International Journal of Applied and Natural Sciences
ISSN: 3005-3471
DOI: 10.61424/ijans
Journal Homepage: www.bluemarkpublishers.com/index.php/IJANS

IJANS
BLUEMARK PUBLISHERS

| RESEARCH ARTICLE

Modelling and Optimization of Banana/Plantain Fiber Extraction Systems through Dimensional Analysis

Ifeanyichukwu Ugochukwu Onyenanu[1] ✉ Nwachukwu Onyeneke Ukwu[2], Vincent Chukwuemeka Ezechukwu[3], Ifunanya Mariagoretti Onyenanu[4] and Chukwuma Jachike Nwadiuto[5]

[1235]*Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University – Nigeria*

[4]*Department of Mechanical Engineering, Caritas University, Enugu – Nigeria*

Corresponding Author: Ifeanyichukwu Ugochukwu Onyenanu, **E-mail**: mecury4eva@yahoo.co.uk

| ABSTRACT

This study presents a comprehensive parametric modelling approach for a locally produced plantain and banana fiber extractor, utilizing the Buckingham Pi theorem to analyze the complex interactions among various operational parameters. Plantain and banana fibers are increasingly recognized for their diverse industrial applications, including textiles, paper, packaging, and food supplements. The mechanical extraction of these fibers is prevalent, necessitating a well-designed process that conserves the natural properties of the fibers while maximizing cost-effectiveness. This research aims to optimize the design and operational parameters of the extractor to enhance its extraction capacity and overall efficiency. Employing the Buckingham Pi theorem, the study constructs dimensionless Pi terms from key parameters impacting the extractor's performance. The analysis reveals a coefficient of correlation (R^2) of 0.9923 for extraction efficiency and 0.9867 for extraction capacity, indicating a strong predictive capability of the developed model. These findings provide valuable insights into optimizing the performance of the plantain and banana fiber extractor, ultimately contributing to more efficient and sustainable fiber extraction processes. This model serves as a critical tool for designers and manufacturers aiming to improve the economic viability of fiber extraction systems.

| KEYWORDS

Parametric modelling, plantain fiber extractor, banana fiber extractor, dimensional analysis, Buckingham Pi theorem.

| ARTICLE INFORMATION

ACCEPTED: 10 November 2024 **PUBLISHED:** 11 December 2024 **DOI:** 10.61424/ijans.v2.i2.161

1. Introduction

The extraction of fibers from banana and plantain species is of paramount significance across a multitude of sectors, encompassing textiles, paper manufacturing, packaging, and agricultural practices. These natural fibers are predominantly sourced from the pseudo-stems of banana and plantain plants, which thrive abundantly in tropical climates. Their distinctive characteristics, which include a remarkable strength-to-weight ratio and inherent buoyancy, render them indispensable raw materials for an array of applications. For example, banana fibers are employed in the fabrication of shipping cables, attributed to their exceptional strength and resilience (Bhatnagar et al., 2018). Furthermore, they are utilized in the creation of eco-friendly products such as tea bags, filter fabrics, and biodegradable packaging solutions (Tharar et al., 2019).

In addition to their industrial roles, banana pseudo-stems are esteemed for their nutritional properties. Research conducted by Buragohain et al. (2010) underscores the potential of banana pseudo-stems as a crucial staple food

Copyright: © 2024 the Author(s). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) 4.0 license (https://creativecommons.org/licenses/by/4.0/). Published by Bluemark Publishers.

source for porcine livestock, offering a sustainable alternative for animal feed in regions where banana cultivation is prevalent. This practice not only amplifies the economic value of banana agriculture but also aids in the mitigation of waste. Moreover, banana fibers have attracted considerable interest within the packaging sector, where their hydrophobic attributes and enhanced strength exceed those of conventional wood-pulp paper (Jacob & Prema, 2008). This multifaceted applicability fosters an increasing inclination towards the utilization of banana and plantain fibers across diverse industries, aligning with both economic viability and environmental sustainability.

The applicability of banana fibers extends to the textile domain, where they are highly regarded for their aesthetic appeal and functional performance. The fiber's distinctive texture and natural hue render it a coveted material for garments, accessories, and home textile products (Bhandari et al., 2017). Additionally, banana fibers are increasingly preferred for their sustainable attributes, notably their biodegradability and reduced ecological impact when juxtaposed with synthetic materials (Kumar et al., 2019). They have been integrated into the manufacturing of footwear and other wearable items, thereby promoting environmentally conscious design principles.

Notwithstanding the myriad advantages associated with banana fibers, challenges persist in the extraction process. While numerous techniques are available for the extraction of natural fibers, mechanical extraction remains the predominant method employed. Such mechanical extraction processes require meticulous design to maintain the intrinsic properties of the fibers while ensuring operational efficiency and cost-effectiveness. The architecture of these extraction systems is instrumental in determining both the quality and yield of the resultant product (Khan et al., 2015). Recent advancements include the creation of an economically viable banana fiber extractor, which seeks to enhance accessibility for local agricultural producers and optimize fiber yield (Ukwu et al., 2023).

Although chemical extraction techniques—such as alkali and acid treatments—have been investigated, they frequently jeopardize the structural integrity of the fibers and raise significant environmental concerns (Akubueze et al., 2015). These methodologies may necessitate the use of harmful reagents that compromise ecological safety. Within the realm of mechanical extraction, traditional methodologies have transitioned into modern techniques that prioritize both efficiency and sustainability. For instance, the Bacnis and Leonit processes have facilitated the emergence of novel mechanical extraction methodologies, such as decortication. In the decortication procedure, the plant stems are subjected to crushing between rotating drum rollers, thereby effectively segregating the fibrous material from the softer pulp (Sreekumar et al., 2018).

The efficacy and capacity of fiber extraction methodologies represent pivotal determinants affecting the practicality and economic viability of large-scale production (Ogunwolu et al., 2019). An optimally calibrated fiber extractor possesses the potential to substantially augment productivity while concurrently minimizing labor input and processing time. A conventional banana/plantain fiber extractor constitutes a mechanical apparatus engineered to execute the separation of the pulpy or moist soft segments of the pseudo-stem from the fibrous material. The operational efficiency of such extractors is contingent not solely upon the machinery's design but also on an array of operational variables, encompassing rotational velocity, moisture content of the botanical material, and intrinsic characteristics of the utilized banana or plantain stalks (Kumar et al., 2021).

Comprehending the complex interrelations among these parameters is crucial for the optimization of the fiber extraction process. For example, the dimensional attributes of the extractor may exert influence over the flow dynamics of the material undergoing processing, thereby impacting the overall extraction efficiency (Komal et al., 2020). In a similar vein, the rotational speed of the apparatus serves a vital function in facilitating the adequate separation of fibers from the pulp without compromising their structural integrity. The moisture content present in the raw material may also affect fiber quality; materials that are excessively wet or dry can result in diminished extraction efficiency and inferior fiber quality (Maqsood et al., 2019).

To navigate these complexities, the present study employs dimensional analysis to formulate a mathematical model that elucidates the interrelations among the various parameters involved in the extraction process, akin to models implemented in the optimization of palm fruit digesters and biomass gasifiers (Onyenanu et al., 2024; Erhimona et al., 2023). Dimensional analysis offers a systematic framework for identifying and quantifying the influences of disparate factors on the efficiency and capacity of fiber extraction systems (Dey et al., 2020). By constructing dimensionless Pi terms from pertinent physical quantities, the model aspires to yield insights that can be leveraged to enhance the design of the extractor.

The primary objective of this investigation is to examine and optimize the operational parameters of the banana and plantain fiber extractor with the intent of maximizing both its extraction capacity (quantified in kg/s) and extraction efficiency (quantified as a percentage). By scrutinizing the correlation between the design parameters of the extractor and the operational conditions, this research endeavours to contribute significant knowledge to the domain of fiber processing. The findings of this study may serve as a valuable reference for engineers, designers, and manufacturers who are engaged in the development of efficient and sustainable fiber extraction technologies (Sahu et al., 2021).

In sum, the importance of banana and plantain fibers across various sectors is of paramount significance. As industries increasingly pursue sustainable alternatives and environmentally friendly materials, the demand for efficient fiber extraction techniques is anticipated to escalate. Through the application of advanced modelling and optimization strategies, this research aims to refine the extraction processes, ensuring that the valuable properties of banana and plantain fibers are preserved while simultaneously meeting the economic demands of contemporary production systems.

2. Literature review

The following are some of the related literature which has been conducted about the current research study.

2.1 Review on plantain/ banana fiber extracting machine

Oreko et al. (2018) worked on the design and development of a plantain fiber extraction machine. The method employed involved the selection of appropriate materials, design, fabrication, and assembly of the various components of the machine parts. From the analysis, a 2-horsepower electric motor is required to drive the machine. The length of the flat belt required to drive the pulley was at an angle of the lap on the smaller pulley of 2.87 rad. A resultant load of the act on an 11.6 mm diameter shaft with a maximum bending moment of 10.33 Nm. The total weight of the shaft, pulping drum, and bearing on the frame was 67.51 N. Also, a force of 150 N, 200 N, and 250 N could pulp a thickness of plantain ribs of approximately 6 mm, 6.5 mm, and 7 mm, respectively. They stated that the extraction machine would help to reduce the plantain fiber extraction rate and human labor associated with the setting method.

According to Poudel et al. (2019), banana (Musa paradisiacal L) is the fourth most important crop in the world after rice, wheat, and maize. Banana cultivation in Nepal is more popular than other agricultural products and has an annual fiber production of about 1,977 tons. The cost of importing extraction machines from other countries is expensive. The research and development of such machines at low cost, which ultimately provides the opportunity for local entrepreneurship to farmers and helps in the proper utilization of agricultural management, was felt necessary. The developed machine from this project used a combined application of a roller and a decorticator for fiber extraction. The machine can extract fibre from 1,648 Kg of input which was about 100-160 banana pseudostem. The fiber production obtained was 54 Kg per day with NRS. 11 operation cost per 1 Kg of fiber. The production efficiency in comparison to available commercial machines was 180%.

Ukwu et al. (2024) worked on the development of a low-cost mechanized banana fiber extractor aimed at enhancing the efficiency of fiber extraction for smallholder farmers in Africa. Traditional manual methods are labour-intensive, limiting potential income from banana cultivation; thus, their study focused on creating an affordable and effective machine with a target extraction efficiency of 85%. The prototype, designed for easy operation, portability, and durability, can significantly promote the commercialization of banana fiber, contributing to improved rural livelihoods by leveraging a previously underutilized natural resource.

2.2 Review on parametric modeling using Buckingham Pie theorem

Asonye et al. (2018) stated that information on the optimum energy requirements for cutting vegetables is useful in estimating the amount of energy needed to cut given products with known physical characteristics. In this study, predictive equations were developed to describe the cutting energy of cocoyam (Colocasia esculenta) cormels. Dimensional analysis based on the Buckingham pi theorem was used to obtain the functional relationship between the cutting energy of the selected vegetable and the independent variables such as tool weight (w), the height of tool drop (Hd), tool edge thickness (t), cutting speed (v), crop size(s), crop moisture content (φ), crop contact area(A) and crop density (σ). The developed model was validated with experimental data, and a high coefficient of determination, R2=0.982, between the predicted and measured values was established. The obtained predictive model proved appropriate for determining the cutting energy required for cocoyam cormels up to 98%.

Ikejiofor, Ndirika, and Onwuka (2016) worked on the mathematical expression for predicting the throughput capacity for the chipping process of a mechanically operated cocoyam chipper is presented. The chipper throughput capacity model was developed by dimensional analysis using the concept of Buckingham's Pi Theorem. The model was verified and validated by fitting it into experimental data from the developed mechanical cocoyam chipper. The results obtained revealed that the fitted model correlated well with the experimental data with an R-square value of 0.91. Also, the difference between the means of the predicted and the measured throughput capacity was not statistically significant at a 5% level of significance.

Idowu and Owolarafe (2017) also worked on the mathematical model for the prediction of shelling efficiency of an impact snake gourd seed decorticator, which was presented using dimension analysis based on Buckingham's pi theorem. Experimental verification of the models was conducted by comparing the theoretical predictions with estimates from the representation of conventional methods. A high coefficient of determination was found between the predicted and the experimental values (98.45% for the effect of moisture content on decortication efficiency, 99.69% for the effect of hammer diameter on decortication efficiency, and 97.35% for the effect of hammer speed on the decortication efficiency) showing that the model is appropriate.

3. Description of the locally produced plantain/ banana fiber extraction machine

The locally produced plantain/ banana fiber extracting machine being studied has some of its major components and parts, which include The frame, designed with mild steel (angle iron) –45 x 45 x 5mm, The drum, designed with SAE-950A alloy mild steel with a volume of 1731076.543mm^3, The collector designed with SAE-950A alloy mild steel with a volume of 820654.85mm3, The inlet roller bars designed with African mahogany wood with a weight of 0.434kg, The belt cover was designed with SAE-950A alloy mild steel with a weight of 2027.11kg, The drum cover also designed with SAE-950A alloy mild steel, The Pulley was designed with special considerations such as noise, chemical, resistance etc, The solid steel shaft, The pillow block (Rolling Bearing) of NSK 70 - Standard Series (7005C-25x47x12) designation, The comb and The prime mover with a speed of 1440RPM. Figure 1 shows the 3D- CAD modelling of the locally fabricated plantain/ banana fiber extraction machine.

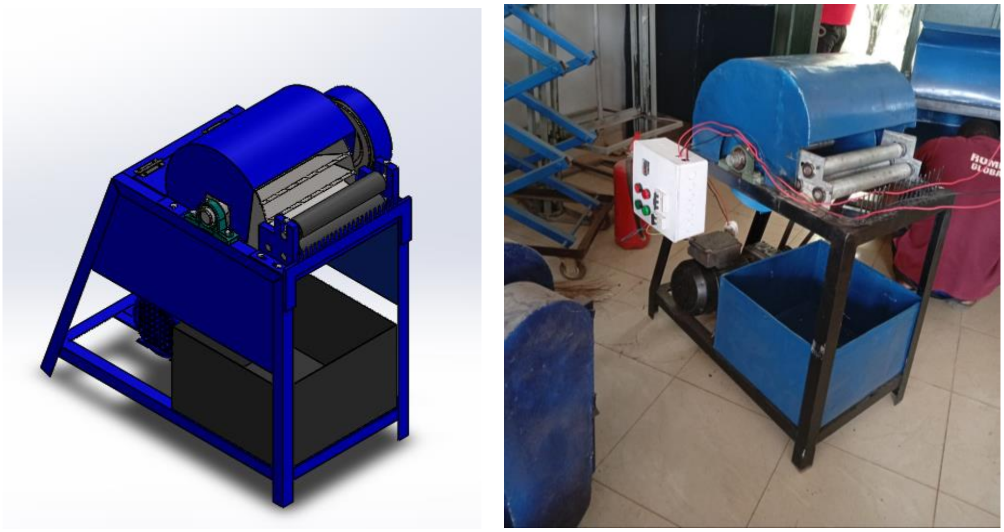

Fig. 1: Pictorial view of the locally produced plantain/ banana fiber extraction machine.

3.1 Parametric model development

Dimensional analysis, a well-developed methodology in physical sciences and engineering studies, was employed to develop the predictive equations for the efficiency and capacity models of the plantain/ banana fiber extractor. This evidence suggests that any physically significant equation must exhibit dimensional homogeneity, ensuring the validity of the relationship between actual physical quantities regardless of the magnitudes of the base unit.

3.2 Extracting Efficiency Model

The efficiency of the extracting machine η_e depends on the L_f, length of the fiber, Blade speed, Blade angle, Blade material young modulus, Density of the fiber, and N, number of blades. Therefore, the efficiency η_e in terms of dimensionless parameters is expressed as:

Table 1: Basic dimension of variables for Extracting Efficiency Model

S/N	Variables	Symbol	Units	Dimension Unit
1.	Machine Efficiency	η_e	-	$M^0T^0L^0$
2.	Length of the fiber	L_f	mm	L
3.	Blade speed	V	ms^{-1}	LT^{-1}
4.	Blade angle	Θ	-	$M^0T^0L^0$
5.	Blade material young modulus	E	N/m^2	$ML^{-1}T^{-2}$
6.	Density of the fiber	ρ	Kgm^{-3}	ML^{-3}
7.	Number of blades	N	-	$M^0T^0L^0$

$\eta_e = f\ (Lf, V, \Theta, E, \rho, N\ )$ Eqn.3.1

Note that ***dependent variables = independent variables***

However, the functional relationship between the dependent and independent variables can be written as:

$f\ (\eta_e, Lf, V, \Theta, E, \rho, N\ ) = 0$ .... Eqn. 3.2

The total number of variables, n, is equal 7.

Number of fundamental dimensions = 3 (MLT)

Therefore, the number of π-term = n-m = 4

However, there will be four $\pi_1, \pi_2, \pi_{3,}\pi_4$

$\pi_1 = C_e f(\pi_2, \pi_{3,} \pi_4)$ .... Eqn. 3.3

Where; C_e=Efficiency constant, $\pi_1 \pi_2 \pi_3 \pi_4$= Pi terms to be determined

Table 3.2: Dimensional matrix of variables for efficiency model

Dimensional Unit	Variables						
	$\boldsymbol{\eta_e}$	$\boldsymbol{L_f}$	$\boldsymbol{V}$	$\boldsymbol{\theta}$	$\boldsymbol{E}$	$\boldsymbol{\rho}$	$\boldsymbol{N}$
	a	b	c	d	e	f	g
M	0	0	0	0	1	1	0
L	0	1	1	0	-1	-3	0
T	0	0	-1	0	-2	0	0

$[\mathrm{M^0L^0T^0}]^a = [L]^b\ [LT^{-1}]^c\ [\mathrm{M^0L^0T^0}]^d\ [\mathrm{ML^{-1}T^{-1}}]^e\ [ML^{-3}]^f\ [\mathrm{M^0L^0T^0}]^g$

$M = e + f$ .... Eqn. 3.4

$L = b + c - e - 3f$ .... Eqn. 3.5

$T = -c - 2e$ .... Eqn. 3.6

To obtain $\pi_{1,}$ assume arbitrary values of a = 1, b = 0, c = 0, d = 0

$e\,(0) + f\,(0) = 0$

$b\,(0) + c\,(0) - e\,(0) - 3f\,(0) = 0$

$-c\,(0) - 2e\,(0) = 0$

$[\mathrm{M^0L^0T^0}]^1 = [L]^0\ [LT^{-1}]^0\ [\mathrm{M^0L^0T^0}]^0\ [\mathrm{ML^{-1}T^{-1}}]^0\ [ML^{-3}]^0\ [\mathrm{M^0L^0T^0}]^0$

$\boldsymbol{\pi_1 = \eta_e}$ .... Eqn. 3.7

To obtain π_2, assume arbitrary values of a = 0, b = 0, c = 0, e = 1

$-c - 2(1) = 0$

$c = -2$

$b + (-2) - (1) - 3f = 0$

$-3 - 3f = 0$

$f = -1$

$\boldsymbol{\pi_2 = \frac{E}{V^2\rho}}$ .... Eqn. 3.8

To obtain π_3, assume arbitrary values of a = 0, b = 0, c = 1, d = 0

$-(1) - 2e = 0$

$-2e = 1$

$e = -\frac{1}{2}$

$-\frac{1}{2} + f = 0$

$f = \frac{1}{2}$

$\boldsymbol{\pi_3} = \frac{V\sqrt{\rho}}{\sqrt{E}}$ .... Eqn. 3.9

To obtain $\pi_{4,}$ assume arbitrary values of a = 1, b = 1, c = 0, d = 1

$e\ (0)\ +\ f\ (0)\ =\ 0$

$b\ (0)\ +\ c\ (0) - e\ (0)\ - 3f\ (0)\ =\ 0$

$-c\ (0) - 2e\ (0)\ =\ 0$

$[\mathrm{M^0L^0T^0}]^0 = [L]^0\ [LT^{-1}]^0\ [\mathrm{M^0L^0T^0}]^1\ [\mathrm{ML^{-1}T^{-1}}]^0\ [ML^{-3}]^0\ [\mathrm{M^0L^0T^0}]^0$

$\boldsymbol{\pi_4 = \theta}$ .... Eqn. 3.10

According to Shafii et al. (1996), multiplication and division can combine the dimension terms to reduce it to a manageable level. However, we have equation 3.11 as:

$\pi 5\ = \frac{\pi_4 \pi_3}{\pi_2}$ .... Eqn. 3.11

$\boldsymbol{\pi_5} = \frac{\theta\, V^3 (\sqrt{\rho})^2}{(\sqrt{E})^2}$ .... Eqn. 3.12

To determine the Ŋ-model, equate equation 3.12 with equation 3.13. However, the efficiency model can be expressed as:

$\boldsymbol{\eta = C_E} \left(\frac{\theta\, V^3 (\sqrt{\rho})^3}{(\sqrt{E})^3} \right)$ .... Eqn. 3.13

3.3 Extracting capacity model

The extracting capacity of the extracting machine η_e depends on the Motor speed, Number of blades, Drum diameter, Roller/feed clearance, Roller diameter, Extracting Force. Therefore, the Extracting Capacity E_c in terms of dimensionless parameters is expressed as:

Table 3.3: Basic dimension of variables for Extracting Capacity Model

S/N	Variables	Symbol	Units	Dimension Unit
1.	Extracting Capacity	E_c	Kg/mins	$\mathrm{MT^{-1}}$
2.	Motor speed	S	Rev/sec	$\mathrm{T^{-1}}$
3.	Number of blades	N	-	$\mathrm{M^0L^0T^0}$
4.	Drum diameter	D_d	mm	L
5.	Roller/feed clearance	C_f	mm	L
6.	Roller diameter	D_r	mm	L
7.	Extracting Force	Fe	N	$\mathrm{M}L^{-1}T^{-2}$

$Ec\ =\ f\ (S, N, Dd, Cf, Dr, Fe)$ Equ.3.14

Note that ***dependent variables = independent variables***

However, the functional relationship between the dependent and independent variables can be written as:

$f\ \ (Ec, S, N, Dd, Cf, Dr, Fe)\ =\ 0$ Equ.3.15

The total number of variables, n, is equal 7.

Number of fundamental dimensions = 3 (MLT)

Therefore, the number of π-term = n-m = 4 .... Equ.3.16

However, there will be four $\pi_1, \pi_2, \pi_{3,} \pi_4$

$\pi_1 = E_e f\,(\pi_2, \pi_{3,} \pi_4)$ Equ.3.17

Where; E_e =Efficiency constant, $\pi_{12}\pi_{22}\pi_{33}\pi_{44}$ = Pi terms to be determined

Table 3.4. Dimensional matrix of variables for extracting capacity model

Dimensional Unit	Variables						
	E_c	S	N	D_d	C_f	D_r	F_e
	a	b	c	d	e	f	g
M	1	0	0	0	0	0	1
L	0	0	0	1	1	1	-1
T	-1	-1	0	0	0	0	-2

$[\mathrm{MT^{-1}}]^a = [\mathrm{T^{-1}}]^b [\mathrm{M^0L^0T^0}]^c [\mathrm{L}]^d [\mathrm{L}]^e [\mathrm{L}]^f [\mathrm{ML^{-1}T^{-2}}]^g$

$M = a + g$ Equ.3.18

$L = d + e + f - g$ Equ.3.19

$T = -a - b - 2g$ Equ.3.20

To obtain $\pi_{11,}$ assume arbitrary values of a = 1, b = 0, c = 0, d = 0

$a\,(1) + g = 0$

$g = -1$

$d\,(0) + e\,(0) + f\,(0) + g\,(0) = 0$

$\boldsymbol{\pi_{11}} = \frac{E_c}{f_e}$ Equ.3.21

To obtain $\pi_{22,}$ assume arbitrary values of a = 0, b = 1, c = 0, d = 0

$T = -(0) - (1) - 2g = 0$

$-1 - 2g = 0$

$g = -\frac{1}{2}$

$\boldsymbol{\pi_{22}} = \frac{1}{\sqrt{Fe}}$ Equ.3.22

To obtain $\pi_{33,}$ assume arbitrary values of a = 1, b = 0, c = 1, d = 0

$a\,(0) + g\,(0) = 0$

$d\,(0) + e\,(0) + f\,(0) - g\,(0) = 0$

$-a\,(0) - b\,(0) - 2g\,(0) = 0$

$\boldsymbol{\pi_{33} = N}$ Equ.3.23

To obtain $\pi_{44,}$ assume arbitrary values of a = 1, b = 0, c = 0, d = 1

$a\,(0) + g\,(0) = 0$

$d\,(0) + e\,(0) + f\,(0) - g\,(0) = 0$

$-a\,(0) - b\,(0) - 2g\,(0) = 0$

$\boldsymbol{\pi_{44} = D_d}$ Equ.3.24

According to Shafii et al. (1996), multiplication and division can combine the dimension terms to reduce it to a manageable level. However, we have the equation 3.25 as:

$\pi 55 = \frac{\pi_{44}\pi_{33}}{\pi_{22}}$ .... Eqn. 3.25

$\pi 55 = \boldsymbol{Dd \ x \, N \, x \, F_e}$ .... Eqn. 3.26

To determine the Ƞ-model, equate equation 3.26 with equation 3.27. However, the efficiency model can be expressed as:

$\boldsymbol{Ec = C_c(Dd \ x \, N \, x \, F_e)}$ .... Eqn. 3.27

3.4 Value of the Constant

3.4.1 Determination of the efficiency constant

The determination of the efficiency constant C_E involved the utilization of linearized expressions for π5 and π1 namely, $\left[\frac{\theta \, V^3(\sqrt{\rho})^3}{(\sqrt{E})^3} \ and \ \eta \ \right]$extracted from the developed model. This process was executed employing the method of least squares, a statistical technique, as elaborated by the works of (Bolaji et al., 2008). Consequently, the gradient of the line that best fits the data furnished the value of the efficiency constant, which, intriguingly, was ascertained to be 46.8E+04. However, as shown in Figure 3.28, the regression coefficient, R^2, obtained was 0.839.

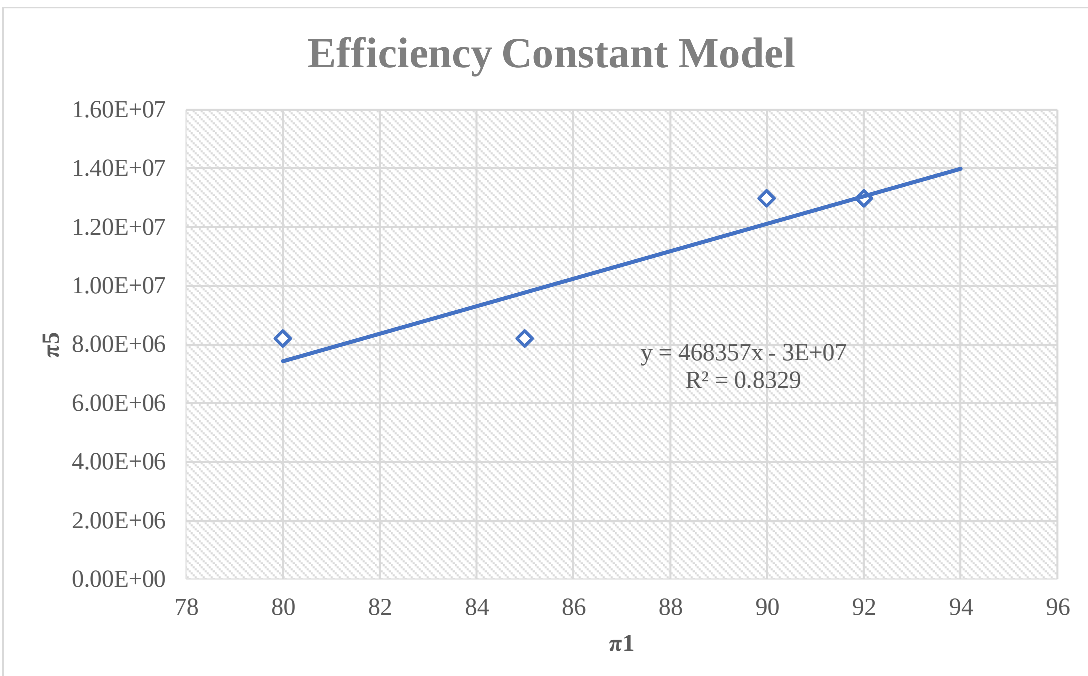

Figure 3.1: Determination of efficiency constant coefficient

3.4.2 Determination of the extracting capacity constant

The determination of the extracting capacity constant C_c involved the utilization of linearized expressions for π55 and π11 namely, $\left[\, (\boldsymbol{Dd \ x \, N \, x \, F_e}) \ and \ \frac{E_c}{f_e} \right]$extracted from the developed model. This process was executed employing the method of least squares, a statistical technique, as elaborated by the works of (Bolaji et al., 2008). Consequently, the gradient of the line that best fits the data furnished the value of the efficiency constant, which, intriguingly, was ascertained to be 1E+07. However, as shown in Figure 3.29, the regression coefficient, R^2, obtained was 0.399.

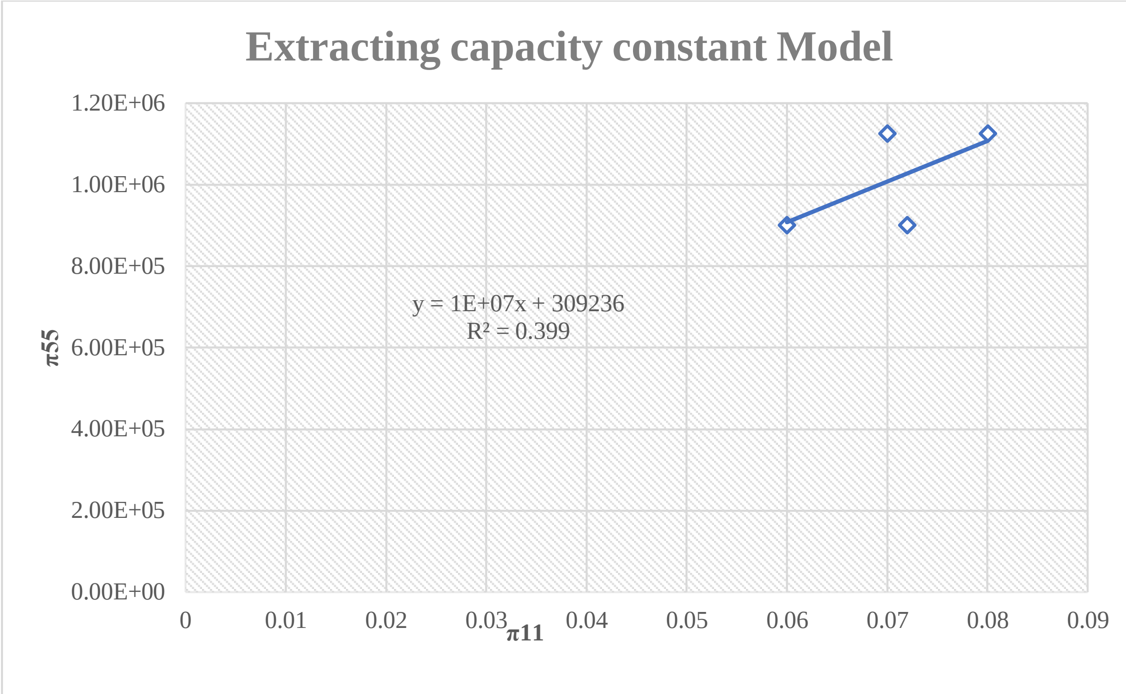

Figure 3.2: Determination of extracting constant coefficient

4. Results

Predictive models relating to the fiber yield and quality to the operating variables were developed based on dimensional analysis and multiple regression analysis of experimental data. The models were:

Machine efficiency = $C_E\left(\frac{\theta\, V^3(\sqrt{\rho})^3}{(\sqrt{E})^3}\right)$

Extracting Capacity = $C_c(Dd\ \ x\, N\, x\, F_e\,)$

The coefficient of determination (R^2) values indicated a very good fit of the models. These models allow the prediction of extraction outputs under varying operational conditions without extensive experimentation.

Constraints for the variables based on their operating ranges were defined. The optimized settings obtained through numerical optimization techniques were Motor speed (***501.701***), Feed clearance (***5.633***), and Number of blades (***15***). These settings, when applied on the machine were found to result in improved fiber outputs meeting the specified constraints compared to baseline runs.

Evaluation of the extraction machine performance proved it to be more efficient compared to traditional manual methods of fiber recovery from the banana pseudo stem. Extraction efficiencies averaged 85% which is higher than 65-75% reported for hand scraping technique. The productivity of the mechanical system at 5.59kg/hr was also found to be adequate for commercial operations, considering the limited scale.

5. Design validation

5.1 Efficiency validation

Table 4.1 and Figure 4.1 present the comparative data used to assess efficiency, considering both experimental results and those derived from formulated performance models. A statistical analysis comparing average predicted and measured efficiencies revealed no significant difference at a 5% level of significance. This was supported by the calculated 't' value (0.9923), which was smaller than the table 't' value (1.0203). These results underscore a robust relationship between the model and the data obtained from the developed fiber extraction machine.

Table 4.1. The Measured and computed efficiencies for the extractor machine

Number of Blades	Efficiency (%)	
	Computed	Measured
2.2	64.9	65.6
5	69.5	71
5	69.5	71
4	62.10	63.45

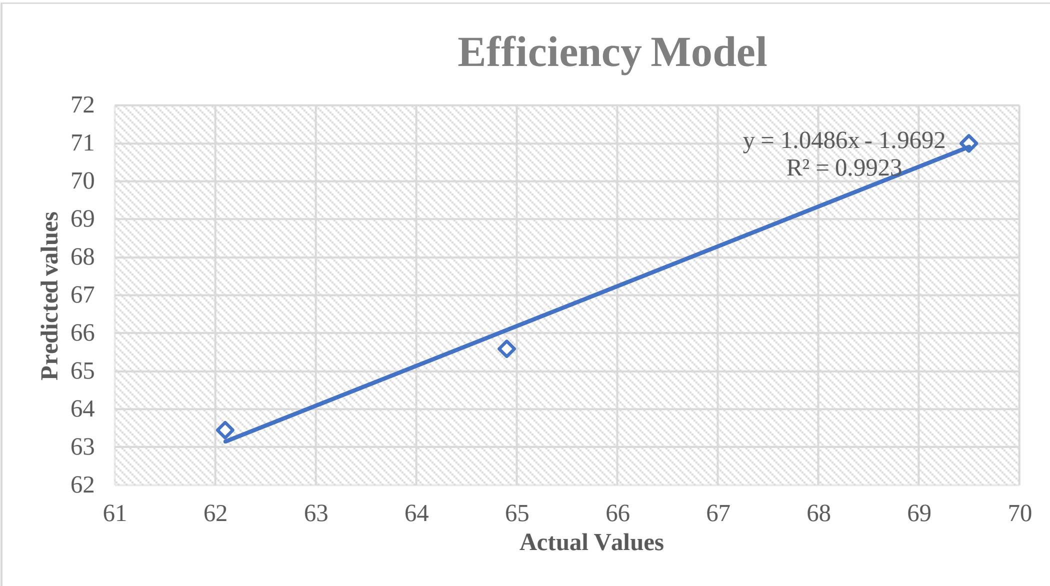

Figure 4.1: Measured Efficiency Versus Computed Machine Efficiency

5.2 Capacity validation

In Table 4.2, both calculated and measured extracting capacities are displayed. Measured extracting capacity values were determined using Equation 3.27. The analysis demonstrated a favourable alignment between the model and the data obtained from the existing solar pond. The coefficient of determination (R^2), indicating the model's fit to the data, was found to be 0.9923. Table 4.1 and Figure 4.1 present the comparative data used to assess efficiency, considering both experimental results and those derived from formulated performance models. A statistical analysis comparing average predicted and measured efficiencies revealed no significant difference at a 5% level of significance. This was supported by the calculated 't' value (0.9923), which was smaller than the table 't' value (1.0203). These results underscore a robust relationship between the model and the data obtained from the developed fibre-extracting machine.

Table 4.2. The Measured and computed extracting capacities for the extractor machine

Number of Blades	Extracting Capacity (Kg/hr)	
	Computed	Measured
2.2	2.19	2.2
5	4.45	5
5	4.45	5
4	3.89	4

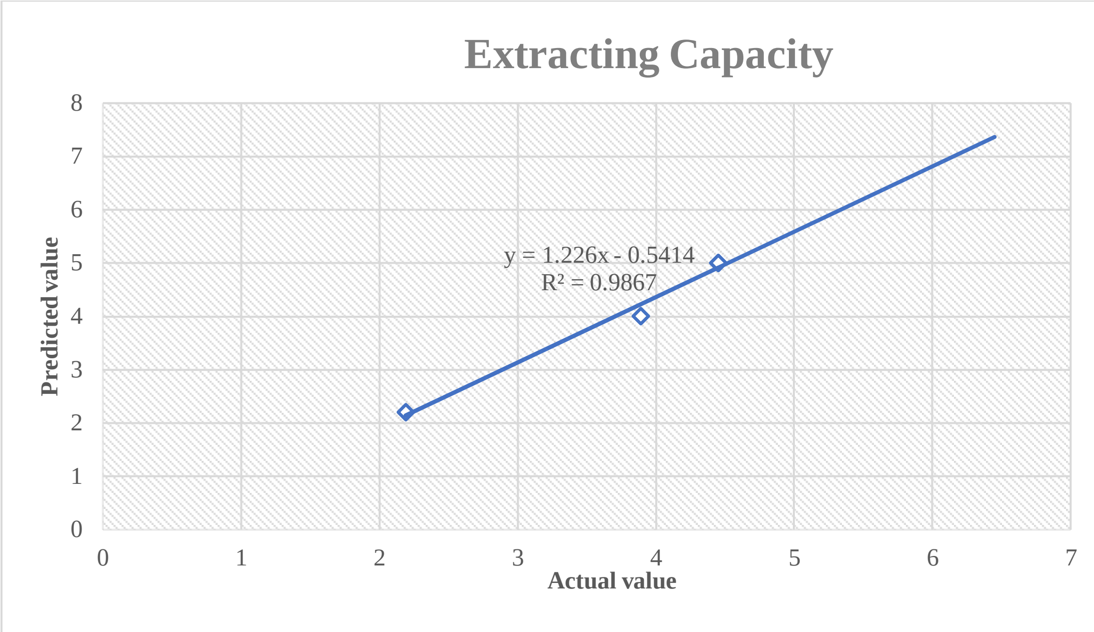

Figure 4.2: Measured Extracting Capacity Versus Computed Extracting Capacity

6. Conclusion

In conclusion, the parametric modelling of the locally produced plantain/banana fiber extractor using the Buckingham Pi-theorem has provided valuable insights into the extraction process. By applying dimensional analysis and developing predictive models, a mathematical framework was introduced to predict the efficiency of the machine and its capacity. This framework utilizes dimensional analysis and is founded on Buckingham's pi theorem.

- The model equation, represented as $\boldsymbol{Ec} = C_c(Dd\ x\ N\ x\ F_e)$ and $\boldsymbol{\eta} = \boldsymbol{C_E}\left(\frac{\theta V^3(\sqrt{\rho})^3}{(\sqrt{E})^3}\right)$ for predicting the capacity and machine efficiency, respectively
- The R^2 values obtained from the analysis were 0.839 and 0.399 for the machine efficiency and capacity, respectively.
- The optimization of variables such as fiber length, blade speed, blade angle, blade material young modulus, the density of the fiber, and the number of blades has the potential to significantly enhance the performance of the extraction process.

The findings of this study contribute to developing a robust and efficient model for fiber extraction, which can lead to increased production rates, improved productivity, and reduced waste. Further research can explore additional variables and conduct experiments to validate and refine the parametric model. This study provides a foundation for advancing plantain/banana fiber extraction technology and its applications in various industries.

References

[1] Akubueze, E. U., Ezeanyanaso, C. S., Orekoya, E. O., Ajani, S. A., Obasa, A. A., Akinboade, D. A., Oni, F., Muniru, O. S., Affo, G., & Igwe, C. C. (2015). Extraction & production of agro-sack from banana (Musa sapientum) & plantain (Musa Paradisiaca l) fibers for packaging agricultural produce. *International Journal of Agriculture and Crop Sciences, 8*(1), 9.

[2] Asonye, G. U., Asoegwu, S. N., Maduako, J. N., & Madubuike, C. N. (2019). A mathematical model for predicting the cutting energy of cocoyam (Colocasia esculenta). *Arid zone journal of engineering, technology & environment, 15*(1), 174–189.

[3] Bhandari, U., Gupta, A., & Kumar, R. (2017). Use of Banana Fiber in the Textile Industry: An Overview. *Textile Research Journal, 86*(4), 403–415.

[4] Bhatnagar, R. K., Sandeep, B. S., & Singh, A. (2018). Techniques for Processing and Utilization of Banana Fiber. *Journal of Cleaner Production,* 191, 272–290.

[5] Bolaji, B. O., Adejuyigbe, S.B., & Ayodeji, S. P. (2008). Performance Evaluation of a Locally Developed Cassava Chipping Machine. *South African Journal of Industrial Engineering, 19*(1), 169-178.

[6] Buragohain, J., Das, B., & Boro, R. A. (2010). Utilization of Banana Pseudo-Stem for Livestock Feeding in Assam, India. Tropical Animal Health and Production, 42(8), 1583–1589.

[7] Buragohain, R., Kalita, G., & Sarma, K (2010). Nutritional significance of banana as swine feed. *Indian Veterinary Journal, 87(*3), 301-302.

[8] Dey, A., Sarma, D., & Gupta, B. K. (2020). Dimensional Analysis of Processing Parameters for Improved Fiber Extraction Efficiency from Herbal Plants. Advanced Manufacturing Technology, 110(5), 1369–1381.

[9] Erhimona, G. O., Onyenanu, I. U., & Utu, O. G. (2023). Optimization of a Locally Fabricated Palm Fruit Digester Using the Response Surface Method (RSM). *International Journal of Engineering Research & Technology (IJERT),* 12(7), 18–24.

[10] Idowu, D. O., & Owolarafe, O. K. (2017). Mathematical modelling of the performance of an impact snake gourd (Trichosanthes cucumerina. L) seed sheller. Agricultural Engineering International: CIGR Journal, 19(1), 142–149.

[11] Ikejiofor, M. C., & Ndirika, V. I. O. (2022). Mathematical Model for Predicting Power Requirement of A Cocoyam Chipper. *Nigeria Agricultural Journal, 53*(1), 55–59.

[12] Jacob, N., & Prema, P. (2008b). A novel process for the simultaneous extraction and degumming of banana fibers under solid-state cultivation. *Brazilian Journal of Microbiology, 39*, 115–121. https://doi.org/10.1590/S1517-83822008000100025

[13] Khan, M. I., Yousuf, W., & Shah, H. A. (2015). A Comprehensive Study of Mechanical Extraction of Fibers and Technological Innovations in Fiber Processing. *International Journal of Agricultural Engineering,* 8(1), 23–31.

[14] Komal, J., Singh, R. P., & Kaur, H. (2020). Influence of Structural Parameters on the Efficiency of Banana Fiber Extractors. *Journal of Agricultural Engineering Research, 139*, 84–95.

[15] Kumar, A., Kumar, K., & Kumar, V. (2019). Innovations in Sustainable Textiles: The Role of Natural Fibers. *Indian Journal of Fiber and Textile Research*, 44(1), 58–78.

[16] Kumar, P., Singh, K., & Verma, R. (2021). Mechanical Properties of Banana Fiber and Their Influence on Textiles. *Journal of Natural Fibers, 18*(2), 122–132.

[17] Maqsood, M. I., Bhat, N. A., & Ganai, M. A. (2019). Moisture Content Effects on Fiber Extraction from Banana Pseudostems: Implications for Quality and Efficiency. *Journal of Agricultural and Food Chemistry,* 67(22), 6347–6355.

[18] Ogunwolu, E. O., Oyewole, O. A., & Olaniyan, O. T. (2019). Optimization of Mechanical Fiber Extraction Systems: A Review of Current Trends and Technologies. *International Journal of Agriculture and Biological Engineering, 12*(4), 109-118.

[19] Onyenanu, I. U., & Uwadibe, U. O. (2024). Development of a Cost-Effective Coconut Dehusking Machine. *International Journal of Innovative Science and Research Technology (IJISRT)* IJISRT24APR2283, 1682-1690.

[20] Onyenanu, I. U., Nwadiuto, C. J., Okeke, C. V., & Okafor, A. M. (2024). Development of a Mathematical Model for Palm Fruit Digester Design: Integrating Dimensional Analysis and Process Optimization. *International Journal of Applied and Natural Sciences*, 2(2), 15–26.

[21] Oreko, B. U., Okiy, S., Emagbetere, E., & Okwu, M. (2018c). Design and development of plantain fibre extraction machine. *Nigerian Journal of Technology, 37*(2), 397–406.

[22] Poudel, S., Chapai, S., Subedi, R. K., Giri, T. R., & Adhikari, S. (2019). Design, fabrication, and testing of banana fibre extraction machine. *Journal of Innovations in Engineering Education*, *2*(1), 165–173. https://doi.org/10.3126/jiee.v2i1.36668

[23] Sahu, S., Sharma, R., & Prasad, A. (2021). Transitioning to Sustainable Fiber Extraction Practices: A Guide for Engineers and Practitioners. *European Journal of Sustainable Development Research, 5(*1), 1-15.

[24] Shafii, S., Upadhyaya, S. K., & Garrett, R. E. (1996). The importance of experimental design to the development of empirical prediction equations: A case study. Transactions of the ASAE, 39(2), 377–384.

[25] Sreekumar, B., Kiran, B. R., & Nikitha, K. (2018). Advances in Mechanical Fiber Extraction Techniques for Flax and Banana Fibers. *Journal of Natural Fibers, 15*(1), 35–47.

[26] Tharar, S., Manokaran, P., & Sobhan, A. (2019). Environmental Benefits of Using Natural Fibers: Applications in the Packaging Industry. Waste Management & Research, 37(6), 596–602.

[27] Ukwu, N. O., Onyenanu, I. U., & Owuama, K. C. (2023). Development of a Low-Cost Banana Fiber Extractor. *International Journal of Innovative Science and Research Technology*, 8(2), 86–92.

[28] Yu, L., Liu, Y., & Gupta, G. (2015). Performance Optimization of an Improved Biomass Gasifier Charcoal Stove Using Response Surface Method (RSM). Energy for Sustainable Development, 29, 90–98.