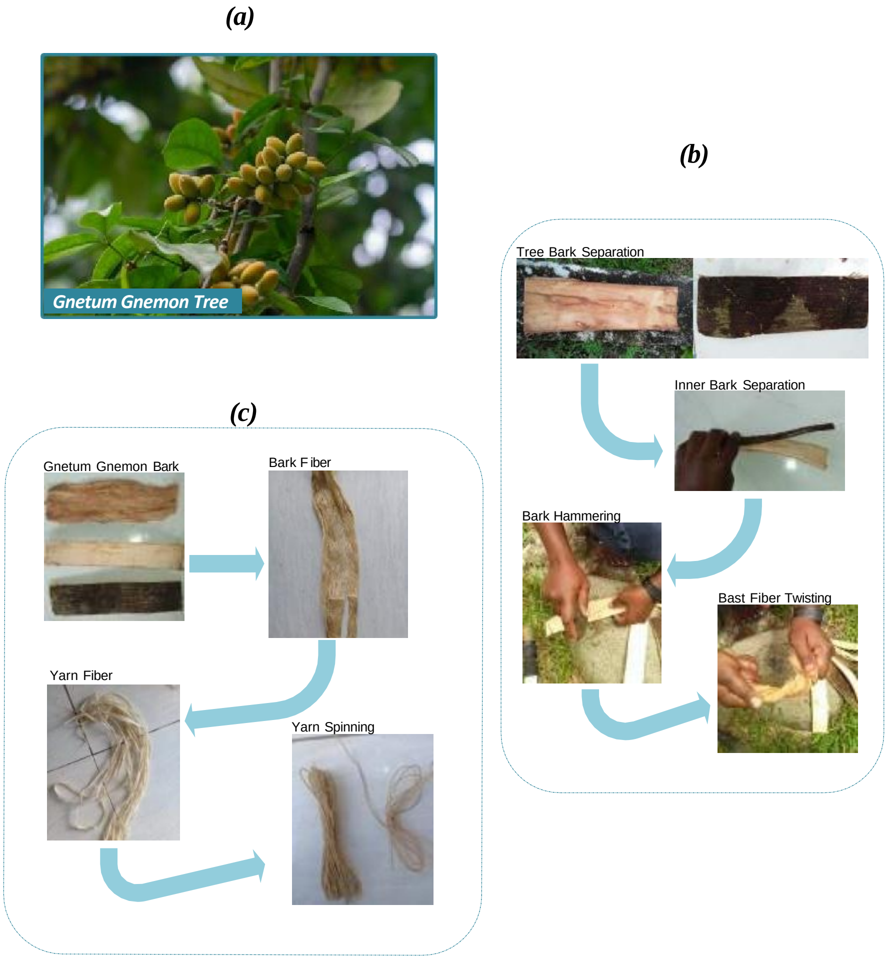

Figure 1. Gnetum Gnemon Extraction: (a) Gnetum Gnemon L Tree, (b) Bark Separation, (c) Bark to Fiber Process

2.2 Tensile Test

Tensile testing using both ISO 13934 and SNI 0276:2009. Three specimens were extracted from each weaving pattern of Gnetum gnemon textile. Each specimen measures 150mm x 25mm, with a consistent thickness of 2.2 mm, as illustrated in Fig. 2, resulting in nine specimens for comprehensive mechanical characterization. This methodological approach provides statistically robust data for analyzing the fiber's tensile properties and mechanical response under controlled stress conditions [16,17].

Figure 2. Weaving Pattern: (a) 1X1 Weave, (b) 2X1 Weave, (c) 2X2 Weave.

The tensile testing was conducted using a calibrated Universal Testing Machine (HungTa HT2402). Test parameters were using constant crosshead speed of 30 mm/min, the initial gauge length was set at 75 mm, and all tests were performed under room temperature conditions. The ultimate tensile strength (σ) was calculated according to paper published by [18].

$$\sigma = F/A \tag{3.1.}$$

Where F represents the maximum load at failure (N) and A denotes the initial cross-sectional area (mm²) of the specimen's narrow section. The results were expressed in N/mm² (MPa) to facilitate comparison with other natural fiber studies in the literature. The extensibility characteristics of the specimens under tensile loading were quantified through percentage elongation at break (ε), according to paper published by [19].

$$\varepsilon = [(Lf - Lo)/Lo] \times 100 \tag{3.2}$$

Where Lf represents the final length at rupture and Lo denotes the original gauge length. This parameter provides crucial insights into the fiber's ductility and its capacity for elastic and plastic deformation under load.

Figure 3. Tensile Testing of Gnetum Gnemon L. Woven

3. Result and Discussion

Gnetum gnemon fibers exhibit distinct mechanical properties and structural characteristics among natural fibers. Compare with other natural fiber listed on Table 1. suggest that the Gnetum Gnemon fiber density of 1.72 g/cm³ exceeds that of pineapple (1.41 g/cm³), yucca (1.33 g/cm³), coir (1.15-1.46 g/cm³), cotton (1.14 g/cm³), and bamboo (1.1 g/cm³). The mechanical properties stem from structural and compositional characteristics, influenced by fiber structure, chemical composition, and constituent interactions [20]. This higher density suggests a more compact internal structure, which may contribute to its enhanced mechanical performance.

Table 1. Comparison With Other Natural Fiber Yarn

Fiber Material	Source	Density (g/cm3)	Tensile Strength (N/mm2)	Elongation (%)
Gnetum Gnemon	Present Study	1.72	739	191
Pineapple	(Kaewpirom and Worrarat, 2014)	1.41	242	48
Yucca	(Kacem et al., 2024)	1.33	444	4.3
Coir	(Lotfi et al., 2021)	1.15-1.46	95-230	15.-51.5
Cotton	(Aruchamy et al., 2020)	1.14	494	22.95
Bamboo	(Gao et al., 2022)	1.1	630	23.8

The fibers display controlled deformation behavior, different from the rigid and brittle failure patterns of other natural fibers, indicating specific cell wall architecture and interfibrillar bonding mechanisms. Mariscus ligularis fiber, with a microfibril angle of 13.35–20.33°, shows comparable tensile strength and elasticity characteristics [21]. The similarity in mechanical behavior suggests analogous structural arrangements at the cellular level. Cellulose crystalline structure affects mechanical behavior through compressibility and crystal orientation under stress [22], contributing to structural integrity under tensile loads [23,24]. The interaction between crystalline and amorphous regions within the fiber structure potentially explains the observed combination of strength and flexibility.

Analysis of weave patterns as seen on Table 2. indicates that the 2X2 weave configuration achieves optimal mechanical properties with a mean breaking force of 678.09 N, exceeding both 2X1 (562.62 N) and 1X1 (510.79 N) configurations. The superior performance of the 2X2 weave suggests that increased structural complexity contributes to enhanced load-bearing capacity. Elongation characteristics show a non-linear relationship: 1X1 pattern exhibits 195.37% mean elongation at break, 2X2 pattern 184.83%, and 2X1 configuration 143.03%. These results align with studies on weave pattern effects on fiber mobility [25-28]. The 2X2 weave structure enables stress distribution that reduces stress concentration points [29,30]. This distribution pattern suggests that the more complex weave architecture allows for better force dissipation throughout the fiber matrix.

Table 2. Tensile Tests Result

Woven's Pattern	Tensile Properties	Specimens			
		1	2	3	Avg
1X1	Max. breaking force (N)	495.99	537.46	498.92	510.79
	Elongation at break (%)	194.5	205	186.6	195.37
2X1	Max. breaking force (N)	521.6	554.04	612.22	562.62
	Elongation at break (%)	160.5	117.3	151.3	143.03
2X2	Max. breaking force (N)	662.34	632.46	739.48	678.09
	Elongation at break (%)	196.5	167	191	184.83

The mechanical behavior of different weave patterns indicates a correlation between structural organization and performance characteristics. The reduced elongation in the 2X1 configuration suggests that intermediate structural complexity may impose constraints on fiber movement under tensile loading. This phenomenon warrants further investigation into the relationship between weave architecture and mechanical properties. In comparative analysis seen on Fig. 4, Gnetum gnemon shows a tensile strength of 739 N/mm² and 191% elongation at break, higher than pineapple (242 N/mm²), yucca (444 N/mm², 4.3% elongation), coir (95-230 N/mm², 15.1-51.5% elongation), and cotton (494 N/mm², 22.95% elongation). Bamboo presents comparable properties with 630 N/mm² tensile strength and 23.8% elongation. The substantial difference in elongation characteristics particularly distinguishes Gnetum gnemon from other natural fibers, suggesting unique structural adaptations that permit extensive deformation without failure.

Figure 4. Comparative Chart of Tensile Properties in Gnetum Gnemon Fiber Weave

These mechanical properties indicate potential applications across multiple technical domains [31-35]. In textile applications, the combination of high tensile strength and exceptional elongation characteristics suggests suitability for technical textiles and protective clothing. Previous studies by Pattanayak et al. [36] have demonstrated the potential of Gnetum gnemon fibers in developing sustainable textile composites, while research by Suryanto et al. [37] explored its applications in eco-friendly fabric production. In composite material development, the high strength-to-weight ratio and significant elongation capacity present advantages for automotive, aerospace, and construction applications. The fiber's mechanical properties suggest potential for enhancing composite material performance through improved stress distribution and impact resistance. Studies by Wahyudi et al. [38] have highlighted the promising characteristics of Gnetum gnemon in advanced composite manufacturing, particularly in lightweight structural applications.

The geographical distribution and current utilization patterns of Gnetum gnemon present additional considerations. In Papua, where populations are abundant yet underutilized, the fiber presents opportunities for material development beyond traditional applications such as Noken bags. This Southeast Asian native fiber offers potential for sustainable material sourcing and local economic development. Research by Iswanto et al. [39] has emphasized the economic and environmental benefits of developing local natural fiber resources. The integration of traditional knowledge with modern material science may provide insights into optimal processing and application methods. Further research into the relationship between processing conditions, structural characteristics, and mechanical properties could enhance understanding of this fiber's potential in advanced material applications.

4. Conclusion

The mechanical behavior of Gnetum gnemon fibers demonstrates significant dependence on weaving configurations. Testing results indicate that the 2X2 basket weave pattern achieved maximum tensile strength with 678.09 N breaking force, whereas the 1X1 plain weave exhibited peak elongation at break of 195.37%. These results indicate that the weave architecture substantially influences the fiber's mechanical characteristics. The data suggests potential applications in textile manufacturing, particularly for the 2X2 weave configuration. Its combination of tensile strength and controlled deformation properties indicates suitability for performance textiles and composite materials where predictable failure mechanisms are essential. Additional research areas require investigation to maximize the fiber's utility. Key research directions include weave pattern optimization, durability testing, refinement of extraction methods, and development of hybrid textile systems. Further development necessitates comprehensive studies in composite integration, industrial performance evaluation, environmental impact assessment, and economic viability analysis to facilitate the transition from laboratory findings to industrial implementation.

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