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Analysis of the mechanical properties of banana stem fibers and coconut fibers through tensile strength measurement based on Hooke's Law

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Abstract

The utilization of natural fibers such as banana stem fiber and coconut fiber is still not widespread even though both have good mechanical properties. This study aims to compare the tensile strength of the two types of fibers using the hanging load test method. The study was conducted experimentally at the Physics Education Laboratory of Syiah Kuala University using four specimen groups with 20 samplesin each group (n = 20). The process includes drying the fibers indoors, cutting samples with a size of 20 cm for single fibers and 15 cm for bundles, measuring the diameter using a screw micrometer, and applying a load gradually until the fiber breaks. A total of 80 specimens were tasted using a purposive sampling technique, consisting of sigle banana fibers, sigle coconut fibers, banana fiber bundles, and coconut fiber bundles with relatively similar physical characteristics and diameters. The data obtained were analyzed descriptively using average values of stress, strain, and elastic modulus. The results showed that single coconut fiber had the highest stress of 4.49×10^{6} Pa, an elastic modulus of 2.30×10^{8} Pa, and a strain of 0.0210. Meanwhile, single banana fiber had a stress of 4.34×10^{6} Pa, a modulus of 3.57×10^{8} Pa, and a strain of 0.0017. Coconut fiber bundles showed a stress of 1.76×10^{6} Pa, a modulus of 1.29×10^{8} Pa, and a strain of 0.0145, while banana fiber bundles produced a stress of 1.77×10^{6} Pa, a modulus of 6.91×10^{8} Pa, and a strain of 0.0033. Coconut fiber was more elastic and less prone to breaking during testing, while banana fiber was stiffer and more prone to breaking. The results of this study concluded that coconut fiber is better suited for applications requiring flexibility, while banana fiber is better suited for applications requiring high stiffness.

Keywords: coconut fiber; banana stem fiber; tensile strength; hanging load test.

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INTRODUCTION

The utilization of natural fibers as alternative materials continues to develop due to the increasing demand for environmentally friendly materials. Natural fibers have advantages such as being lightweight, abundantly available, biodegradable, and having the potential to replace synthetic fibers in various engineering applications (Sudarisman, Kamiel, and Rahadi, 2015). In addition, natural fibers are also widely developed as environmentally friendly materials for applications such as sound absorption due to their porous structure and ability to reduce noise (Saputri et al., 2024). On a global scale, natural fibers are increasingly being considered because of their competitive properties compared to modern synthetic materials (Mulenga, Ude, and Vivekanandhan, 2021). In Indonesia, agricultural waste such as banana stems and coconut husks is available in large quantities, but most of it has not been optimally utilized. Indonesia produces abundant banana stem and coconut husk waste every year, yet much of it is still discarded or burned, contributing to environmental problems. Therefore, the utilization of natural fibers as environmentally friendly alternative materials is highly important.

Banana stem fiber has a high cellulose content, making it potentially suitable as a reinforcement material in composites (Asroni and Handono, 2018). Previous studies reported that banana fiber composites can reach tensile strengths above 40 Mpa depending on fiber treatment and orientation (Norman and Hashim, 2022). Treatments applied to banana stem fibers, such as alkaline treatment, have been shown to improve mechanical strength by reducing excessive lignin and hemicellulose content. Mechanical studies on banana fibers also indicate that extraction methods affect fiber structural homogeneity and the resulting tensile strength values (Ruangnarong et al., 2024). Meanwhile, coconut fiber has been proven to have stable mechanical properties and is frequently used in composite research (Zarviansyah, Juanda, and Pranandita, 2023). Previous studies reported tensile strengths ranging from 15-30 Mpa for coconut fiber composites depending on fiber composites depending on fiber fraction and matrix composition (Rachmat et al., 2023). Coconut fiber also has strong, elastic characteristics and a porous structure, enabling it to absorb energy effectively in various applications (Saputri et al., 2024). Furthermore, its stable tensile strength and good durability make coconut fiber highly suitable for reinforcement in composite materials, particularly when combined with polymer matrices (Rachmat et al., 2023). Previous studies also show that natural fibers can exhibit good mechanical performance depending on fiber morphology and microfibril structure (Alves Fidelis et al. 2013).

However, most previous studies focus only on natural fiber–based composites. Direct ,comparisons between banana fiber and coconut fiber using simple tensile testing methods are still rarely conducted. In fact, tensile testing is an important method for determining the mechanical characteristics of natural fibers and composites, especially to assess material strength and elasticity. Differences in tensile strength are strongly influenced by cellulose, lignin, hemicellulose composition, and irregularities in fiber cross-sectional shape. The mechanical properties of natural fibers are also affected by the degree of cellulose crystallinity, where higher crystallinity tends to significantly increase tensile strength. In addition, fiber morphology characteristics have been shown to strongly affect stress and strain variations under load (Alves Fidelis et al., 2013). Other studies have also reported that the tensile properties of banana fibers can be significantly improved if fiber morphology is enhanced through chemical or mechanical processes (Norman and Hashim, 2022). Variations in fiber morphology, including diameter and cross-sectional shape, greatly affect the tensile strength values produced by natural fibers.

On the other hand, coconut fiber or coir has been widely used in composite material research and has been proven to possess stable mechanical properties, particularly tensile strength (Zarviansyah, Juanda, and Pranandita, 2023)

Although research on both types of fibers has been extensively conducted, most studies focus on their application as composites with variations in chemical processing or volume fraction. Research that directly compares the tensile strength of banana fiber and coconut fiber through simple rod testing such as the hanging load test is still very limited. This comparison is important to determine which type of fiber is stronger in resisting pure tensile forces before being used as composite materials. Theoretically, the tensile strength of natural fibers is strongly influenced by cellulose microfibril structure, lignin and hemicellulose content, and fiber orientation. In addition, moisture conditions and fiber extraction processes also affect mechanical properties. Differences in microfibril structure between banana fiber and coconut fiber have been reported as one of the factors causing tensile strength variations between the two fiber types (Raghul et al., 2021). Therefore, research comparing the tensile strength of banana stem fiber and coconut fiber under the same testing conditions will provide more objective data that can serve as a basis for material selection.

The tensile strength of natural fibers is influenced by their constituent components such as cellulose, hemicellulose, and lignin. Fiber morphology, including diameter, cross-sectional shape, and lumen presence, directly affects mechanical performance (Alves Fidelis et al., 2013). In addition, the porous structure and internal cavities in natural fibers contribute to their ability to absorb energy, which also affects their overall physical behavior (Saputri et al., 2024).

Natural fibers are increasingly attracting industrial interest due to their lower cost compared to metals or synthetic fibers and their abundant availability (Ashik and Sharma, 2015). Tensile testing is a standard method for evaluating the mechanical strength of fibers and composites, as it can demonstrate a material’s ability to withstand loads before failure (Velmurugan et al., 2014).

This study uses an experimental method by applying a hanging load test to determine how strongly each type of fiber resists tensile forces. In this method, fibers are hung vertically and gradually loaded until they break. The maximum force causing fiber failure is recorded and compared between banana stem fiber and coconut fiber. This approach is simple and sufficiently effective for measuring the actual tensile strength of natural fibrous materials without requiring complex testing equipment such as a Universal Testing Machine (UTM). The test results are then analyzed to determine differences in tensile strength between the two fiber types and the factors contributing to these differences. Through this method, a clearer understanding of the tensile performance of banana stem fiber and coconut fiber is obtained.

This research is important to support the utilization of agricultural waste as renewable raw materials. Furthermore, the results can contribute to the development of natural fiber–based materials science while encouraging the use of more environmentally friendly local resources.

The purpose of this study is to compare the tensile strength of banana stem fiber and coconut fiber through the hanging load test method to determine which fiber has higher tensile resistance and its potential use as an environmentally friendly alternative material

METHODS

Research Design

This study employed an experimental laboratory research design to compare the mechanical properties of banana stem fiber and coconut fiber through tensile strength testing based on Hooke’s Law. The experiment was conducted using a hanging load test method to determine the tensile stress, strain, and Young’s modulus of each fiber type under controlled laboratory conditions. The research was carried out at the Physics Education Laboratory, Syiah Kuala University, on September 12, 2025. This design was selected because it enables direct observation of the tensile behavior of natural fibers without requiring advanced testing equipment such as a Universal Testing Machine (UTM).

Sample Preparation

The primary materials used in this study were banana stem fibers and coconut fibers obtained from local agricultural waste sources. Prior to testing, all fibers were dried indoors for three days to reduce moisture content and stabilize their mechanical properties. After the drying process, the fibers were prepared into two specimen forms, namely single fibers and fiber bundles. Single-fiber specimens were cut to a length of 20 cm, while bundled-fiber specimens were cut to 15 cm. Each specimen group consisted of 20 samples, resulting in a total of 80 tested specimens. The samples were selected using purposive sampling to ensure relatively uniform physical characteristics and fiber diameters among all specimens

Materials and Equipment

The materials used in this study consisted of banana stem fibers (Figure 1a) and coconut fibers (Figure 1b). Several laboratory instruments were utilized during the testing process, including a screw micrometer (Figure 2a) with a measuring range of 0–25 mm and an accuracy of 0.01 mm for determining fiber diameter, a 30 cm ruler with 1 mm precision for measuring initial length and elongation, and a set of metal weights for applying tensile loads. The metal weights (Figure 2b) used during the tensile test were 50 g, 100 g, 150 g, 200 g, and 250 g, which were added gradually until the fibers reached their elastic limit or fractured.

Figure 1. Fibers specimen (a) banana fiber and (b) coconut fiber

Figure 2. Equipment used: (a) screw micrometer, (b) weights

Data Collection

Data collection was conducted by measuring the mechanical response of each fiber specimen during tensile loading (Figure 3). The diameter of each fiber was measured at three different points, namely the upper, middle, and lower sections, to obtain the average diameter value used for cross-sectional area calculations. During the tensile test, the elongation of the fibers was recorded after each incremental load addition. The maximum load causing fracture was identified and recorded as the failure load. The obtained data included initial length, final length, elongation, diameter, maximum tensile force, tensile stress, strain, and Young's modulus for each specimen group.

Figure 3. Measuring length after loading

Experimental Procedure

The experimental procedure began with measuring the initial length and diameter of each fiber specimen. One end of the fiber was fixed to a static hook, while the other end was attached to a small container used to hold the tensile loads. Tensile testing was performed by gradually adding metal weights until the fiber specimen fractured. At every load increment, the elongation of the fiber was measured and recorded. The maximum mass causing failure was converted into tensile force using the equation (1):

$$F = m \times g \tag{1}$$

where F is the tensile force (N), m is the mass (kg), and g is the gravitational acceleration (9.8 m/s²).

The tensile strength of each sample was calculated using the equation (2)

$$\sigma = F/A \tag{2}$$

where σ is tensile strength (Pa), F is maximum force (N), and A is the fiber cross-sectional area of the fiber (m²).

The cross-sectional area of the fiber was calculated using equation (3):

$$A = \pi d^2/4 \tag{3}$$

where A is the cross-sectional area (m²) and d is the fiber diameter (m).

Strain was calculated using the following equation (4) :

$$\varepsilon = \frac{\Delta L}{L_0} \tag{4}$$

where ε is strain, ΔL is elongation (m), L_0 is the initial length of the fiber (m), and L is the final length of the fiber after loading (m).

Young's modulus was calculated using the following equation (5) :

$$E = \frac{\sigma}{\varepsilon} \tag{5}$$

where E is Young's modulus (Pa), σ is tensile stress (Pa), and ε is strain.

Data Analysis

The collected data were analyzed descriptively by calculating the average values of tensile stress, strain, and Young's modulus for each specimen group, including single coconut fibers, single banana fibers, coconut fiber bundles, and banana fiber bundles. The mechanical properties of the two fiber types were then compared to identify differences in tensile resistance, elasticity, and stiffness. The interpretation of the results was based on the relationship between tensile stress, strain, and Young's modulus according to Hooke's Law principles.

RESULTS AND DISCUSSION

Tensile testing was conducted on four specimen groups: Single Coconut Fiber, Single Banana Fiber, Coconut Fiber Bundle, and Banana Fiber Bundle. The primary mechanical parameters measured and calculated were Tensile Stress (σ) and Young's Modulus (E), which are important indicators of material strength and stiffness.

The tensile stress was calculated using Equation (2), where stress was obtained from the ratio between the maximum tensile force and the fiber cross-sectional area. Strain (ε) was determined using Equation (4) by comparing the elongation of the fiber (ΔL) to its initial length (L_0). Furthermore, Young's Modulus (E) was calculated using Equation (5) as the ratio between tensile stress (σ) and strain (ε). Higher Young's Modulus values indicate greater material stiffness.

The following tables present the average values of Stress (σ), Young's Modulus (E), and Strain (ε) for each sample group.

Table 1. Average data for single fibers

Sample Group	Single Coconut Fiber	Single Banana Fiber
Average stress (σ) (Pa)	4.49×10^{6}	4.34×10^{6}
Average Young's modulus (E) (Pa)	2.30×10^{8}	3.57×10^{8}
Average strain (ε)	0.0210	0.0017
Description	Predominantly unbroken	Predominantly broken

From the hanging load test, the average values of stress, Young's modulus, and strain for each sample group were obtained, as shown in Table 1. These results were then analyzed to understand their physical meaning and mechanical implications.

In general, single coconut fiber exhibited the highest average stress value of 4.49×10^{6} Pa, with a modulus of 2.30×10^{8} Pa and a strain of 0.0210. The relatively large strain value indicates that coconut fiber has a greater deformation capacity before reaching its elastic limit. This behavior is consistent with the characteristics of natural fibers that possess flexibility, as previously reported in studies on coconut coir fiber composites, where increasing fiber volume fraction increases strain and modulus values (Gundara, 2019).

Meanwhile, single banana fiber showed an average tensile stress of 4.34×10^{6} Pa, but a significantly higher Young's modulus of 3.57×10^{8} Pa, with a very low strain value of only 0.0017, and experienced fracture during testing. The high modulus indicates that banana fiber is stiffer and less capable of elastic deformation before failure. This behavior is typical of fibers with dominant cellulose content and relatively low lignin content (Asroni and Handono, 2018). Due to this brittleness, single banana fiber reached failure under maximum tensile loading.

Table 2. Average Fiber Bundle Data

Sample Group	Average Tensile Stress, σ (Pa)	Average Young's Modulus, E (Pa)	Average Strain, ε	Description
Coconut Fiber Bundle	1.76×10^{6}	1.29×10^{8}	0.0145	Predominantly Not Fractured
Banana Fiber Bundle	1.77×10^{6}	6.91×10^{8}	0.0033	Predominantly Not Fractured

Tensile Behavior of Fiber Bundles, The average mechanical properties of bundled fibers are presented in Table 6. Bundled coconut fiber exhibited a significantly lower average tensile stress of 1.76 × 10^6 Pa, a Young's modulus of 1.29 × 10^8 Pa, and a strain value of 0.0145. Although bundles consist of multiple fiber strands, the decrease in tensile strength can be attributed to uneven load distribution and friction between individual fibers within the bundle. This condition causes some fibers to be less effective in bearing tensile loads. Such phenomena are consistent with observations in composite studies, where fiber pull-out and interfacial failure often reduce load transfer efficiency in bundled or aligned fiber systems (Sudarisman, Kamiel, and Rahadi, 2015).

Similarly, banana fiber bundles exhibited an average tensile stress of 1.77 × 10^6 Pa, which is comparable to that of coconut fiber bundles. However, the Young's modulus was significantly higher at 6.91 × 10^8 Pa, while the strain remained low at 0.0033. This indicates that banana fiber bundles possess high stiffness but very limited flexibility. The low strain value suggests poor deformation capability, likely caused by weak bonding between fibers, microstructural defects, or non-uniform stress distribution among fiber strands. These factors prevent the fiber bundle from fully utilizing the tensile potential of individual fibers.

Comparison Between Single Fibers and Fiber Bundles, experimental results clearly show that tensile stress and Young's modulus values of single fiber specimens are significantly higher than those of bundled specimens for both fiber types. This indicates that single fibers are more efficient in bearing tensile loads compared to bundled fibers. In fiber bundles, some strands may not carry the load optimally due to imperfect alignment, weak bonding, or frictional effects between fibers, as reported in tensile analyses of natural fiber composites (Velmurugan et al., 2014)

Furthermore, the differences between banana fiber and coconut fiber can be explained by their microstructural characteristics and chemical composition. Coconut fiber exhibits higher flexibility and deformation capability due to its relatively high lignin content, which allows internal fiber movement without immediate fracture. In contrast, banana fiber, with its higher cellulose content, tends to be stiffer and more susceptible to microcrack formation when subjected to tensile stress (Boimau, 2020). Studies on banana fiber composites also indicate that fiber orientation and alignment strongly influence tensile performance, where fibers aligned parallel to the tensile load provide better mechanical properties than randomly oriented fibers (Boimau, 2020).

Implications for Material Applications, From a practical application perspective, single coconut fiber, which exhibits relatively high strain and does not fracture during testing, is suitable for applications requiring a balance between strength and flexibility. On the other hand, single banana fiber is more appropriate for applications requiring high stiffness, although additional treatments such as alkaline treatment or surface modification are necessary to prevent premature fracture. Previous studies on alkaline-treated coconut fibers have demonstrated improved interfacial bonding and increased tensile strength in composite systems (Damian et al., 2015).

Since fiber bundles show significantly lower tensile efficiency, composite applications using bundled fibers must consider proper fiber distribution and binding techniques to ensure uniform load transfer. Advanced fiber orientation techniques, weaving methods, or complex fiber binding structures may improve the mechanical efficiency of bundled fibers.

The results of this study are consistent with the theory that variations in fiber diameter, non-uniform cross-sectional shape, and cellulose content can either enhance or reduce tensile strength (Alves Fidelis et al., 2013). These findings also align with the work of (Raghul et al., 2021), which reported that coconut fiber generally exhibits higher flexibility compared to banana fiber.

In addition, differences in microstructure, fibril orientation, and lignin distribution play a crucial role in determining the mechanical behavior of both fibers. (Velmurugan et al., 2014) emphasized that tensile testing is the most effective method for evaluating the mechanical performance of natural fibers, supporting the validity of the results obtained in this study.

Based on the hanging load test results, coconut fiber was found to have higher tensile resistance and better elastic behavior compared to banana stem fiber. This is evidenced by its higher maximum tensile stress and its ability to withstand loading without fracture. Conversely, banana stem fiber exhibited a higher elastic modulus, indicating greater stiffness but lower elasticity under tensile loading. These differences are primarily influenced by chemical composition and fiber structure, where coconut fiber contains higher lignin content, making it more flexible, while banana fiber contains higher cellulose content, making it stiffer but more brittle.

The higher lignin content in coconut fiber enhances flexibility and deformation resistance, while the dominant cellulose content in banana fiber increases stiffness but reduces fracture resistance (Asroni and Handono 2018; Boimau 2020). Additionally, fiber bundling results in uneven stress distribution among strands, leading to a significant reduction in tensile strength compared to single fibers (Sudarisman, Kamiel, and Rahadi 2015).

The results were consistent for both single and bundled samples, although bundled fibers exhibited lower tensile strength due to uneven load distribution among fiber strands. Overall, coconut fiber is more suitable for applications requiring flexibility, while banana stem fiber is more suitable for applications demanding high stiffness. Therefore, both fibers have distinct potential applications depending on composite material requirements.

CONCLUSION

Based on the hanging load test results, significant differences in mechanical characteristics were observed between banana stem fiber and coconut fiber in both single and bundled forms. The highest tensile stress was obtained for single coconut fiber at 4.49×10^6 Pa, followed by single banana fiber at 4.34×10^6 Pa, while bundled fibers exhibited lower tensile stress values. Coconut fiber demonstrated greater elasticity with higher strain (0.0210) and did not fracture during testing, whereas banana fiber showed a higher elastic modulus (3.57×10^8 Pa) but was stiffer and more prone to fracture under maximum tensile load.

Overall, single coconut fiber exhibits the best performance in resisting tensile loads without fracture, making it suitable for applications requiring flexibility and deformation resistance. Conversely, single banana fiber is suitable for applications requiring high stiffness, although additional treatments such as alkalization are recommended to improve tensile resistance.

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Declarations

Author Contribution	:	Author 1: Conceptualization, Writing – Original Draft, Editing and Visualization; Author 2: Writing – Review & Editing, Formal analysis, and Methodology; Author 3: Supervision dan Data Curation;
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