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Development of a Low-Cost Banana Fiber Extractor

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Abstract:- Banana fiber is an underutilized natural resource with potential for industrial applications and value addition at the smallholder farm level. Traditional manual methods for extracting fibers from banana plant wastes are inefficient and labour-intensive. This limits opportunities for rural communities in Africa to commercialize banana cultivation. The study aimed to address this challenge by developing an affordable and effective mechanized solution for extracting banana fibers tailored to small farms. Key design considerations included ease of operation, portability, durability, and optimization for a single operator. Fabrication using basic workshop tools demonstrated technical feasibility. Structural analysis validated structural integrity. Performance testing showed 85% extraction efficiency at 5.36kg/sec, outpacing manual methods. Results confirm the potential of the machine to promote higher fiber yields. With further refinement, the developed technology can stimulate enterprise and industry centered on banana production, contributing to improved rural livelihoods on the continent.

Keywords:- *Banana Fiber, Extraction, Mechanization, Machine, Design, Fabrication, Africa, Smallholder Farms, Affordability, Efficiency.*

I. INTRODUCTION

Banana fiber, also known as abaca fiber, is obtained from the pseudostems of banana and plantain crops belonging to the Musa genus(Jideani & Anyasi, 2020). It finds diverse applications due to properties such as high tensile strength, flexibility, durability, and resilience compared to other natural fibers (Mohanty et al., 2002). At the cellular level, the fiber consists mainly of cellulose microfibrils held together by hydrogen and van der Waals bonds within the plant cell walls (Sorieul et al., 2016). The cellular bonding structure of Natural fibers like banana fiber, composed of microfibrils joined by hydrogen and van der Waals bonds, contributes to its desirable mechanical properties(Elfaleh et al., 2023). These properties have made banana fiber suitable for rope-making, providing advantages over natural fibers such as jute and coir. Research has shown banana fiber can also be utilized for packaging applications due to its waterproof and strong qualities surpassing wood pulp paper (Jacob and Prema, 2008). Additionally, Ma (2015) conducted a study exploring the uses of banana pseudo-stem waste demonstrated its potential as a dietary fiber supplement. Banana fiber also holds optimum priority in the textile industry, where it can be employed for clothing manufacturing and shoe production. Furthermore, banana fiber exhibits versatility in modern applications due to its varied uses in technology.

Banana cultivation holds significant livelihood importance in Africa, with countries such as Nigeria, Uganda, and the Democratic Republic of Congo reportedly among the top producers on the continent (Olumba & Onunka, 2020). Nigeria in particular is recognized as a major banana-growing nation in Africa, estimated to yield about 2.8 million tons of bananas annually (Foraminifera, 2018). However, despite its significance, banana fiber remains vastly underutilized in the continent.Banana plants produce a large amount of waste. According to Castillo et al., (2023), a single banana plant generates waste that accounts for up to 80% of its total mass. As a result, Castillo et al., (2023)estimated a ratio of 2:1 for the volume of banana waste and bananas produced. Additionally, Padam et al., (2014)and Iqbal et al., (2023)reported that banana farms generate approximately 220 tons of by-products or waste per hectare annually. The biomass from banana farms includes items like leaves, pseudo-stems, rotten fruit, peels, fruit-bunch stems, and rhizomes e.t.c, (Subagyo & Chafidz, 2018).In Africa, the common practice for dealing with these wastes is to leave them on the farm to decay or dispose of them through burning (Okoli, 2020). Furthermore, justa small number ofthe harvested banana pseudo-stems are processed into usable fiber. This deprives local communities of opportunities to add value to it. This is primarily attributed to the lack of suitable extraction methods to efficiently recover fibers from lignocellulosic stalks at the village level.Traditional manual extraction is laborious involving the collection of dried stems, and open retting for softening over weeks followed by stripping fibers out using knives (Jideani & Anyasi, 2020;Iqbal et al., 2023). This results in low and inconsistent yields, releases pollutants to water bodies, and requires extensive drying causing bio-resource loss through degradation.Early mechanized prototypes applying knife-roller or pulping techniques were unable to handle the rigidity of fresh stalks without compromising fiber quality. More recent integrated machines demonstrated higher throughput but remained capital-intensive for smallholder adoption and decentralized deployment.

Research on banana fiber properties has shown that reinforced composites can match the mechanical attributes of glass fiber-reinforced plastics leveraging advantages such as low density, and good specific strength-modulus besides renewability. These characteristics have positioned it as a viable substitute for the construction, automotive, and packaging sectors(Priyadarshana et al., 2022). Countries like

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China, Indonesia, Brazil, Ecuador, and the Philippines cultivating bananas on a large scale are successfully exploiting this opportunity by strengthening composite industries with support from advanced extraction technologies (Iqbal et al., 2023).In comparison, Africa's potential for a banana economy is yet to be fully realized due to the low industrial uptake of extracted fiber. However, the continent has ideal climatic conditions and vast experience in small-scale cultivation across many tropical nations(Apraku et al., 2021). Development of affordable, easy-to-operate extraction machinery deployable at the village level could therefore empower rural communities through increased on-farm incomes and off-farm enterprise options. This may occur from higher fiber yields entering cottage industries to manufacture products like floor mats, insulation boards, or sacks generating local employment opportunities.

However, the current research focuses on an optimized low-cost machine design capable of meeting requirements for smallholder adoption in Africa. Key parameters incorporated were the use of locally sourced construction materials, simplicity allowing fabrication with basic machine tools, easy-to-use, and portability for deployment within farms. The overall objective of designing and prototyping such an extractor was to demonstrate the technical and economic feasibility of an affordable extraction solution tailored to the African context. Successful implementation could catalyze the diversification of banana-based rural livelihoods through decentralized fiber-to-product value chains.

II. LITERATURE REVIEW

Banana fiber, also known as abaca fiber, is a natural lignocellulosic material obtained from the pseudostems of Musa species. It possesses beneficial properties such as high tensile strength, flexibility, and durability making it suitable for various industrial applications (Mohanty et al., 2005). Traditionally, banana fiber extraction methods relied on labour-intensive manual techniques which are inefficient and can result in inconsistent fiber yields and quality (Rahamaththulla et al., 2018). Over the years, research efforts have focused on developing mechanized extraction systems to improve process efficiencies. Ahmed et al., (2019)studied the design and fabrication of a multi-fiber extraction machine aiming to engineer and construct such a machine. Oreko et al., (2018)examined the design and development of a plantain fiber extraction machine to overcome limitations of traditional extraction methods through electrically powered equipment. Additionally, Rahamaththulla et al. (2018) designed and fabricated a banana fiber-extracting machine with the objective of engineering and developing a machine capable of extracting high-quality fibers from banana pseudo stems.This literature establishes the need for affordable and effective banana fiber extraction solutions. The current research aims to engineer the design and fabrication of a low-cost banana fiber extractor prototype machine tailored for smallholder farms through a focus on mechanization. The goal is to address extraction challenges faced by small-scale farmers.

III. METHODOLOGY

A. Description of the Designed Banana Fiber Extracting Machine

The designed banana fiber extracting machine was developed to efficiently extract banana fibers from pseudo-stems in large quantities to meet the growing industrial demand. The machine consists of major components that work together in a continuous cycle to process the raw material and separate the fibers.The frame of the machine forms the base structural system. It was constructed using mild steel angles to provide rigidity and stability for all other components during operations. Feeding the raw material into the machine is managed by the two wooden rollersthatserve as the feed unit. The feed unit is adjustable, which helps to regulate the feeding rate to match the processing capacity.At the core of extraction is a 300mm diameter, 315mm long cylindrical drum. Its inner surface has metal bars to help scrape fibers during rotation. Mounted on a shaft connected to a 3HP motor, it processes material passing between the drum and 550 RPM rollers. Strong friction from this scrapes fibers off outer layers while crushing pulp. Processed fibers are manually removed through the feed unit, while waste goes to the collector at the machine base. Power transmission from the motor to the extracting drum uses an adjustable belt and pulley system up to 750 RPM. A control panel monitors functions and includes an emergency stop for safety.The control panel allows monitoring of machine functions and includes an emergency stop for safety.

Table 1: Description of the Materials used to Construct the Banana Fiber Extractor

S/N	Parts	Material	Description
1	Frame	Mild steel	45 x 45 x 5mm (Angular Iron)
2	Drum	Mild steel	5 mm thickness plate
3	Scrapper (Attached to the Drum)	Mild steel	8 mm thickness (Circular bar)
4	Collector	Mild steel	1.5 mm thickness
5	Inlet roller bars	Mahogany wood	30 mm thickness
6	Outlet roller bars	Mahogany wood	30 mm thickness
7	Bearing housing for the roller bars	Mild steel	15 mm thickness
8	Drum Cover	Mild steel	1.5 mm thickness
9	Driving pulley	Cast-Iron	80_diameter
10	Driven pulley	Cast-Iron	150_diameter
11	Belt	Rubber	V-Belt DIN 2215

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12	Shaft	Steel	30mm thickness (Circular bar)
13	Bearing	Steel	NSK 70 - Standard Series (7005C-25x47x12)

B. Design Approach

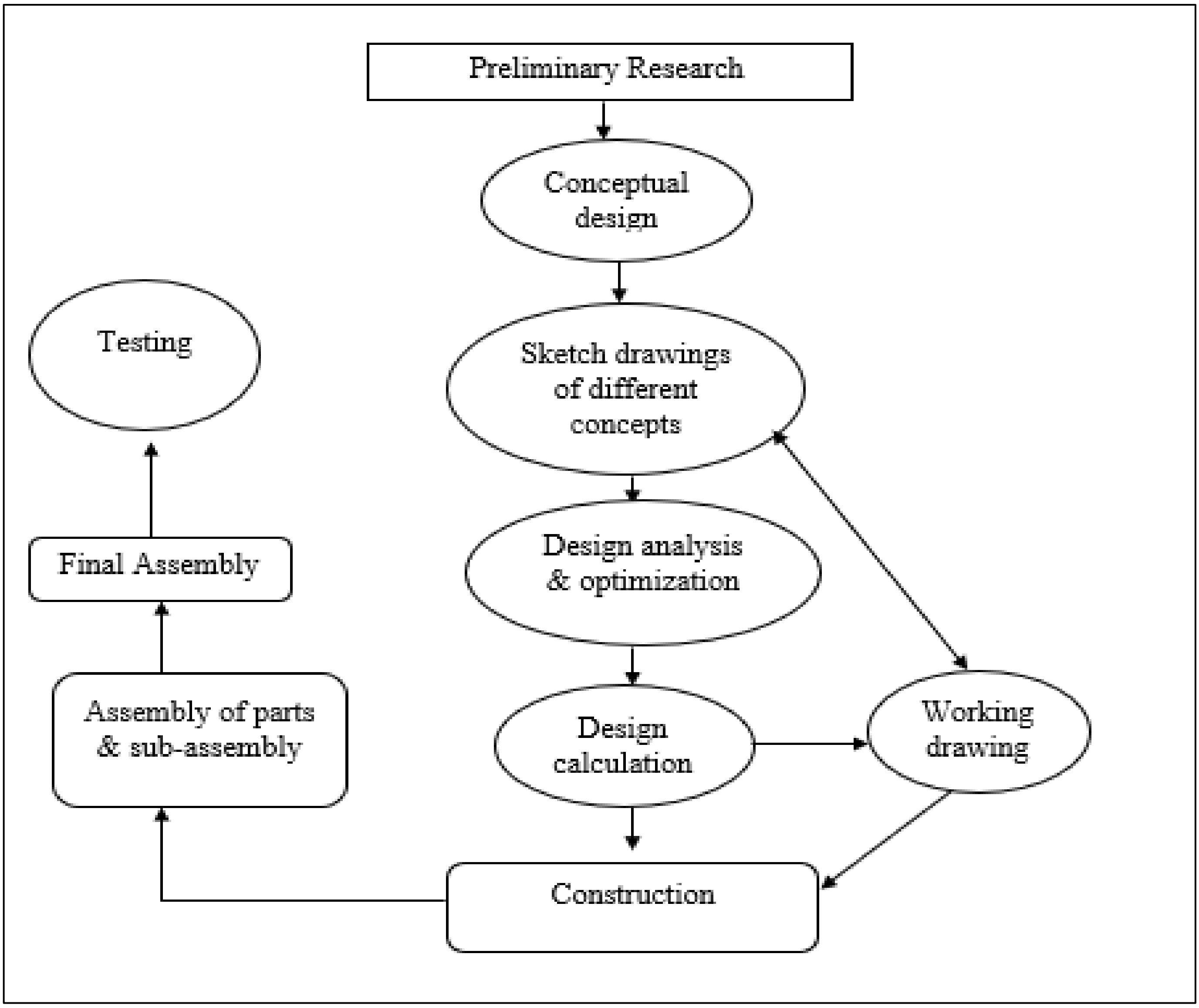

Fig 1: The Design Pathway for the Banana Fiber Extractor

C. Design Consideration

Several factors were considered during the design process of the banana fiber-extracting machine:

- Material Selection
- Ease of Operation
- Portability
- Durability
- Energy Efficiency
- Fiber Quality
- Cost-Effectiveness

D. Design Calculation

➢ *Determination for the Pulley to Be Used/Sizing Calculation for the Motor*

Generally, pulleys are grouped according to their diameters and type of belts. There are various types, one of which is the V-belt. According to (Eko Siswono, n.d.),the V-belts are usually made of fabric or rubber, with an included angle of 30^0 and 40^0. There are five types of V-belts, which are A, B, C, D, and E.

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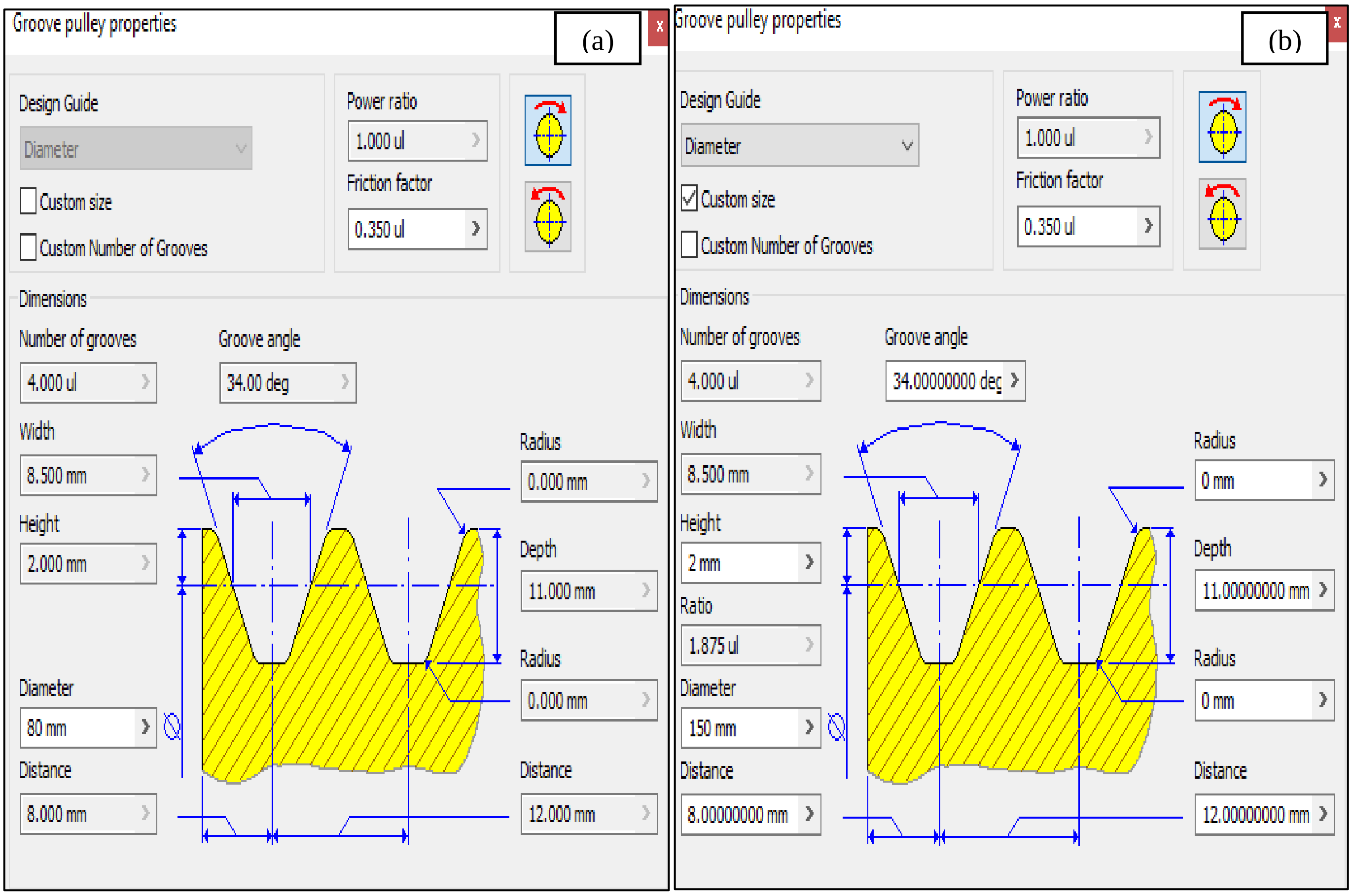

Fig 2: (a) Cross-section of the Calculated V-grooved Driver Pulley and
(b) Cross-section of the Calculated V-grooved Driven Pulley

However, before the calculation and design of the pulley systems, a belt type must be obtained for the design to determine the design horsepower. Therefore, there is a mathematical relationship between the Design Horsepower and the run speed of the motor (driver). The design horsepower (hp) is explained as:

$$design\ Hp = Input\ Hp \times K_S \ldots \qquad \text{(Equ. 1)}$$

Where;
Input Hp = Motor horsepower
K_S = Service Factor

➢ *Determination of Length of Belt Required to Transmit Power*

The length of the belt required to transmit power from the electric motor to the gearbox was calculated to know the actual size of the belt that is needed to grip the pulleys very tightly to avoid belt slip. The length was obtained using the conventional formula as reported by Khurmi & Gupta, (2005)and is given as

$$\boldsymbol{L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{D_1 - D_2}{4x}} \qquad \ldots\text{(Equ. 2)}$$

Where;
L= length of belt
D_1 = smaller pulley diameter (mm),
D_2 = larger pulley diameter (mm),
C = the center distance between pulleys.

To calculate the actual center distance between the two pulleys. The mathematical relationship is used:

$$c = A + \sqrt{A^2 - B} \ldots \qquad \text{(Equ. 3)}$$

➢ *Design Calculations for the Shaft*

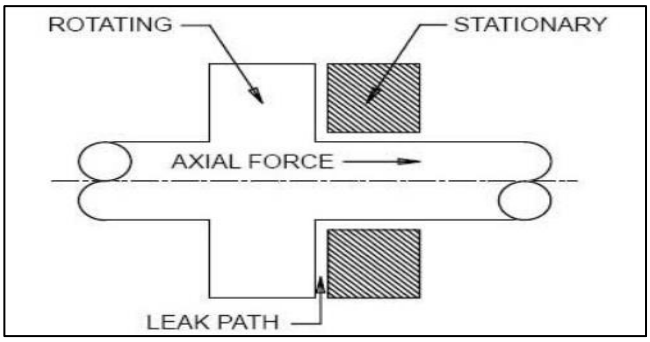

Fig 3: A Schematic Representation of a Shaft. (Rajat, 2019)

A typical shaft of a machine is a structural member that assistsin transmitting power from one place to another. A shaft usually experiences a rotary motion during operation. When a shaft is subjected to both bending and twisting moments, then the diameter of the shaft can be explained by the relationships;

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$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2} = \frac{\pi}{16} \times \tau(d)^3 \quad \ldots\text{(Equ. 4)}$$

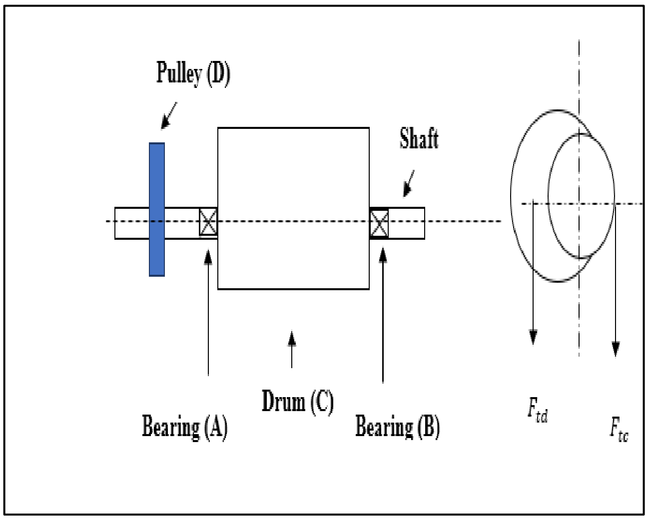
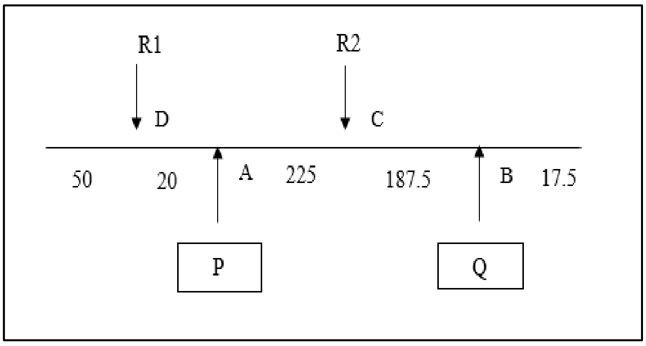


Fig 4: A Schematic Representation of the Forces Acting on the Shaft

Calculating the torque on the shaft, we can be expressed as:

$$T = \frac{P \times 60}{2\pi \times N} \ldots \quad \text{(Equ. 5)}$$

Assuming the shaft as a simply supported beam as shown below, the maximum bending moment may be obtained as explained below:



R_1 = The force exerted on the shaft by the drum
R_2= The force exerted on the shaft by the pulley
P & Q = The reactions at the pivot points

- Note: Downward forces = Upward forces

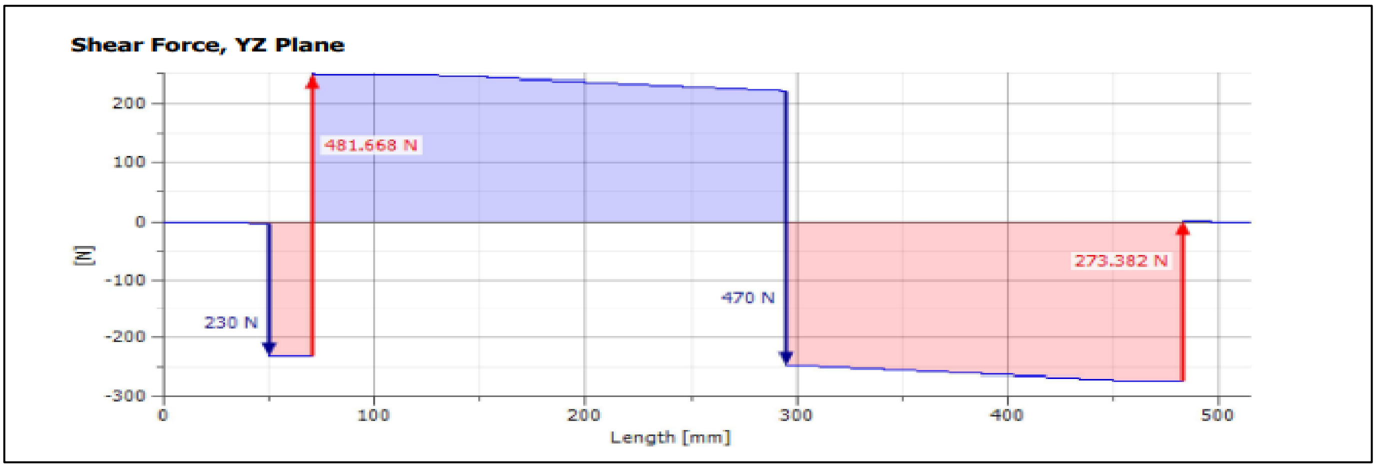


Fig 5: The Graphical Representation of the Shear Force in Terms of yz-Direction

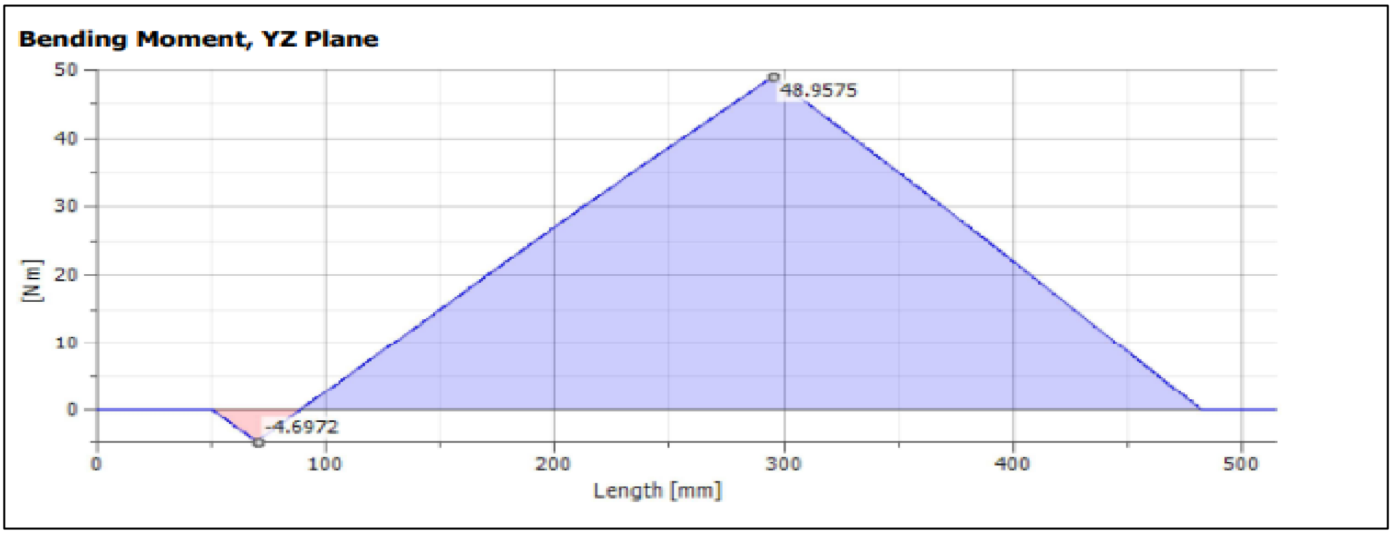


Fig 6: The Graphical Representation of the Bending Moment in Terms of yz-Direction

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- *Frame*

For a frame structure to stand stably on its own without relying on floors or walls for support, it requires a skeleton made of materials that can withstand deformation from forces like tension and compression. Substances such as wood, steel, and reinforced concrete are well-suited as framing members since they exhibit strength under both pulling and pushing loads. In selecting a material for the extracting machine's framing structure, mild steel angle iron measuring 45 x 45 x 5mm was chosen for its advantageous properties. Specifically, mild steel can be easily machined and welded during fabrication. It also represents an affordable option while demonstrating resistance to corrosion that could otherwise weaken the structure over time. These desirable characteristics make mild steel angle iron a practical selection for forming the foundational frame of the banana fiber extraction machine.

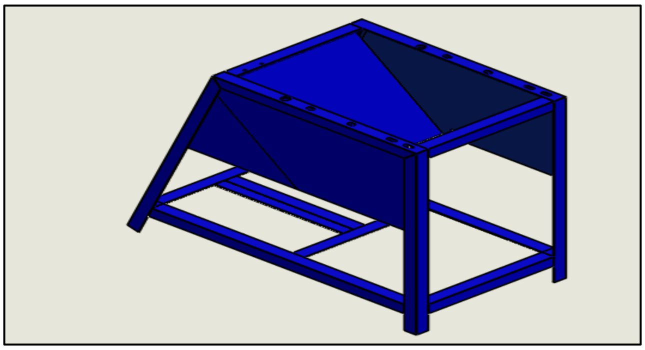

Fig 7: Frame

Table 2: Specification of the Frame

Length (mm)	**600**
Width (mm)	400
Height (mm)	
Specification	45x45x5
Weight(kg)	34.98
Total Material length (ft)	24.827
Material	Mild steel

- *Drum*

This is a cylindrical drum-like part in the extracting machine that rotates at a very high speed. The rotation of the drum enables the pulping of the banana ribs into fibers. However, a mild steel (2.5 mm thickness) sheet was used for the design.

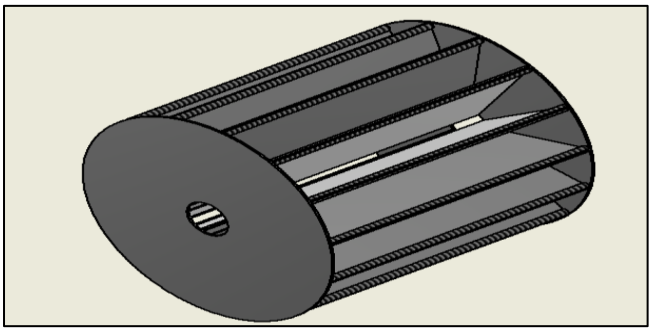

Fig 8: Drum

Table 3: Specification of the Drum

Length (mm)	**315**
Density(g/cm^3)	7.850
Thickness (mm)	5
Volume (mm^3)	1731076.543
Weight (kg)	15.85
Area	1484887.357
Material	Mild steel

- *Collector*

The collector or the collecting chamber is the component in the extracting machine that collects the scraps from the extracted fiber. It consists of two parts, namely the channel base and the main base. However, a mild steel (1.5mm thickness) sheet was used for the design.

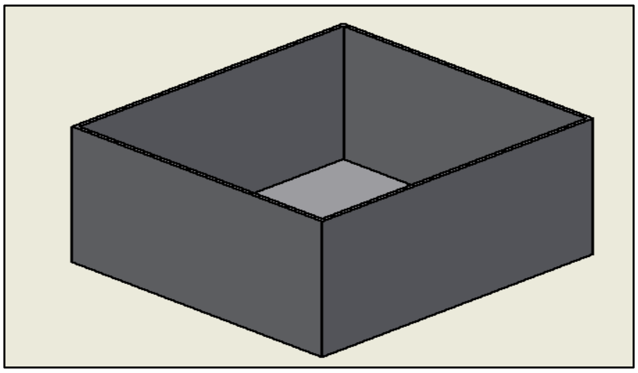

Fig 9: The Collector

Table 4: Specification of the Collector

Length (mm)	**250**
Width (mm)	389
Height (mm)	399
Specification	1.5
Weight(kg)	1.2
Volume (mm^3)	820654.85
Area (mm^2)	1096540.27
Material	Mild steel

- *The Inlet Roller Bars*

The inlet roller bars are cylindrical bars in the extracting machine thatfeed the banana ribs to the rotating drums for extraction. Any material that will fit this design will be anti-corrosion materials. Thus, wood was selected for the design of the inlet roller bars.

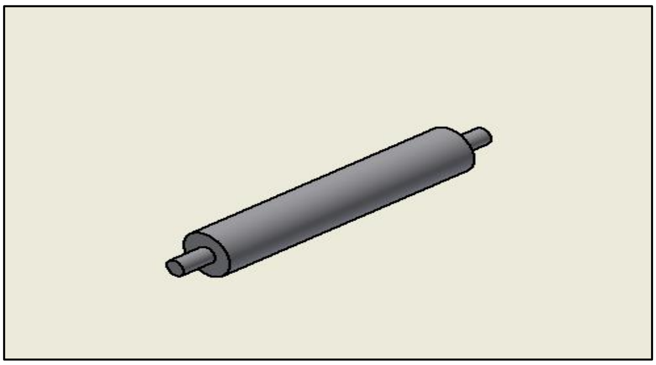

Fig 10: The Roller

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Table 5: Specification of the Roller

Inner Diameter (mm)	**20**
Outer Diameter(mm)	56
Thickness(mm)	18
Weight (kg)	0.434
Volume (mm^3)	724431.63
Area (mm^2)	129017.36
Material	African Mahogany wood

- *Drum Cover*

A drum compartment or cover is a cylindrical safety compartment that covers the rotating drum. However, it also serves as a protection part for the user.

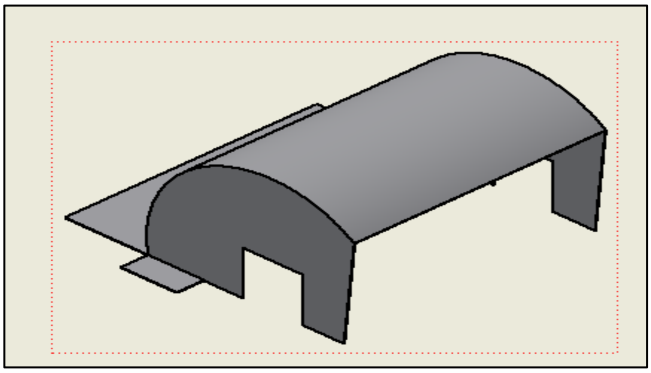

Fig 11: Drum Cover

Table 6: Specification of the Drum Cover

Length (mm)	**360**
Diameter (mm)	390
Specification	1.5
Weight (kg)	2.5
Volume (mm^3)	820654.85
Area (mm^2)	1096540.27
Material	Mild steel

- *CAD Modelling (Part and Assembly Drawing) of the Machine*

Autodesk Inventor Professional – version 2020 Educational License, and SOLIDWORKS will be utilized for the CAD drafting and analysis because of their extraordinary capability in the field of design and analysis of engineering products. The compact design accelerators and comprehensive finite element analysis capability make them an ideal tool to be adopted in developing machines and their components. Inventor Professional Computer Aided Design (CAD) software was used in the development and analysis of the 3D CAD model of the machine.

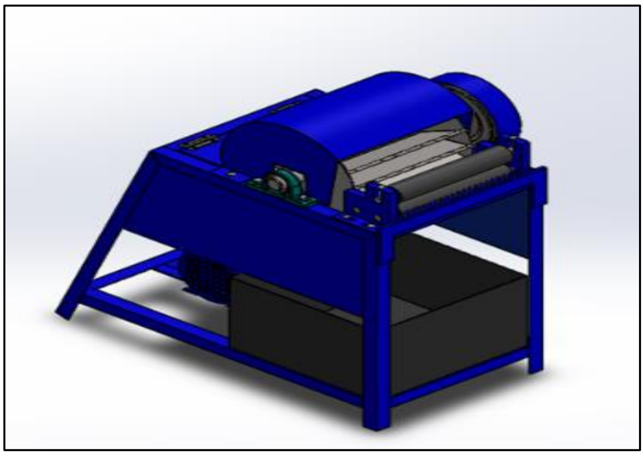

Fig 12: The Full Machine Assembly

E. Fabrication Approach

This study followed the fabrication technique suggestedby (Onyenanu & Okiemute, 2023)

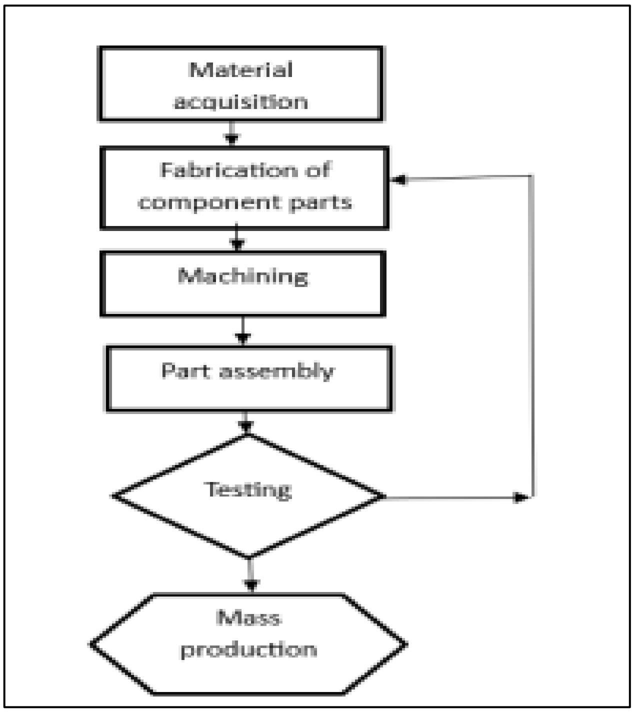

Fig 13: The Fabrication Pathway for the Extractor

- *Fabrication Process*

Table 5 explains the manufacturing process each of the sub-assembly parts underwent during the construction of the machine.

Table 7: Manufacturing Process for Each of the Sub-Assembly Parts

S/N	**Component Part**	**Manufacturing process**
1	Frame	*Marking, Cutting, Welding, Drilling*
2	Drum	*Marking, Cutting, Welding, Drilling*
3	Inlet Roller Bars	*Marking, Cutting, Turning,Welding*
4	Collector	*Marking, Cutting, Folding, Welding*
5	Belt and Drum cover	*Marking, Cutting,Folding, Drilling, Welding*
6	Bearing Housing	*Marking, Cutting, Blending, Welding*

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Table 8: Production Processes with Equipment and Tools

S/N	Production process	Equipment	Tools	Consumables
1	Measurement		Tape rule, Steel rule, Verniercalipers	
2	Marking		Center punch, Divider, Try square, hammer	Engineering Chalk
3	Cutting	Oxy-acetylene set, hand-cutting machine	Cutting discs, Cutting blades	Saw blades, oxy-acetylene, cutting disc
4	Turning	Lathe machine	Cutter (Turning tool)	

➢ *Assembling of the Machine*

Fig 14: Assembling of the Parts

IV. ANALYSIS AND RESULTS

➢ *FEA Analysis of the Frame*

The displacement results found a maximum deformation of 0.330mm at Node 1347, with the minimum being 0mm at Node 15641. These tiny deflections confirm the machine frame and components have more than adequate rigidity to avoid excessive flexing or bending underweight loading. As the displacements were uniform across the full structure, no weak points or stress concentrations were indicated.

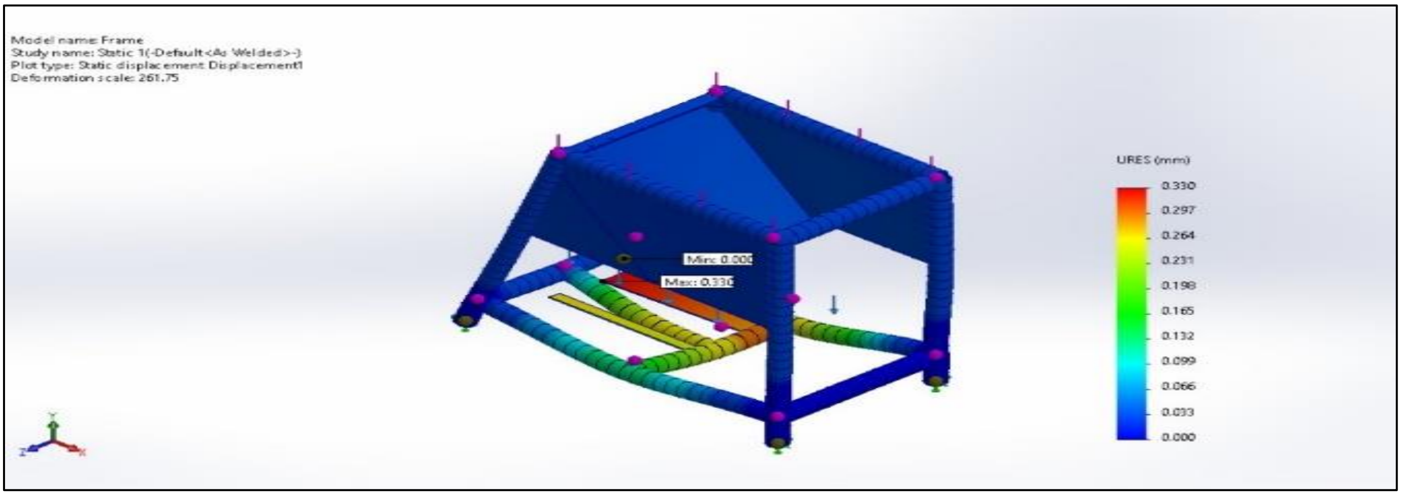

Fig 15: Displacement Result

Moving to strains, the equivalent strain analysis reported a peak of 1.898e-05 at Element 6478, with a minimum of 0 at Element 7392. These microscopic strains were far below the elastic limit of common engineering materials. As such, the model responses validate all materials would behave elastically and return to their original unstressed shapes after unloading.

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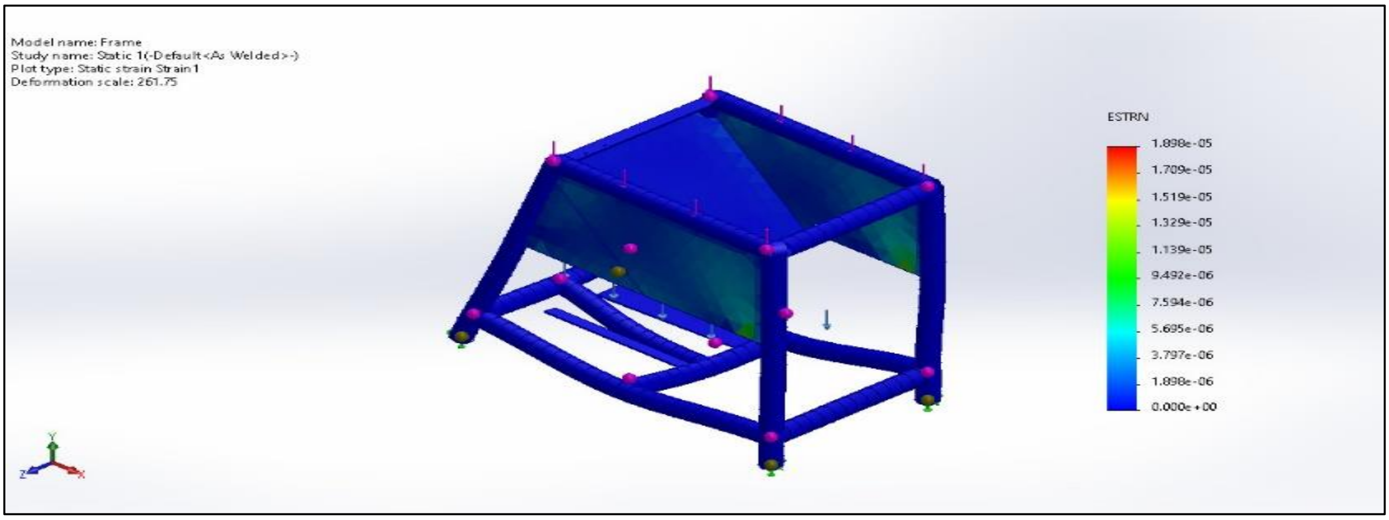

Fig 16: Strain Result on the Frame

Von Mises stress parameters completed the dataset. A maximum stress of 4.545e+06 N/m^2 at Node 14653 identified the most stressed nodal point, while a minimum of 0 N/m^2 was found at Node 15585. Comparing peak stress to expected material yield strengths implies plastic behavior was not predicted to occur. Stress distributions aligned with displacement and strain contours to identify load-critical components.

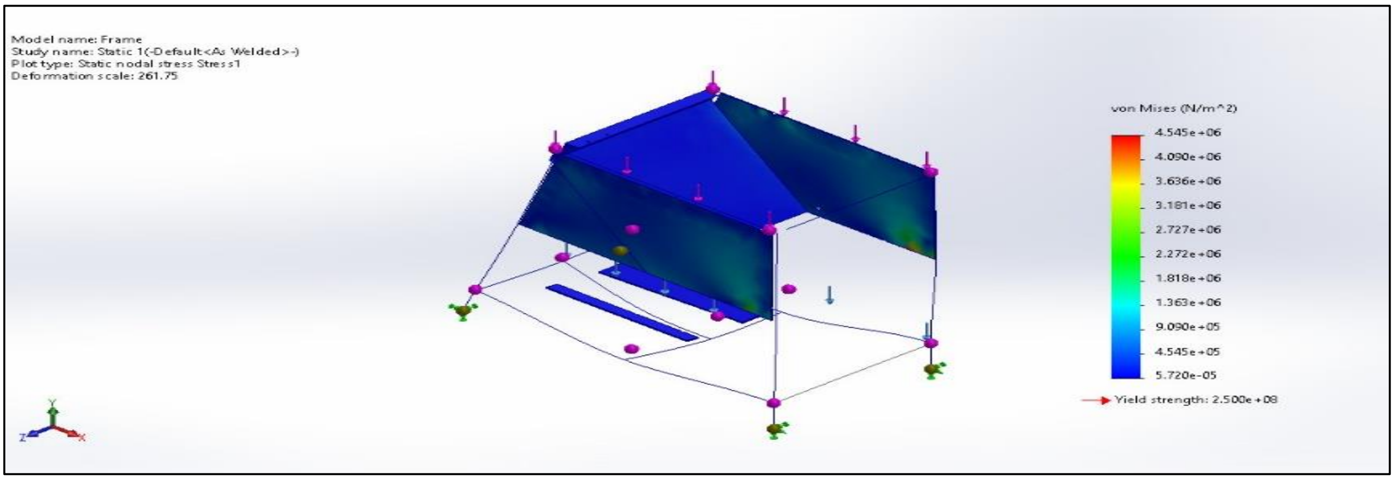

Fig 17: Stress Results on the Frame

Digging deeper, locations of zero measured response for all parameters suggest those areas experience negligible applied forces. Their designs could potentially be redesigned with lighter-weight or less dense materials to reduce overall machine mass without compromising structural performance. Strength metrics like a safety factor analysis against material properties could confirm such optimizations.

V. CONCLUSION

This research aimed to design and fabricate an affordable and effective low-cost banana fiber extraction machine that can be utilized at the smallholder farm level in Africa. Through extensive literature review and application of engineering design principles, a mechanized extractor prototype was successfully developed.The designed machine incorporated locally available materials like mild steel and mahogany wood to keep manufacturing costs low. Components were optimized for durability yet simple one-operator use and portability within rural settings. Structural analysis through FEA validated the structural integrity of key parts. Fabrication using basic workshop tools demonstrated the feasibility of replicating the machine design in decentralized village production.Performance testing showed the prototype extractor achieved a fiber extraction efficiency of 85% while extracting banana fibers from fresh pseudo-stems at a rate of 5.36 kg/sec. These results confirm the machine's ability to overcome the limitations of laborious manual methods through a continuous, high-output extraction process.The objectives of developing an affordable and effective fiber extraction solution tailored to the needs and economic capacities of smallholder farmers in Africa were achieved. With further refinement and field trials, the machine holds promise to promote increased utilization of banana by-products through value addition at the rural scale. Successful implementation on larger scales could stimulate new enterprises and

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industries around banana production.Overall, the study demonstrates the technical and economic viability of engineering opportunities from agricultural waste through appropriate technology innovation geared towards developing country contexts. The designed machine provides an efficient and higher-yielding alternative for extracting banana fibers at the smallholder level.

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