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Developing Sustainable Eco Paper Bags from Leaf Fiber

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Abstract

This project looks into making eco-friendly paper bags using natural fibers from agricultural waste, focusing on pineapple leaf fiber (PALF) and dried leaf fiber. With rising concerns about the buildup of agricultural waste and the overuse of plastic packaging, the aim is to turn these unused materials into something biodegradable and practical. Both types of fibers were tested for their strength, chemical makeup, and surface structure using tensile testing, FTIR, and SEM. The results showed that PALF performed much better overall it handled a maximum load of 56.737 N, with a stress of 0.0103 MPa, strain of 3.957%, and a Young's Modulus of 0.521 MPa. In comparison, the dried leaf fiber only managed 34.859 N, 0.0059 MPa stress, 2.834% strain, and a modulus of 0.210 MPa. FTIR analysis showed lower peaks for hemicellulose and lignin in PALF, which means non-cellulosic content was reduced effectively during treatment, while dried leaf fiber still had higher amounts of these components. SEM images supported this, showing PALF fibers were more aligned and intact, whereas dried leaf fibers looked uneven and full of gaps. What makes PALF especially good for eco-bags is its stronger fiber bonding, cleaner surface, and more uniform structure, all of which contribute to better durability. In summary, this study shows that pineapple leaf fiber has better qualities overall, making it a promising choice for producing sustainable, biodegradable paper bags. Turning waste into useful products like this not only helps reduce environmental impact but also offers a realistic alternative to single-use plastic.

1. Introduction

There has been a growing global movement in recent years to lessen the negative effects of plastic products on the environment, especially in the packaging sector. Even though plastic bags appear to be free, their use in society results in the unnecessary consumption of an unsustainable commodity [1]. Plastic bags have a long-lasting effect on the environment and can take up to 1000 years to degrade completely [2]. This shift has led to the exploration of alternative materials, such as eco-friendly paper bags made from natural fibers. Paper bags are designed to lessen the impact that products have on the environment over the course of their entire life cycle [3]. Researchers from all around the world have been interested in the possibilities of natural fiber-based paper made from jute, kenaf, hemp, coir, sisal, and pineapple because of its exceptional unique qualities [4]. These fibers are renewable, biodegradable, and a potential option for environmentally friendly packaging. They are frequently derived from plant leftovers. Dried leaf and pineapple leaf fibers, two of the many natural fibers

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under investigation, have become viable options for papermaking because of their special qualities and wide availability [5].

Pineapple leaves, typically discarded after harvesting, are rich in tough, durable fibers. Pineapple by-products consist of residual pulp, peels, stem, pomace, and crown. A predictable amount of pineapple trash is produced as pineapple production rises. Every year, the increased manufacturing of processed pineapple products results in massive waste creation. Utilising pineapple trash presents a significant difficulty and contributes to environmental contamination [6]. For pineapple waste to offer value, it must be used effectively and sustainably. It promotes a non-food-based market for the agricultural industry [7]. Similarly, dried leaves, often regarded as agricultural waste, contain cellulose, hemicellulose, and lignin, essential components for papermaking. The use of dried leaf fibers presents a valuable opportunity to repurpose agricultural waste, helping to reduce environmental pollution while promoting sustainable practices [8]. These fibers, have been widely studied for various applications, including textiles and composite materials, and have also shown potential in the development of eco-friendly paper products [9].

This study aims to compare the characteristics of dried leaf fibers from the Sterculia oblongata plant with those of pineapple leaf fibers, specifically in their suitability for producing eco-friendly paper bags. Key parameters such as fiber composition, tensile strength, and papermaking efficiency will be evaluated to determine the most viable and environmentally responsible material for sustainable bag production. The primary objective is to assess the tensile strength of eco-friendly paper bags made from dried leaf fibers and pineapple leaf fibers using a Universal Testing Machine. Additionally, the study will analyze and compare the functional groups present in both fiber types using Fourier-transform infrared spectroscopy (FTIR) to identify chemical compositions that may influence the quality of the paper bags. Furthermore, the surface morphology of the paper bags will be examined using Scanning Electron Microscopy (SEM) to investigate structural characteristics such as fiber alignment, texture, and surface features.

2. Method

2.1 Materials

Pineapple leaves were harvested from a pineapple plantation in Kampung Telok Rimba, 84410 Sungai Mati, Tangkak, Johor. The pineapple leaves were cut into pieces and measured to obtain 600 g. Dried leaves from the Sterculia oblongata plant were collected in Kolej Kediaman Universiti Tun Hussein Onn Malaysia. The lamina of the dried leaves was torn from the midrib and cut into pieces. The lamina was measured at 600 g.

2.2 Alkaline Treatment

In this experiment, pineapple leaves and dried leaves were treated with sodium hydroxide (NaOH). 200 g of NaOH was dissolved in 1 litre of water to form a 5 M solution. To determine the required concentration, the mass of sodium hydroxide (NaOH) was divided by its molecular mass (g/mol). The solution was first brought to a boil before 600 grams of pineapple leaf samples were added and allowed to cook for 10 minutes. Once done, the boiling mixture was left to cool naturally for another 10 minutes. The same procedure was also carried out for the dried leaf samples. After boiling, the pineapple leaf mixture was transferred into a stainless-steel basin, where distilled water was added to dilute the remaining sodium hydroxide (NaOH) solution. The fibers were then gently rinsed with more distilled water to remove any leftover alkali. To separate the solid fibers from the liquid, the mixture was filtered using a fine-pored steel mesh. This process successfully extracted and cleaned the fibers from the pineapple leaves, making them ready for subsequent processing or analysis. The same steps were repeated for the dried leaf samples to ensure consistency across both materials.

2.3 Paper Sheet Preparation

The blended pineapple leaf fibers were placed into a kitchen blender, followed by the addition of water. The mixture was blended for approximately 10 minutes until it formed a smooth and consistent pulp. This step helped to break down the fibers thoroughly, resulting in a uniform, homogeneous texture suitable for papermaking. The same procedure was also carried out for the dried leaf samples to maintain consistency in the process.

To form the paper sheets, a handmade mould and deckle were used. The mould measured 30 cm in width and 40 cm in length. The blended pulp from the pineapple leaf mixture was stirred well before being poured onto the screen of the mould, which was secured beneath the deckle to shape and contain the pulp during sheet formation. A quick back-and-forth and side-to-side shaking motion were performed to align the pulp uniformly on the mould. Additionally, rollers were used to evenly distribute the pulp across the surface. The fibres were dispersed in clean water, and the paper mould served to extract the fibres from the water, forming the sheets. The same method was repeated for the dried leaves sample mixture. Both mould and deckle for each sample were placed horizontally, allowing water to drain completely for 10 minutes. Each wet pulp was then

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transferred to a board to dry under the sun for a day. Once the paper was completely dry, the edges were carefully peeled off the paper mould.

2.4 Developing an Eco-paper Bag

To make a paper bag with 17.5 cm × 7.5 cm × 28 cm, two paper sheets measuring 25 cm wide and 35 cm long were used. Fig. 1(a) shows that two sheets of paper are bound together to become 46 cm. The bound paper will be 35 cm long and 23 cm wide. Fig. 1(b) shows that both sides of the edge, by 4 cm are measured and folded, and measured from the bottom by 9 cm and folded to make the base of the bag. The final paper bag is shown as Fig. 1(c).



(a) **(b)** **(c)**

Fig. 1 *(a) Paper are binded together; (b) paper bag; (c) final paper bag*

2.5 Mechanical Properties Testing: Surface Morphology

The morphological surface of paper made from pineapple leaf fiber and dried leaf fiber was observed using a Scanning Electron Microscope (SEM). The SEM analysis was conducted at an accelerating voltage of 10 kV to minimize damage to the paper. The surface morphology was examined under 200× and 500× magnifications, which were increased to zoom in and observe details. Images of the surface morphology were captured for both paper samples to compare their characteristics.

2.6 Strength Testing: Tensile Strength

The evaluation of tensile strength of eco-friendly paper bags made from dried leaf fiber and pineapple leaf fiber were tested using a universal testing machine (UTM) at a constant speed of 50 mm/min. The test was performed to determine tensile properties such as Maximum Load (N), Deflection at Maximum Load (mm), Stress at Maximum Load (MPa), Strain at Maximum Load (%), and Young's Modulus which were used to calculate the tensile strength. The same procedure ware repeated for dried leaf fiber.

2.7 Chemical Properties Testing: Fourier-Transform Infrared Spectroscopy (FTIR)

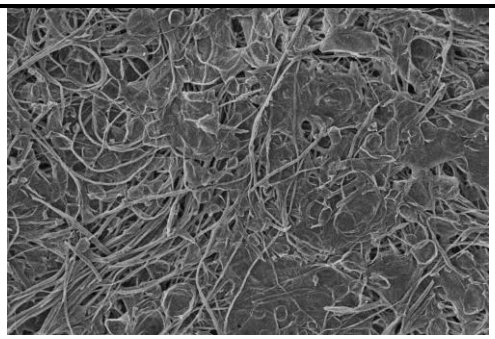
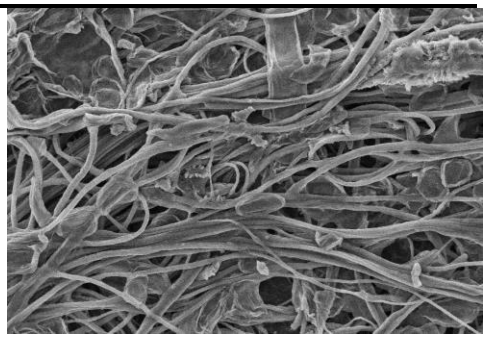
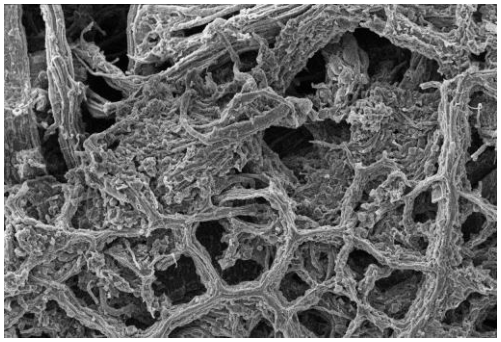
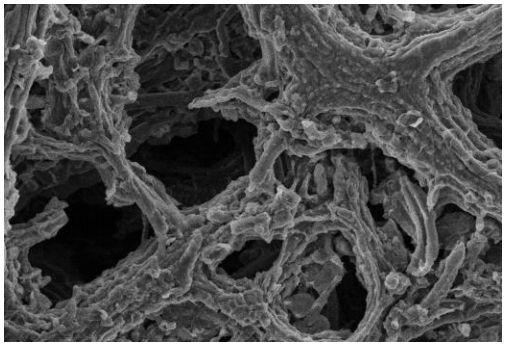
The characterization for functional groups presents in the paper from dried leaves fiber and paper from pineapple leaf fiber to identify the chemical composition that may influence the eco paper bags quality was performed by FTIR (Fourier-transform infrared spectroscopy) (Angilent tech cary 600 series) under wavelength range between 600 to 4000 cm^{-1}. Two paper samples from different leaf fiber which are pineapple leaf fiber and followed by dried leaves fiber were characterized.

3. Result and Discussion

3.1 Surface Morphology

Table 1 shows that at 200× magnification, the morphological differences between PALF and dried leaf fiber are already distinguishable.

Table 1 *Comparison of surface morphology of PALF and dried leaf fiber*

Sample	200× Magnification	500× Magnification
PALF		
Dried Leaf Fiber		

Pineapple leaf fiber displays a dense network of fine, continuous fibers with some visible entanglement, indicating a relatively intact and cohesive structure. This suggests good potential for fiber bonding, even at lower magnification, due to the uniformity and preserved fiber length. In contrast, dried leaf fiber at 200× appears coarser and more disrupted, with signs of fragmentation and uneven texture, indicating possible degradation and weaker structural integrity.

At 500× magnification, the SEM analysis clearly highlights distinct morphological differences between pineapple leaf fiber and dried leaf fiber. The pineapple leaf fiber presents a rough, entangled structure with fibers arranged in a random orientation. Although the alignment appears disordered, the fibers' continuous and elongated forms contribute positively to inter-fiber bonding during the papermaking process. This improved bonding is likely due to the increased effective surface area and roughness created after the partial removal of lignin and hemicellulose through the alkaline treatment [10]. The enhanced surface roughness supports stronger adhesion between fibers, which is essential for producing structurally stable paper sheets. Furthermore, the presence of moderate voids between the fibers may help improve breathability without greatly compromising mechanical strength. While some non-fibrous residues are visible, the overall fiber integrity remains well-preserved, making pineapple leaf fiber a promising material for eco-friendly paper bags with acceptable tensile strength and durability.

On the other hand, dried leaf fiber exhibits a more fragmented and damaged morphology. The fibers appear broken, irregularly shaped, and loosely arranged, leading to high porosity and weak structural cohesion. This compromised structure limits the fibers' ability to interlock and form strong bonds, which are crucial for manufacturing durable paper. Natural fibre pre-treatments help eliminate surface pollutants [11], chemically modify the surface, minimise moisture absorption processes, and increase surface roughness [12], [13]. The significant number of voids and the disrupted surface suggest that the material may not possess the required strength for paper bag applications. Although the high porosity may enhance biodegradability and reduce

overall weight, these benefits are offset by reduced mechanical performance. In summary, pineapple leaf fiber demonstrates superior structural consistency and bonding capability compared to dried leaf fiber, making it more suitable for producing strong and sustainable paper bags. While dried leaf fiber offers advantages in biodegradability, it may require reinforcement or combination with stronger fibers to ensure functional reliability in practical use.

3.2 Tensile Strength Data

Table 2 displays the mechanical characteristics of papers made from pineapple leaf fiber and dried leaf fiber.

Table 2 *Comparison of tensile properties of PALF and dried leaf fiber*

Sample	Maximum Load (N)	Deflection at Maximum Load (mm)	Stress at Maximum Load (MPa)	Strain at Maximum Load (%)	Young's Modulus (MPa)
PALF	56.737	1.1870	0.0103	3.957	0.521
Dried Leaf Fiber	14.358	1.3299	0.0026	4.429	0.173

The pineapple leaf fiber paper recorded a distinct maximum load of 56.737 N at a deflection of 1.1870 mm, indicating a strong load-bearing capacity with limited deformation. In contrast, the dried leaf fiber paper reached a much lower peak load of 14.358 N and a slightly higher deflection of 1.3299 mm. The sharper rise and earlier failure in the pineapple fiber paper reflects higher stiffness and internal structural integrity, likely due to a denser and more aligned fiber network enhanced by alkaline treatment. Meanwhile, the broader load-deflection behaviour in the dried leaf paper suggests a weaker and more flexible structure with less cohesive fiber bonding.

The stress and strain data in Table 2 also shows that the pineapple leaf fiber paper achieved a maximum stress of 0.0103 MPa at a strain of 3.957%, while the dried leaf fiber paper only reached 0.0026 MPa at 4.429%. Although both samples failed at nearly the same strain, the higher stress sustained by the pineapple fiber paper suggests greater molecular bonding and improved load distribution within the fiber matrix. This could be attributed to the removal of lignin and hemicellulose during the alkaline treatment, which improves fiber exposure and interaction, enhancing tensile performance. The untreated structure of the dried leaf fiber limits its stress-handling capability and results in poor mechanical resistance.

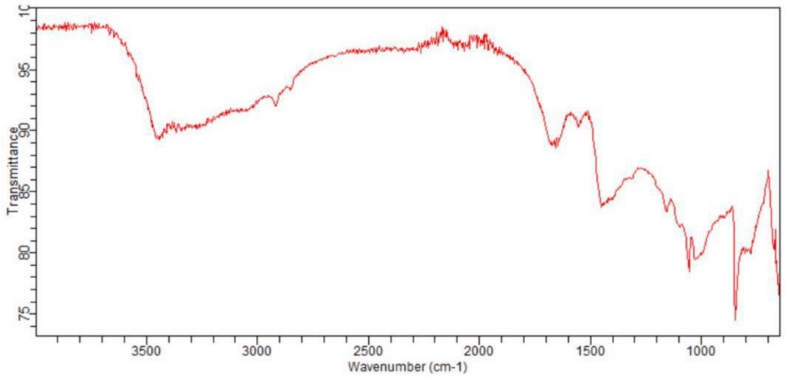
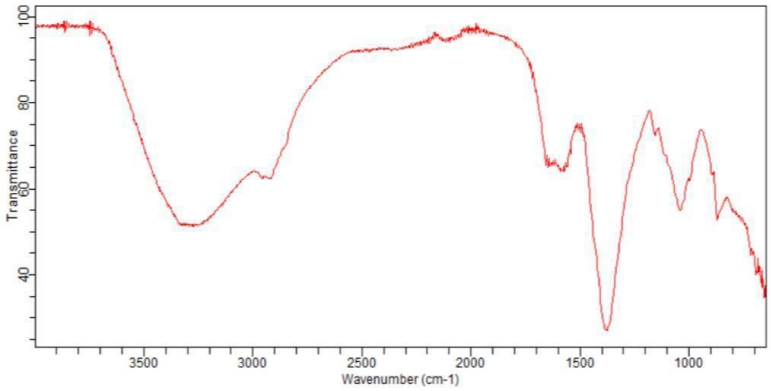
Stiffness comparison through Young's Modulus in Table 2 further supports the mechanical superiority of the pineapple leaf fiber paper, which recorded 0.521 MPa compared to just 0.173 MPa in the dried leaf fiber paper. This suggests that the pineapple fiber sheet is much more rigid and resistant to elastic deformation, showing a strong, well-bonded fiber structure. The lower modulus of the dried leaf paper indicates a more compliant and loosely packed fiber network that deforms more easily under tensile stress.

In summary, there are several factors that have affected mechanical properties of PALF have been studied in this work, included effect of surface treatment. According to [14], because the binding materials, hemicellulose and lignin, were partially eliminated during alkaline and heat treatment, the interfibrillar region became less dense and rigid. This allowed the fibrils to reorganize along the direction of tensile deformation, which improved load sharing and increased the development of stress fibers. These findings are consistent with study [12], which showed that PALF-based polymer composites exhibit superior stiffness and strength compared to other cellulose-based composites. The eco-paper made from pineapple leaf fiber significantly outperforms paper made from dried leaf fiber in terms of strength, stiffness, and structural stability. The improved performance of the pineapple-based paper can be linked to alkaline treatment that enhances fiber alignment and bonding, whereas the lack of treatment in the dried leaf fiber results in weaker inter-fiber cohesion and reduced mechanical integrity.

3.3 Chemical Composition

Table 3 shows the FTIR spectrum of pineapple leaf fiber PALF, which presents a broad O–H stretching peak at approximately 3330 cm^{-1}, indicating the presence of hydroxyl groups typical of cellulose and lignin.

Table 3 *Comparison FTIR spectrum of PALF and dried leaf fiber*

Sample	FTIR Spectrum
PALF	
Dried Leaf Fibre	

A sharp C– H stretching peak at 2915 cm^{-1} confirms the presence of aliphatic structures from cellulose and hemicelluloseA moderate peak appearing around 1735 cm^{-1} is associated with the C=O stretching vibration of ester bonds, which are typically found in hemicellulose. Meanwhile, the aromatic C=C stretching observed near 1605 cm^{-1} is a distinctive feature of lignin. Additional peaks around 1245 cm^{-1} and 1030 cm^{-1} represent the C–O and C–O–C stretching vibrations, further confirming the presence of both cellulose and lignin within the fiber structure. This happened because Alkaline processing has a direct effect on cellulose fibril size, polymerization degree, and extraction of lignin and hemicellulose compounds [15].

When compared to this, the FTIR spectrum of the dried leaf fiber shows similar peaks, but with higher intensity in several key regions. The O–H stretching band near ~3340 cm^{-1} is broader and more intense, which suggests stronger hydrogen bonding and a potentially higher concentration of hydroxyl groups. Moreover, the C=O stretching peak around 1720 cm^{-1} appears more prominent than that of the pineapple leaf fiber (PALF), indicating that the dried leaf fiber may contain a higher amount of hemicellulose. The aromatic C=C peak at ~1610 cm^{-1} is also stronger, showing a relatively higher lignin presence in dried leaves. Peaks at ~1230 cm^{-1} and 1030 cm^{-1} again indicate the presence of C–O and ether linkages within the lignocellulosic matrix.

Comparatively, both samples contain cellulose, hemicellulose, and lignin, but dried leave fiber shows greater intensities in regions associated with hemicellulose and lignin, suggesting a more complex or denser natural structure than PALF. From an alkaline treatment perspective, such treatment typically reduces or removes hemicellulose and lignin, which would result in weaker or absent C=O and C=C peaks. The same outcome and result show, according to [16], that hemicellulose can be removed more effectively with alkali treatment than lignin, and that hemicellulose has a structure that is easily removed.

However, since these peaks are still clearly visible, especially in dried leaves, it suggests that no alkaline treatment was applied or the treatment was insufficient to significantly alter the fiber's chemical composition.

Thus, both fibers remain in their natural lignocellulosic state, which should be considered in applications requiring fiber modification or reinforcement.

4. Conclusion

Pineapple leaf fiber (PALF) shows greater potential than dried leaf fiber for producing eco-friendly paper bags. PALF paper recorded a maximum load of 56.737 N, deflection of 1.1870 mm, stress of 0.0103 MPa, strain of 3.957%, and Young's Modulus of 0.521 MPa, all of which were higher than the values obtained from dried leaf fiber. SEM analysis revealed that PALF has a more continuous and intact fiber structure, while dried leaf fiber appeared fragmented and porous. FTIR results also confirmed better chemical composition in PALF due to alkaline treatment, with reduced lignin and hemicellulose content. This research highlights the effective use of agricultural waste, offering a sustainable alternative with better mechanical and structural properties. To further improve performance, future work should use distilled water during blending, as it ensures fiber cleanliness and prevents the presence of impurities or minerals commonly found in tap water that may affect fiber bonding. Researchers should also explore different types or stages of pineapple leaves, apply simple pre-treatments like alkaline soaking, and consider adding a natural wax coating to enhance water resistance and durability for practical use.

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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 authors confirm contribution to the paper as follows: ***study conception and design:*** *Norbaizura Nordin, Iman Fitri, Nurain Zulaika, Alya Afifah;* ***data collection:*** *Iman Fitri, Nurain Zulaika, Alya Afifah;* ***analysis and interpretation of results:*** *Norbaizura Nordin, Iman Fitri, Nurain Zulaika, Alya Afifah;* ***draft manuscript preparation:*** *Norbaizura Nordin, Iman Fitri, Nurain Zulaika, Alya Afifah. All authors reviewed the results and approved the final version of the manuscript.*

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