



EVALUATION OF EDWUMA PA FIBRE EXTRACTION MACHINE FOR SISAL AND BANANA LEAVES: A SUSTAINABLE APPROACH FOR TEXTILE APPLICATIONS

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ABSTRACT

Purpose: This study assesses the effectiveness of a mechanical extraction machine designed for sisal and banana leaves in producing natural fibres.

Design/Methodology/Approach: This study uses experimental research with a mechanical extraction machine to get fibres from banana and sisal leaves. Testing equipment like a scale, microscope, and strength machine is used to analyse the fibres. Flexure analysis is used to optimize the design to achieve a balance between performance, sustainability, and reliability.

Findings: Through analysis of extracted fibres' tensile strength and diameter, as well as extraction efficiency, the study reveals that both banana and sisal leaves hold promise for fibre yield. Banana fibres exhibit a diameter of 0.102mm and tensile strength ranging from 175.71 N/mm² to 423.934 N/mm². In comparison, sisal fibres have a diameter of 0.1mm and tensile strength between 190.96 N/mm² and 1489.50 N/mm².

Research Limitation/Implications: This research underscores the potential for utilizing locally available natural fibres for textiles and industry, exploring the challenges and prospects of mechanical extraction systems for fibre.

Practical Implications: It aligns with the global push for sustainable textiles and offers insights into improving efficiency and viability, essential for integrating natural fibres into the textile sector.

Social Implications: This emphasis on sustainable practices can lead to increased awareness within local communities about the importance of preserving natural resources and ecosystems.

Originality/Value: The flexure analysis conducted in this study unveils the structural resilience of banana and sisal fibres.

Keywords: *Banana fibre. fibre yield. mechanical extraction. sisal fibre. sustainable textiles*

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INTRODUCTION

The term “sustainable textile” refers to a strategy being utilized by environmentalists to encourage the manufacturing of textiles from environmentally friendly resources (Yang et al., 2020). To protect the body from either cold or heat in various climatic conditions, a particular sort of textile must be used (Omer & Huang, 2018). This has highlighted the research of the most effective natural textile alternatives for either utilitarian or industrial textiles.

Natural fibres are an essential material in many industries such as textiles, paper, wood and other composites. Among the different natural fibres, banana and sisal leaf fibres have attracted significant attention due to their unique properties such as high tensile strength, high rate of absorption, low density, and biodegradability. Banana (*Musa sapientum*) and plantain (*Musa paradisiacal*) are widely cultivated in the whole wide world but abundantly as a natural resource in tropical and subtropical countries purposely for their fruits for consumption, According to Shahbandeh, (2020) 72.5 million tons are produced annually and experimentation and research have made it possible to utilise almost every part of the plant from the leaves, shoots, and especially the pseudo-stem which will otherwise remain and rot on the farms (Subagyo & Chafidz, 2016).

Though extraction of these fibres from the plant is a labour-intensive and time-consuming process, it requires specialized equipment and techniques to make it easy. The traditional process of fibre extraction for leafy plants especially banana and sisal fibres are manually achieved which involves cutting the leaves into small pieces, soaking them in water or chemicals, and then separating the fibres by hand or beating them up with a mallet, (Kozlowski & Wang, 2011). For mass production, this method is labour-intensive and time-consuming and can lead to low fibre yield and quality. Thus, mechanical methods of fibre extraction have been developed to automate the process and increase efficiency. These methods include decortications, fibre separation, and cutting. (Oreko, Okiy, Emagbetere & Okwu, 2018) For many years, the mechanical extraction of fibre from crops has attracted attention. (Rasheed et al., 2019). Research has focused in particular on the extraction of fibre from banana and sisal leaves because of their potential use in the textile industry. (Ghavami et al., 2020). For this aim, several mechanical extraction machines have been created although their effectiveness and performance have not been properly examined.

This study intends to assess the efficiency of a mechanical extraction device made for sisal and banana leaf fibre. The machine’s effectiveness in terms of fibre yield and quality, as well as the operational factors that influence its performance, will be the main subjects of the evaluation. The results maximize the machine’s design and operation, leading to enhanced fibre production and possibly increasing the economic viability of banana and sisal leaf fibre extraction. The emerging fibre’s output, fineness, strength, and other quality parameters are assessed. To access the quality of the extracted fibre, findings of results from fibre characterization will serve as reliable evidence for providing critical information about the design and operation of mechanical

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extraction machines for banana and sisal leaf fibre (Wang et al., 2021). The abundance of this fibre in Ghana, as well as the likely extraction machine, will allow researchers and engineers to use the findings to improve the performance of the extraction machines and advance the use of this natural fibre in the textile industry.

OVERVIEW OF BANANA FIBRE

Bananas are among the earliest cultivated plants in the world, as is widely known. The Arabic word "banana," which meaning "finger," is its source. There are about 300 species in the Musaceae family, however about 20 of them are cultivated for usage (Castañeda Niño, Mina Hernandez & Valadez González, 2021). Tropical and subtropical regions of the world produce about 102 million metric tonnes of bananas annually (Vu, Scarlett, & Vuong, 2018).

Since it is abundant in tropical regions like Ghana and Nigeria where bananas are grown in large quantities, banana fibre is an easily accessible byproduct of banana farming. Among its many benefits, this fibre outperforms synthetics in terms of mechanical strength. Since Ghana exported 65,000 tonnes of banana (BusinessNews, 2018) and stems in the last five years, there is the possibility of producing more sustainable fibres for the Ghanaian market and some West African nations by taking into account the demand for more ropes, agricultural sacks, and reinforced composites for innovative constructional material. The availability of the stem will therefore be advantageous for mass manufacturing if the extraction machine is efficient and reliable to extract a large number of fibres in a short amount of time.

Furthermore, the sustainable fashion industry is actively pursuing the development of fabrics made from ecological yarns in response to the increasing demand for sustainable products. Several multinational corporations have initiated investments within sustainable product categories (Cecci, Passos, de Aguiar Neto & Silva, 2020).

Several studies (Khan, Srivastava & Gupta, 2018; Kenned, Sankaranarayanan, Binoj & Chelliah, 2020; Sumesh & Kanthavel, 2022) have been conducted to forecast the different mechanical characteristics, such as tensile strength and flexure strength, of banana fibre and banana fibre combined with polymers.

Both human and mechanised methods exist for extracting the essential natural fibre from plants, but extreme caution must be exercised to prevent any harm. A composite reinforced with banana fibres has low density, which results in high tensile modulus, low elongation at break, and high tensile strength (Ramesh, Atreya, Aswin, Eashwar & Deepa, 2014). With the right, cost-effective design approach to fibre separation and composite production, banana fibre and composites could become even more appealing.

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When polymers absorb moisture, their physical and mechanical qualities are affected. Changes in temperature and moisture content can impact banana fibres. Composite materials that include hemp fibre in addition to a concrete matrix have a decreasing water absorption ratio and linear specific gravity.

Figure 1 provides a visual representation of the cross-sectional area of a banana stem, highlighting its various components. In this illustration, the internal structure of the banana stem is depicted in a sliced view (cross sectional area), revealing the arrangement of different parts. These parts include the outer protective layer, known as the epidermis, which serves as a shield against external elements. Beneath the epidermis lies the cortex (middle layer), a region responsible for storing nutrients and water. Deeper within the stem (inner layer), the vascular bundles are visible, encompassing both the xylem, responsible for water transport, and the phloem, responsible for nutrient transport which constitute the core. This intricate organization showcases the complexity of the banana stem's internal composition and provides valuable insights into its potential uses and properties, particularly in terms of fiber extraction and textile applications.

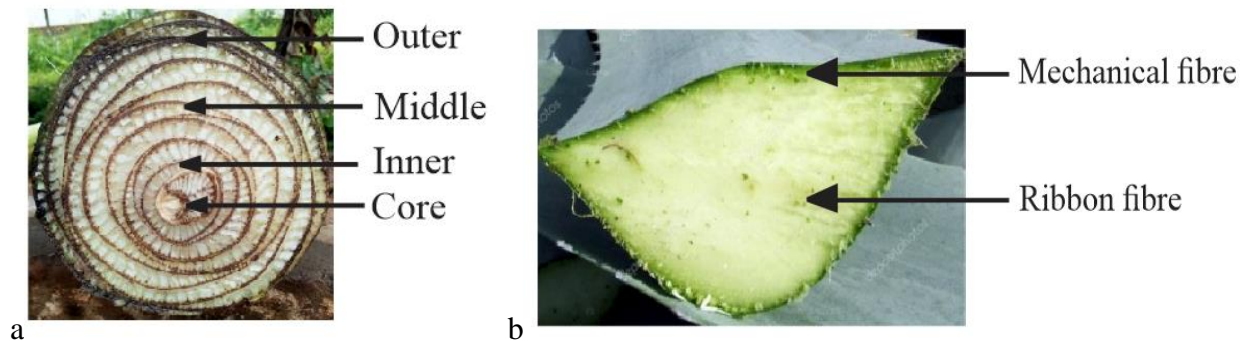


Figure 1: Parts of the cross-sectional area of banana stem

MATERIAL AND METHODS

This study uses experimental research with a mechanical extraction machine to get fibres from banana and sisal leaves.

Materials:

- i. Mechanical extraction machine
- ii. Fresh banana and sisal leaves
- iii. Weighing scale
- iv. Plastic containers
- v. Measuring cylinder
- vi. Water



Methods:

- i. Collection and Preparation of Materials: Fresh banana and sisal leaves were obtained and stored in plastic containers.
 - a. Harvesting: The initial step involves harvesting banana or sisal leaves, which can be done manually or with the use of a cutting machine.
 - b. Stripping: Subsequently, the leaves are stripped of their outer layers to expose the fibers, either through manual stripping or by employing a stripping machine.
 - c. Washing: The stripped fibers are washed to eliminate impurities such as dirt and sap. The leaves are then cleaned and cut into appropriate sizes to ensure effective extraction.
 - d. Decorticating: The dried fibers are fed into the decorticating machine, where they undergo beating and crushing processes to separate the fibers from the pith and other undesired materials.
 - e. Sorting: Following decorticating, the separated fibers are sorted based on their quality and fineness attributes.

- ii. An electronic sensitive scale was used to weigh the leaves before and after extraction to determine the weight of the fibres extracted.
 - a. “Edwuma pa” fabricated mechanical extraction machine was used to extract the fibres from the leaves.
 - b. *ZEISS EVO MA15* scanning electron microscope (SEM) image analysis from the University of Mine-Takwa – Ghana was used to analyse the surface of the material.
 - c. A universal tensile strength machine (Mark 10 ESM301L) from the University of Ghana-Legon, material science laboratory was utilised to check the strength of the single fibres to examine their strength for mechanical operation.

Fabrication material

This represents a raw material that undergoes processing or shaping to achieve the required dimensions essential for the optimal functioning of the component.

The fibres were extracted from sliced strips of banana stem that were fed through a pair of squeezing and scraper rollers. Manual combing was employed to eliminate any excess pith from the fibers.



Table 1: Parts and functions of the mechanical extraction machine

S/N	Material	Functional Part
1	2" angle iron	The superstructure of the work.
2	0.1 iron plate	The covering of the framework (the side spout/the top covering of the machine)
3	¾ iron rod	Support to the revolving blade for extraction.
4	50mm rod	The rod is cut to form the spindle of the revolving roller.
5	2" by 0.5" flat bar	The Feed-in blade is fixed between the revolving blade. This is adjustable depending on the size of the raw material to be extracted.
6	5mm plate	Cut to form the support for the revolving blade.
7	Bearings	Spoke to the revolving disc for easy movement by the pulley.
8	Pulley 1:2 ratio	A motion which generates movement from the motor at 1800rpm. The ratio segregation is to reduce speed.
9	1.5 horsepower single-phase motor	This motor is an average speed to propel the revolving disc to enable it to extract the fibres.
10	Switch	A plug is made to effect a change in power or switch on the machine or put it off.
11	Bolt & nuts (12" type)	This was used mount to enable the operator to dismount certain parts for cleaning or maintenance.
	Electrodes and electric welding machine	A device for joining metal parts permanently to attain mechanical strength.

Description of machine parts

The biggest pulley is fixed on the revolving disc while the smaller pulley is fixed on the motor. The adjustable blade at the feed-in point is set right between 0.1-0.2mm for the extraction. The motor is switched on and motion is transmitted via a belt to the revolving disc.

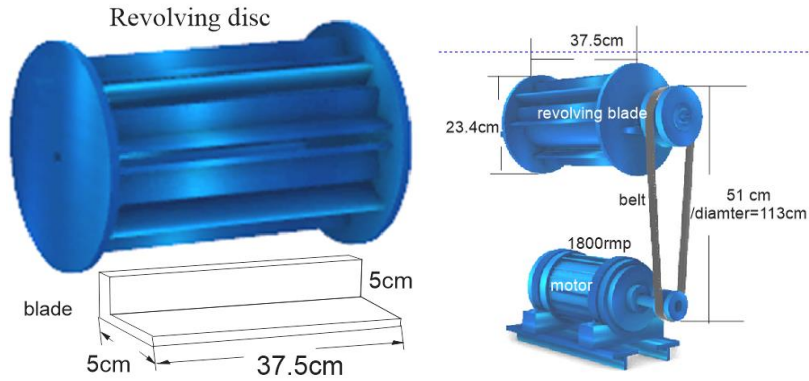


Figure 2: Motion transmission of the extraction machine

This speed is limited and reduced by the sizes of the pulley arrangement; a 2:1 ratio

New Motor Speed = Motor Speed / Pulley Ratio

where:

Motor Speed = 1800 rpm (the initial motor speed)

Pulley Ratio = 2:1 (the ratio of the pulley and the motor)

Substituting the values into the formula, we get:

New Motor Speed = 1800 rpm / 2

New Motor Speed = 900 rpm

Therefore, the motor speed after the reduction using a 2:1 pulley is 900 rpm



Figure 3: Banana and sisal fibre extraction machine



Types of Cost Estimation:

Table 2: Material cost for construction of “edwuma pa” extraction machine

Material	Cost (GH¢)
2” angle iron	120
2mm iron plate	125
¾ iron rod	45
50 mm rod (400mm long)	30
2” by 0.5” flat bar	35
5mm plate	130
2 Bearings	90
Pulley	30
1.5 horsepower single-phase motor	350
Switch/cable	120
Bolt & nuts (12” type)	30
Electrodes and electric welding machine	35
Miscellaneous	200
TOTAL	1340

Using material cost estimation, the overall cost necessary to purchase the raw material, which must then be processed or produced to the desired size and functioning of the components, is determined. The resources in this collection fall into two categories. This cost estimate makes an effort to predict overall expenses, which could also include material and manufacturing prices. Cost estimation for manufacturing components can be viewed as a decision that is made after carefully weighing the labour, supplies, and factory services needed to make the desired product. By adding up the price of the fundamental supplies bought one can obtain the value of the materials of the machine fabricated.

Operation of the machine

The leafy stem is cut into a moderate size of at least 24 inches long and 4 inches wide. This is fed between the adjustable blade and revolving disc. The fibre must be held very tight making sure all safety equipment is worn for the protection of the eyes and the body. Banana sheaths are fed between the revolving disc 0.2mm and the feed-in blade. The thickness of the sheath of 0.5 mm is fed between the feeding-in point. The speed of the revolving blade constantly hits and removes the pulpy part of the stem thereby separating the fibres from the rest of the bark. It is important to note that one has to feed in with the back of the leaf facing upwards for effective extraction. The adjustable blade is regulated to conform to the thickness of the fibre sheath for the extraction process as shown in figure 4

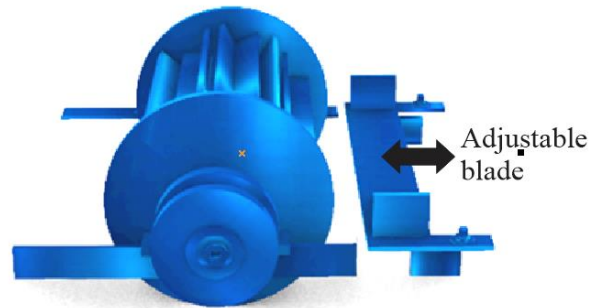


Figure 4: Adjustable blade and roller for feeding-in of the leafy fibre

During this process of beating up the fibres, a pneumatic force is generated between the lower receptacle plate and the revolving disc which causes the fibres to glide around the revolving roller for further beating and crushing as shown in fig. 5 a and b

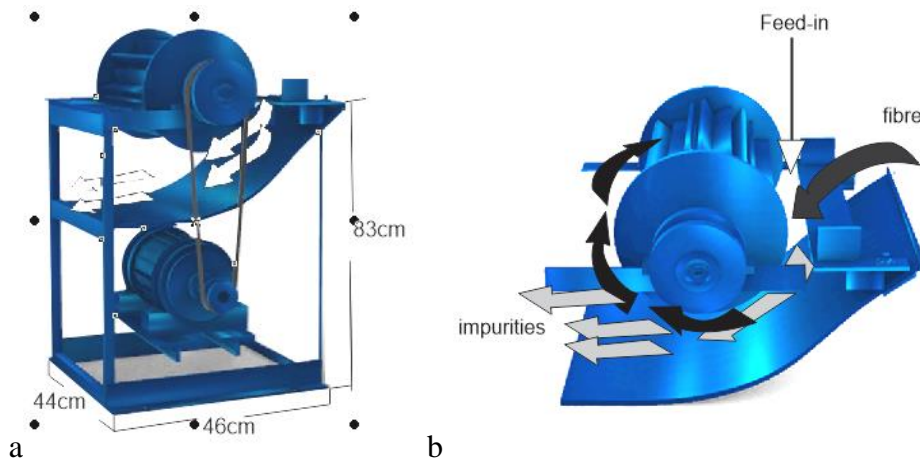


Figure 5: Movement of the fibres and impurities in the extraction machine

This force pushes the bunch of fibres to glide over the roller as illustrated with the black arrow in figure 5b. The pull and feed-in motions must be carefully observed to ensure effective extraction. A loose handling of the fibre may pull the fibres from the operatives' hands and the trash can. A Series of feeding-in and withdrawal renders effective extraction.



Figure 6: Extracted (a-banana; b-sisal) fibres

It is important to take into consideration the length of the banana or sisal fibre for extraction. If the length is longer than the revolving drum, it may wrap around it and may be difficult to pull. If it is too short, the middle part of the fibre may not be extracted.

Space Consideration:

Robust materials were used to construct the machine and per the size, eight (8) machines can occupy a space of 16 by 16 feet long room. This is to enable the high capacity of production to minimize accidents and allow the free movement of personnel within the space.

Safety Precautions:

The following factors should be taken into account for safe machine use and to prevent accidents:

- i. Verify that the machine's components are correctly aligned.
- ii. Verify that every bolt and nut is firmly attached.
- iii. The operational switch should be positioned at a comfortable distance from the user to control the machine with ease.
- iv. The equipment has to have frequent inspections and maintenance.

Data Analysis

Flexure analysis is used to optimize the design to achieve a balance between performance, sustainability, and reliability. Ensure that bending stresses remain within acceptable limits to prevent material failure and maintain the longevity of the machine. The analysis focus in understanding how the machine components deform under applied loads, and maintaining structural integrity.

RESULTS AND DISCUSSION

This section presents the results and discussion of the paper. This includes the efficiency of the machine, effects of the extraction machine on the fibre and the tensile strength of the materials under consideration.

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Calculating the efficiency of the machine

The roller is revolving at 900rpm (revolutions per minute). The distance between the roller and a grid bar is 0.1mm. A banana sheath with a thickness of 4mm is fed between the roller and the grid bar at 40mm/s.

Determining the Efficiency of the machine

Extraction at a feed-in speed of 40mm/s

$$\text{Efficiency} = (\text{Weight of extracted fibres} / \text{Weight of banana sheath fed into the machine}) \times 100\% \quad 1$$

$$\text{Wastage percentage} = (\text{Wastage} / \text{Total input}) \times 100 \text{ Wastage percentage} \quad 2$$

Table 3: Efficiency of the extraction machine per part of the banana stem

Stem part	Extraction of Sample at (330g)	Efficiency rate %	Wastage (%)
Outer	27.9g	8.45%	91.55
Middle	124g	37.58%.	62.42
Inner	170g	51.5%.	48.5

Table 4: Efficiency of the extraction machine per part of the sisal leaf

Sample	Extraction of Sample (g)	Efficiency rate %	Wastage (%)
1 (370.34g)	184.3	49.76	50.24
2 (379.67 g)	197.8	52.10	47.9
3 (410.86g)	201.45	49.03	50.97

Effects of The Extraction Machine on The Fibre

A series of six hard metal blades running at a velocity of 900rpm/s hits against the fragile soft protected fibres of a pulpy part to reveal the beautiful fibres have direct effects on the fibres. The SEM image at 20kV and a with a magnification of between 63x to 2.61Kx magnification at a 12.5mm distance shows the various levels of damage to the surface of the fibres.

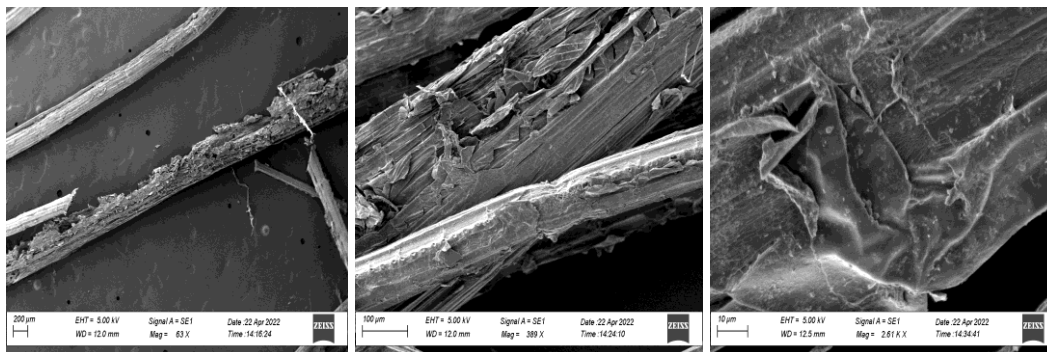


Figure 7: SEM image between 63x and 369x

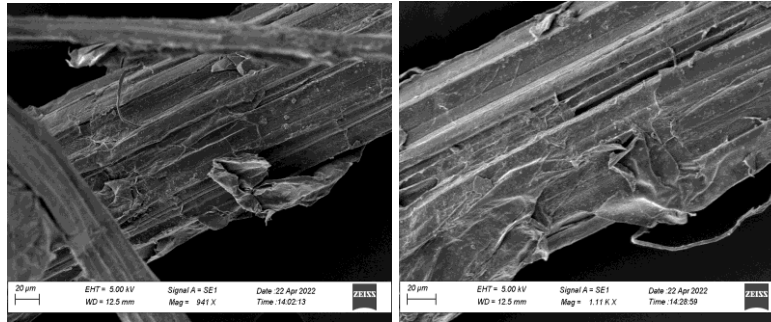


Figure 8: SEM revealing layers of fibrils that constitute the fibre 1.11kx

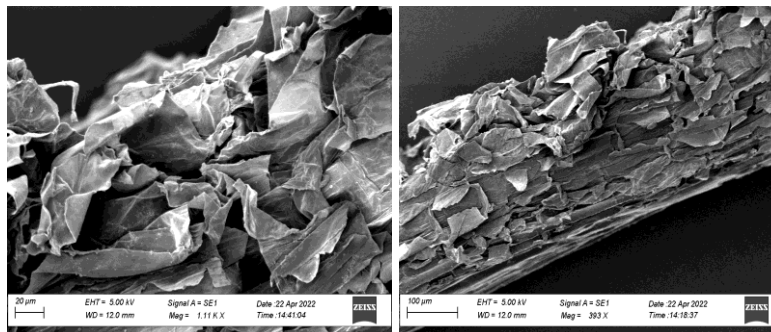


Figure 9: SEM of scrapped surfaces 393x

In Figures 7 to 9, it can be observed that the blade has scratched the surface revealing the layers of fibre which constitutes the fibre structure. The scraped surface reveals physical evidence of wear and tear, such as surface cracks and rips. A rough and uneven surface with exposed fibres and contaminants that were left behind during the extraction procedure may also be present. There can also be indications of fibre breakage or distortion, which might impair the strength and quality of the final fibres. Overall, cautious handling and improved extraction techniques are essential to reduce fibre damage and enhance fibre quality, as seen in these SEM pictures. The finding is in consistent with that of Andrew and Dhakal (2022) who confirmed that difficulty in handling, and poor mechanical behaviour tends to affect the quality of the fibre. Added that fibres during the fabrication process is another vital issue in the manufacturing of biocomposites

To support this deformation of the fibre surface, a fibre strength was undertaken and it revealed the different states of fibre rupture and test failures as shown in Tables 5 and 6.



Tensile Strength of Banana and Sisa Fibres

Table 5: Tensile strength of single-strand banana fibre.

s/n	Diameter (mm)	Area (mm ²)	Ultimate Force (N/mm ²)	Ultimate stress (N/mm ²)	Breaking Distance (mm)
1	0.1	0.00786	3.330	423.934	45.9
2	0.11	0.00950	1.67	175.71	18.7
3	0.09	0.00636	1.67	262.47	1.37
4	0.11	0.00950	1.67	175.71	1.87
5	0.1	0.00786	1.7	216.42	1.84
Average	0.102	0.00822	2.01	250.85	13.94

Table 6: Tensile strength of single-strand sisal fibre

s/n	Diameter (mm)	Area (mm ²)	Ultimate Force (N/mm ²)	Ultimate stress (N/mm ²)	Breaking Distance (mm)
1	0.1	0.00786	1.5	190.96	2.61
2	0.11	0.00950	12.8	1346.72	5.95
3	0.08	0.00503	6.5	1292.97	5.94
4	0.11	0.00950	11.3	1188.90	5.5
5	0.1	0.00786	11.7	1489.50	5.33
Average	0.1	0.00795	8.76	1101.81	5.07

The tensile strength range from 175.71 – 423.934 N/mm² for banana far less strong as compared to sisal whose strength ranges from 190.96 – 1489.50 N/mm². the low variables could be because of such deformation on the surface of the material, ageing, temperature, and degree of loss of moisture content. The more prevailing cause could be the destruction of the surface due to the mechanical operations. These results were in agreement with the findings of Kipchumba, (2022) which showed that improved interfacial bond strength between surface-modified lignocellulosic fibres and polymeric matrices results in composites with better strength properties.

CONCLUSION

The tensile strength and diameter, as well as extraction efficiency, the study reveals that both banana and sisal leaves hold promise for fibre yield. The findings reveal promising tensile strength and extraction efficiency, emphasizing the feasibility of integrating these fibres into the textile sector to promote sustainability.



The use of sustainable textiles is a priority for those who are more environmentally conscious; to reduce the environmental impact of textile production. In a tropical country like Ghana, the climate necessitates the use of breathable materials, and alternative natural textiles need to be researched for practical and industrial applications. Natural fibres like sisal and banana are underused while cotton and linen are frequently used in the textile industry, despite their potential for use. The development of mechanical extraction machinery can increase the economic feasibility of these fibres, taking into consideration the diversification of the material for easy access and effective use.

Evaluation and performance of the mechanical fibre extraction mechanism fabricated for banana and sisal leaves are aimed at efficiency and quality. The fabricated product is for widely available untapped leafy natural textile fibres in the Ghanaian ecological environment for the textile sector and recommendations for future development and performance of the machine. The novelty of the paper lies in the flexure analysis conducted, it unveils the structural resilience of banana and sisal fibres. The fibres exhibit a surprising capacity to withstand bending stresses, indicating their suitability for various textile applications.

Practical Implications

Manufacturers and textile designers can consider integrating sisal and banana fibers into their materials portfolio, taking advantage of their promising tensile strength. These fibers can be used alongside traditional materials, providing an eco-friendly alternative without compromising on strength.

In terms of the economic effects on machines and usage, sisal and banana farms would be more productive with the development and application of mechanical sisal and banana fibre extraction gear.

Social Implications

The integration of sisal and banana fibers into the textile sector could lead to increased demand for these natural resources. This, in turn, may create job opportunities in the agricultural and extraction sectors, particularly in regions where these fibers are cultivated. This can contribute to community development and poverty alleviation.

By way of recommendation, further study is needed to develop mechanical extraction systems that are more efficient and less expensive. Ultimately, employing sustainable textiles can contribute to the textile industry's future sustainability and the economic development of the local farming communities involved in the cultivation and production of raw materials.



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