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Machine Analysis for Pineapple and Banana Fibre Extraction

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Abstract

This study examines the mechanical extraction of natural fibres from banana stems and pineapple leaves, highlighting their potential as sustainable alternatives to synthetic materials. Pineapple leaf fibre (PALF) and banana fibre (BF) offer significant advantages due to their environmental friendliness, high tensile strength, and diverse industrial applications in textiles, composites, and biodegradable products. Traditional extraction methods often result in inconsistent quality and low efficiency, leading to resource wastage and limiting their industrial adoption. The study also aligns with the global shift towards eco-friendly and renewable resources, promoting sustainable industrial practices. PALF and BF exhibit distinct mechanical properties that make them suitable for a variety of applications, supporting the reduction of dependency on non-renewable synthetic materials. The findings advocate for the integration of advanced technologies, such as automated feed systems and improved roller designs, to further optimize the extraction process. This work underscores the importance of sustainable resource utilization and provides a framework for advancing the natural fibre industry, driving innovation in extraction techniques, and fostering the transition to a circular economy. This research emphasizes the optimization of mechanical extraction processes to enhance fibre yield and quality while minimizing operational inefficiencies.

1. Introduction

In recent years, the demand for sustainable and eco-friendly materials has driven significant interest in natural fibres such as pineapple leaf fibre (PALF) and banana fibre (BF). These fibres are derived from agricultural by-products, offering a renewable and biodegradable alternative to synthetic materials. With properties such as high tensile strength, low density, and biodegradability, PALF and BF have found applications in textiles, composites, and biodegradable products [1]. However, the widespread adoption of these fibres is hindered by challenges in the extraction process, including inconsistent fibre quality, low efficiency, and high labour costs [2].

Pineapple leaves, a by-product of pineapple cultivation, are a rich source of PALF, which contains 70-82% cellulose, contributing to its superior mechanical properties [3]. Similarly, banana pseudo-stems, often discarded as agricultural waste, yield BF with high tensile strength and flexibility, making it suitable for various industrial applications [4]. Despite their potential, traditional extraction methods are labour-intensive and inefficient, leading to underutilization of these resources [5]. Recent advancements in mechanical extraction technologies have shown promise in improving fibre yield and quality, but further optimization is needed to meet industrial standards [6].

This study focuses on the mechanical extraction of PALF and BF using a machine developed by Bambusoideae Technology Sdn Bhd. The objectives are to analyze the production of the extraction process, analyze the density and yield of the extracted fibres, and assess their suitability for industrial applications. By addressing the gaps in current extraction methods, this research aims to contribute to the development of sustainable and efficient processes for natural fibre production, promoting the use of eco-friendly materials in various industries.

2. Method

This study employed a systematic approach to evaluate the mechanical extraction of pineapple leaf fibre (PALF) and banana fibre (BF) using a specialized extraction machine. The methodology encompassed the preparation of raw materials (pineapple leaves and banana pseudo-stems), mechanical extraction using fibre extraction machine, and post-extraction cleaning and drying of fibres. The extraction process was conducted at varying time intervals to assess the relationship between extraction time and fibre yield. Fibre density was measured using the ASTM D792 standard, while production capacity was evaluated by analyzing input weight, output weight, and yield percentage. This structured approach ensured a comprehensive assessment of the extraction machine's efficiency and the quality of the extracted fibres, providing reliable data for industrial applications.

2.1 Project Flowchart

The project flowchart provides a visual overview of the sequential steps involved in the extraction and analysis of fibres from pineapple and banana sources. It outlines key processes from material preparation to the conclusion, ensuring a structured approach to achieving the research objectives.

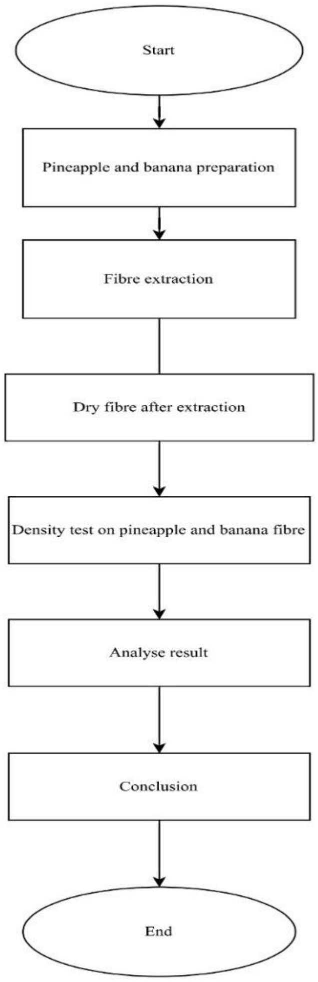

Fig. 1: Flowchart

2.2 Pineapple and Banana Preparation

The preparation of raw materials involved collecting pineapple l and banana pseudo-stems from local plantations. Pineapple leaves were washed thoroughly to remove dirt and debris, followed by air-drying to eliminate excess moisture. Banana pseudo-stems were peeled to remove the fibrous outer layers, and the inner core was cut into smaller, manageable sections for processing. These prepared materials were then fed into the mechanical extraction machine to ensure efficient fibre separation. Proper preparation was critical to maintaining the quality and consistency of the extracted fibres, as it minimized impurities and optimized the extraction process.

2.3 Fibre Extraction

The fibre extraction process was conducted using a mechanical extraction machine developed by Bambusoideae Technology Sdn Bhd. The machine utilized a series of rollers and blades to crush and scrape the prepared pineapple leaves and banana pseudo-stems, effectively separating the fibres from the non-fibrous tissue. The extraction process was carried out at varying time intervals (15, 30, 45, and 60 minutes) to evaluate the relationship between extraction time and fibre yield. The extracted fibres were then collected and subjected to a cleaning process to remove residual impurities, ensuring high-quality fibres suitable for further analysis and industrial applications.

2.4 Fibre Output

Following the initial mechanical separation stage, pineapple and banana plant materials yield coarse fibres containing impurities. These fibres undergo a combing or carding process to align them and remove short strands or residual debris, ensuring a clean and consistent texture suitable for further processing into textiles or composites. For wet extraction, the cleaned and chopped plant materials are submerged in water tanks to release the fibres from the plant matrix. After soaking, the fibres are physically extracted, thoroughly cleaned to eliminate any remaining plant material, and aligned to produce high-quality, clean fibres ready for industrial applications.

2.5 Fibre Dry After Extraction

After extraction, the fibres undergo a critical drying process to ensure cleanliness and readiness for further processing. The fibres are first washed in clean water to remove residual dirt, plant matter, or chemicals, with multiple rinses ensuring complete contaminant removal. Subsequently, the fibres are spread out and air-dried in a controlled environment to prevent contamination. Proper drying is essential to maintain the fibres' elasticity, strength, and overall quality, ensuring they are suitable for industrial applications.

2.6 Density Test on Fibre

Density testing is essential to evaluate the suitability of pineapple and banana fibres for industrial applications, such as composite materials. The test follows the ASTM D792 standard, measuring the mass (m) and volume (V) of fibre samples, with volume determined through geometric or displacement methods. Density (ρ) is calculated using the formula:

$$Density\ (\rho) = \frac{Mass\ (m)}{Volume\ (V)} \tag{1}$$

These density variations influence their applications in reinforced composites, textiles, and paper manufacturing. Understanding fibre density enables optimal material selection, ensuring the durability and performance of end products meet required standards.

3. Result and Discussion

This section presents the findings on pineapple leaf fibre (PALF) and banana fibre (BF) extraction, focusing on yield, density, and production efficiency. The results evaluate the extraction machine's performance and fibre quality, highlighting PALF's superior yield and density over BF. The linear relationship between extraction time and output is also discussed, providing insights for optimizing the process and advancing sustainable industrial applications.

3.1 Density Properties

Density testing is a fundamental assessment to evaluate the compactness and physical properties of extracted fibres, providing critical insights into their quality, strength, and suitability for applications such as textiles and composite materials. Understanding fibre density is essential for assessing mechanical characteristics, uniformity, and industrial potential. In this study, multiple density tests were conducted on pineapple leaf fibre (PALF) and banana fibre (BF) to generate accurate and reliable data, enabling detailed analysis and comparison of their properties.

Table 1: Density Properties

Fibre	Density ($\frac{g}{ml^3}$)			Reference
	Average ($\frac{g}{ml^3}$)	Standard Deviation ($\frac{g}{ml^3}$)	Coefficient Variation (%)	
BF	1.58	0.28	17.56	1.35 (Libog et al., 2023)
PALF	4.49	0.96	21.34	1.4 (J. P. Siregar et al., 2009)

The density analysis of pineapple leaf fibre (PALF) and banana fibre (BF) revealed significant differences in their properties. BF exhibited an average density of 1.58 g/cm^3, with a low standard deviation (0.28) and coefficient of variation (17.56%), indicating consistent density readings. In contrast, PALF showed a higher average density of 4.49 g/cm^3, with a standard deviation of 0.96 and a coefficient of variation of 21.34%, reflecting greater variability likely due to differences in plant traits or extraction techniques. These results highlight the distinct structural properties of PALF and BF, with PALF's higher density suggesting greater compactness and potential suitability for applications requiring durability.

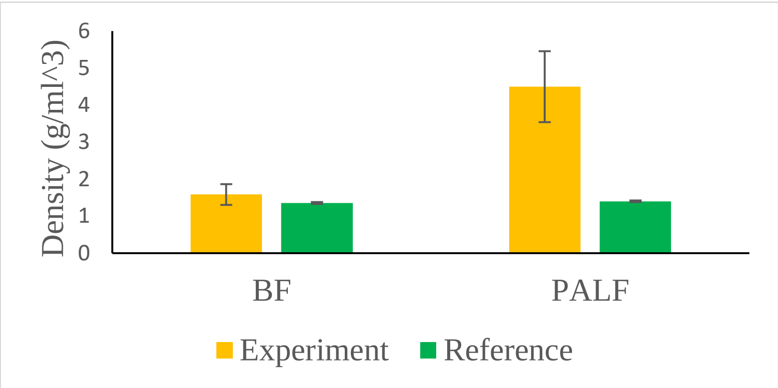

Fig. 2: Average Density PALF and Banana Fibre

Figure 2 revealed that the average density of banana fibre (BF) was 1.58 g/cm^3, exceeding the reference value of 1.35 g/cm^3, with minimal variability indicated by a standard deviation of 0.28. This suggests that BF in this study exhibited higher compactness or lower porosity, potentially influenced by extraction methods, moisture content, and fibre maturity. In contrast, the average density of pineapple leaf fibre (PALF) was significantly higher at 4.49 g/cm^3 compared to the reference value of 1.40 g/cm^3, with greater variability reflected by a standard deviation of 0.96. The higher density of PALF is attributed to its greater cellulose content, contributing to superior mechanical strength. Differences in density values for both fibres may stem from differences in plant characteristics, extraction techniques, and preparation methods. These findings highlight the potential of both fibres, particularly PALF, for applications requiring structurally dense and durable materials.

3.2 Analysis of Input Raw Material

Production inputs refer to the weight of raw materials (pineapple leaves and banana stems) and their input rate (kg/min) into the extraction process. These parameters are critical for evaluating the efficiency of fibre extraction, as they directly influence output yield and overall performance. Understanding the relationship between input material weight and production rate enables the assessment of resource utilization and identifies opportunities for optimizing the extraction process.

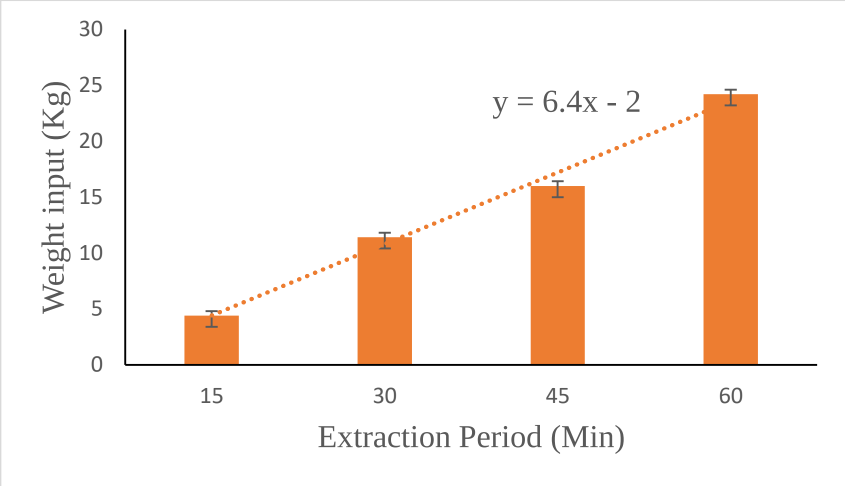

Fig. 3: Banana Stem Input

Figure 3 illustrates a linear relationship between weight input (kg) and extraction duration (minutes), with weight input increasing proportionally as extraction time extends from 15 minutes (4.4 kg) to 60 minutes (24.2 kg). The regression model;

$$y = 6.4(x) - 2 \quad (2)$$

demonstrates a steady input rate, where the slope (6.4) indicates a weight increase of 6.4 kg per minute, and the y-intercept (-2) reflects a minimal starting offset. For an extended operation of 8 hours (480 minutes), the projected input weight is approximately 3070 kg, confirming the machine's reliability for continuous processing. The error bars, representing standard deviations, highlight consistency in weight measurements, underscoring the system's dependability over prolonged use. This performance ensures efficient resource allocation, reduced labour costs, and maximized productivity, making the extraction machine highly suitable for industrial-scale operations requiring sustained and reliable output with minimal downtime.

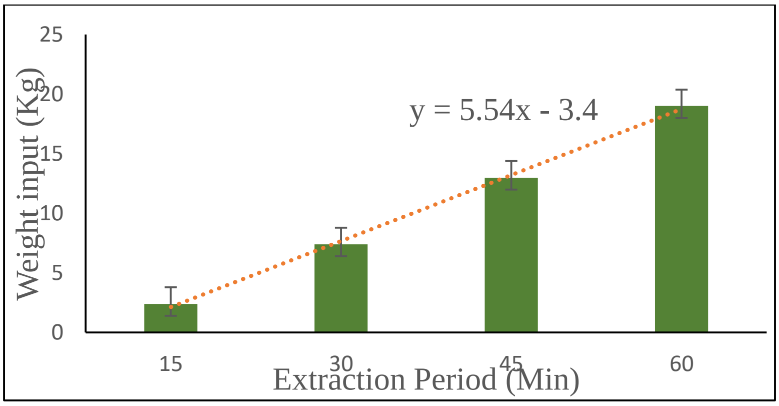

Fig. 4: Pineapple Leaf Input

Figure 4 demonstrates a linear correlation between extraction time (minutes) and weight input (kg), with input weight rising consistently as processing duration increases, starting at 2.4 kg at 15 minutes and reaching 19 kg at 60 minutes. The regression model;

$$y = 5.54(x) - 3.4 \quad (3)$$

predicts a weight input of approximately 2655.8 kg for an 8-hour operation (480 minutes), showcasing the machine's scalability and efficiency during extended runs. Error bars representing standard deviations highlight variability in measurements, confirming consistent and reliable input performance. Prolonged operation enhances material throughput, minimizes downtime, and ensures effective resource utilization, making the machine a viable solution for industrial-scale applications. Additionally, the system's linearity and predictive capability support process optimization, enabling accurate forecasting of raw material requirements and improved return on investment.

3.3 Analysis of Output Fibre

Figure 5 illustrates a linear relationship between fibre extraction weight output (grams) and extraction time (minutes), with output progressively increasing from 32.7 g at 15 minutes to 130.8 g at 60 minutes.

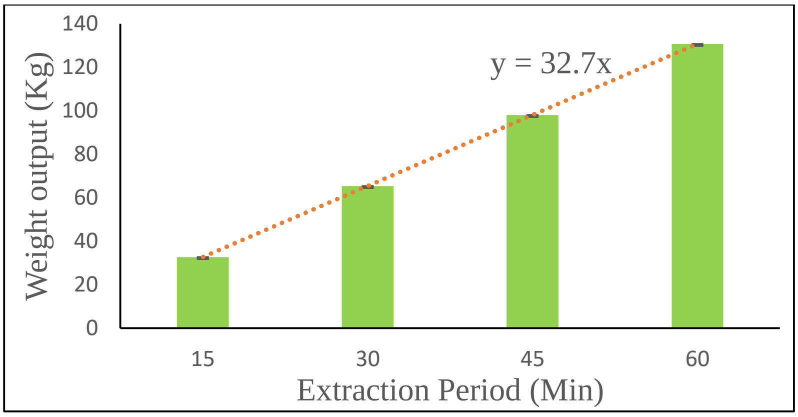

Fig. 5: Banana Fibre Output

$$y = 32.7(x) \tag{4}$$

The regression model highlights a stable and predictable production rate, demonstrating the machine's ability to scale output consistently over time. This reliability supports efficient planning for large-scale operations, enabling accurate estimation of output for extended production periods, such as an 8-hour cycle. The machine's consistent performance reduces downtime, maximizes resource utilization, and enhances cost-effectiveness, making it a robust solution for industrial fibre extraction applications.

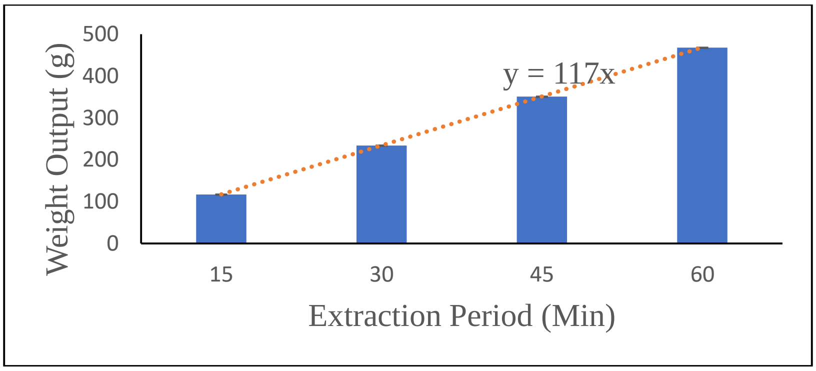

Fig. 6: Pineapple Fibre Output

Figure 6 demonstrates a linear relationship between weight output (grams) and extraction time (minutes), with output increasing proportionately from 117 g at 15 minutes to 468 g at 60 minutes, as described by the regression model;

$$y = 117(x) \tag{5}$$

This consistent production rate, with a slope of 117 g per minute, highlights the machine's efficiency and reliability over extended operations. The predictable output supports industrial demands, enabling accurate planning for prolonged periods, such as an 8-hour cycle. This operational consistency minimizes resource waste, enhances efficiency, and ensures streamlined production planning, making the machine a dependable solution for large-scale fibre extraction processes.

3.3.1 Average Yield

Figure 7 shows the average yield output between pineapple leaf fibre (PALF) and banana fibre (BF). PALF exhibits a higher average yield of 3.30% with a standard deviation of 1.09, indicating greater variability, whereas BF shows a lower average yield of 0.62% with minimal variability (standard deviation of 0.09). These results demonstrate PALF's superior production potential under comparable extraction conditions, making it a more efficient option for maximizing fibre recovery and reducing raw material waste. While BF offers consistent but limited extraction efficiency, the variability in PALF suggests potential for process optimization to enhance stability. For industries prioritizing resource and sustainability, the higher yield of PALF provides significant operational and financial advantages, reinforcing its suitability for large-scale applications.

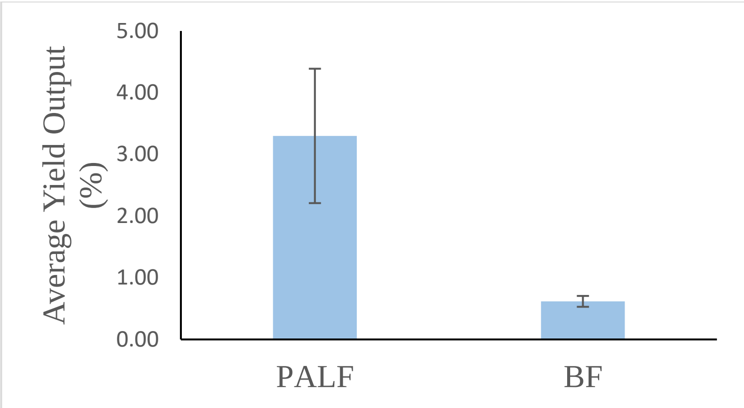

Fig. 7: Average Yield Output

4. Conclusion and Recommendation

4.1 Conclusion

This study evaluated the extraction performance of pineapple leaf and banana fibres through detailed production and yield analysis, highlighting the superior performance of pineapple leaf fibre (PALF). PALF demonstrated a significantly higher average yield of 3.30% compared to banana fibre's (BF) 0.62%, with regression models enabling accurate predictions of production performance over extended periods, such as 8-hour operations. The findings emphasized PALF's advantages in production efficiency, reduced raw material waste, and improved economic viability for fibre-based industries. The extraction machine exhibited consistent and reliable performance, maintaining steady output across varying input weights and extended durations, ensuring optimal fibre recovery with minimal downtime. This study underscores the suitability of PALF for large-scale industrial applications and provides critical insights into sustainable resource utilization and the improvement of fibre extraction technologies.

4.2 Recommendation

To enhance the extraction machine's performance, several upgrades are recommended, including optimizing roller configurations and blade sharpness to reduce material loss and improve fibre extraction efficiency. Implementing an automated feed system will ensure steady output rates and minimize operator dependency, while using corrosion-resistant materials in critical components and incorporating energy-efficient motors will extend machine lifespan and reduce operational costs. Extended operational cycles, such as 8-hour runs, significantly improve weight intake and production efficiency, making the machine suitable for industrial-scale applications. The findings highlight the superior yield of pineapple leaf fibres (PALF) compared to banana fibres (BF), emphasizing the need to prioritize PALF for maximizing fibre recovery. Regular monitoring of key performance metrics, such as yield percentage and extraction rate, is essential to identify inefficiencies and facilitate continuous improvement. Scaling the machine to accommodate higher input volumes and longer operating hours will further enhance its industrial viability and productivity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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