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Research Article

Synergistic Application of Dimensional Analysis to Optimize Virgin Coconut Oil Press

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About Article

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ABSTRACT

This research explores the optimization of virgin coconut oil (VCO) extraction by integrating dimensional analysis with experimental validation. It aims to create mathematical models that predict machine efficiency, throughput capacity, and oil yield quality based on key variables such as pressure, grind size, moisture level, viscosity, feed rate, and temperature. By applying Buckingham's π theorem, dimensionless groups were formulated to define the functional relationships that regulate oil extraction behavior. The approach employed included constructing a dimensional matrix, developing parametric models, and deriving π-terms, followed by experimental verification. The created models were evaluated against the actual performance of the machine, resulting in regression coefficients (R^2) of 0.0014 for efficiency, 0.0345 for throughput capacity, and 0.4009 for oil yield quality. These values indicate that, while the oil yield model had reasonable predictive strength, the efficiency and throughput models showed little correlation under the testing conditions, indicating opportunities for improvement. Nevertheless, the models captured key trends and exhibited promise for assisting in optimization efforts. This study highlights the effectiveness of dimensional analysis as an economical approach for improving VCO extraction, especially in low-resource settings. Suggested actions include refining the π-terms, applying machine learning techniques to account for non-linear effects, and performing field validations to enhance real-world relevance.

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1. INTRODUCTION

Virgin Coconut Oil (VCO) is being quickly embraced by the United States, other developed countries, and coconut-producing regions as a valuable new coconut product (Bawalan & Chapman, 2006). The term "VCO" refers to an oil that is derived from a fresh, ripe coconut kernel either spontaneously or mechanically, with or without heat and without chemical refinement (Bawalan & Chapman, 2006). At the end of the 20th century, virgin coconut oil (VCO) was first introduced to consumers. It is believed to represent the highest value obtainable from fresh coconuts. Due to its wide range of uses, virgin coconut oil has become one of the most sought-after high-value coconut products in coconut-producing countries (Bawalan & Chapman, 2006; Muralidharan & Jayashree, 2011). The global demand for virgin coconut oil is high because of its various applications in pharmaceuticals, food, cosmetics, and hair care products (Ng *et al.*, 2021). While virgin coconut oil is derived from coconut milk, conventional coconut oil is produced from copra and then refined. Virgin oils are by definition exempt from refining procedures; their superior quality results from the differences in their processing techniques, including fermentation, cold extraction, chilling, freezing and thawing, low-pressure centrifuging, enzymatic methods, supercritical carbon dioxide extraction, expeller processing, and wet milling (Srivastava *et al.*, 2018).

As a result, three production lines were used to demonstrate a conceptual design for the integrated virgin coconut oil processing technology (Bautista *et al.*, 2023). First, Line 1: Low-pressure Oil Extraction for the Production of Virgin Coconut Oil (Bautista *et al.*, 2023). It makes use of virgin coconut oil obtained by the Centrifugation Method, which entails drying grated coconut meat, extracting it under low pressure, centrifuging it, and then decanting the finished product (Bautista *et al.*, 2023). Second, Line 2: Low-pressure oil extraction method for producing virgin coconut oil (which includes collecting rejected sepals, drying the sepals, pressing by hand, settling, and decanting the final virgin coconut oil) (Bautista *et al.*, 2023). Lastly, a modified kitchen process that includes settling, slow heating, filtering, collecting residue (sinuses), and oil drying is used in the virgin coconut oil Production Line 3 (Bautista *et al.*, 2023).

In response to this need, recent initiatives have concentrated on enhancing machine performance through parametric modeling (Idogho *et al.*, 2025). Important physical factors influencing VCO press efficiency include the rate of oil production, levels of free fatty acids, color, refractive index, specific gravity, and pH (Adeyanju *et al.*, 2016). To improve and forecast machine efficiency, throughput capacity, and oil output quality, the current study uses dimensional analysis, specifically Buckingham's π theorem, to create mathematical models (Onyenanu *et al.*, 2024; Rendón-Castrillón *et al.*, 2021). The π theorem guarantees dimensional consistency, making it easier to understand the relationships among various influential variables (Ezechukwu *et al.*, 2025; Flaga, 2015; Zohuri, 2017). Previous research has shown the effectiveness of this methodology in related areas (Onyenanu, 2025). Consequently, this study aims to enhance comprehension by employing dimensional analysis in the design and functioning of VCO extraction systems. The study outlines the theoretical framework of Buckingham's π theorem and elaborates on the parametric modeling technique (Onyenanu *et al.*, 2025). It also shares the results verified through experimental assessments (Onyenanu *et al.*, 2025), with the overarching aim of improving machine performance in settings with resource limitations.

2. LITERATURE REVIEW

Investigators have examined both experimental and theoretical methods to improve the effectiveness and quality of virgin coconut oil extraction. These investigations vary in scope, approach, and application, ranging from chemical extraction methods to complex mathematics and machine learning algorithms. To frame this research, Table 1 presents a summary of chosen related studies that concentrate on the use of dimensional analysis and various optimization techniques in this area.

Table 1. Related works based on the synergistic application of dimensional analysis to optimize the virgin coconut oil press.

Author(s) and year of publication	Study Title	Methods used	Key findings	Significances or limitations noted by the author(s)
Sulaiman *et al.*, (2013)	"Optimization and demonstration of the extraction of strong coconut squander oil"	"…using batch and Soxhlet extractor"	"…it was observed that the mass exchange demonstrated a great fit with the test information for the oil extraction of coconut squander utilizing hexane and petroleum ether with R2 over 0.99."	"…the extraction process was spontaneous, irreversible, and endothermic based on thermodynamic parameters."
(Agarwal & Bosco, 2013)	"Optimization of Aqueous Extraction of Virgin Coconut Oil Using Response Surface Methodology"	"One-factor-at-a-time (OFAT) method and response surface methodology"	"The analysis of variance (ANOVA) of central composite design revealed that temperature (P<0.05), pH (P<0.05), and interaction of these two parameters were highly significant for the yield of VCO with the second order model having the coefficient of determination (R2) of 0.97."	-

(Onyenanu *et al.*, 2025b)	"Advancing Coconut Dehusking Technology: A Dimensional Analysis-Based Parametric Model for Local Production"	"Using dimensional analysis based on Buckingham's π theorem"	"The model was created to help regional producers optimize their equipment for better output. The model was validated using experimental study data, showing a maximum correlation coefficient (R2 = 0.388) between the predicted and measured dehusking efficiencies."	"The model is a useful tool for supply chain participants, especially in environments with limited resources. This research opens the door for future advancements in agricultural machinery design by using dimensional analysis to better understand dehusking mechanisms."
(Idrus *et al.*, 2013)	"Optimization of the Aqueous Extraction of Virgin Coconut Oil by Response Surface Methodology"	"...using response surface methodology"	"The optimization study showed that the method can produce the best yield with quality by using coconut milk (73.8%), fermented (14.1 h), and refrigerated time (20.5 h). Coconut milk percentage and fermentation time significantly affected the response of extraction yield ($p \leq 0.01$)."	"The aqueous extraction can be used commercially for the production of virgin coconut oil as the method is environmentally friendly."
Ionescu *et al.*, (2016)	"Mathematical Modeling of Oil Extraction Process by Dimensional Analysis"	Dimensional Analysis	"Analyzing the graphs obtained based on the mathematical model and the regression analysis of the experimental data, it can be seen that the extracted oil flow increases with the increase in the feeding rate in the range of 0.006-0.014 kg/s."	"...the use of a nozzle with a smaller diameter leads to an increase in the extracted oil flow."
(Mote *et al.*, 2024)	"Manufacturing and performance evaluation of Al/SiC/coconut & bagasse ash composite using novel integrated dimensional analysis (DA) and adaptive neuro fuzzy inference system (ANFIS) techniques"	Novel integrated dimensional analysis (DA) and adaptive neuro fuzzy inference system (ANFIS)"	"From the experimental findings, it has been observed that the yield strength of the new composition is 161.03 N/mm2, which is increased by 23.86%. DA-based MRR prediction models show good results with a correlation coefficient (R2) of 0.9968."	"The model was found to be more reliable."

The reviewed studies utilize diverse methodologies to enhance the extraction of virgin coconut oil, each with distinct strengths. Response Surface Methodology (RSM), employed by Agarwal & Bosco, (2013) and Idrus *et al.*, (2013), focuses on statistical optimization under controlled circumstances. These models demonstrated high R^2 values (up to 0.97), indicating precise management of variables such as temperature and pH. Nevertheless, RSM's dependence on empirical adjustments restricts its flexibility in modeling mechanical systems.

In contrast, Onyenanu *et al.*, (2025b) and Ionescu *et al.*, (2016) utilized dimensional analysis for mechanical systems, developing models founded on essential physical relationships. While Onyenanu's model proved contextually beneficial for local dehusking machines ($R^2 = 0.388$), its predictive ability was not as robust as that of RSM-based models. Ionescu's research linked feeding rate with oil flow but did not examine higher-order interactions.

Mote *et al.*, (2024) addressed this gap by combining dimensional analysis with Adaptive Neuro-Fuzzy Inference System (ANFIS), resulting in enhanced predictive performance ($R^2 = 0.9968$). This hybrid model surpassed both independent dimensional analysis and Response Surface Methodology methods, underscoring its potential for modeling intricate, nonlinear behaviors in extraction systems. In comparison to batch or chemical extraction techniques like Soxhlet, as implemented by Sulaiman *et al.*, (2013), mechanical and computational models provide more scalable options for designing systems and optimizing processes.

3. METHODOLOGY

3.1. Flow chart of the research pathway

In the course of this work, the following are the patterns in which we undertake to achieve this research;

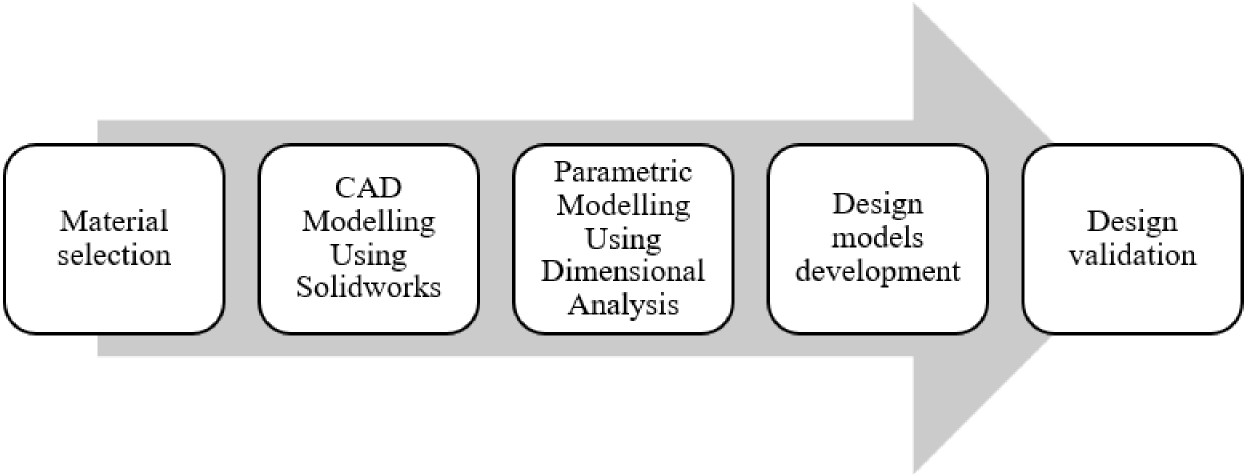

Figure 1. Flow chart of the virgin coconut oil extraction machine

3.2. Overview of the machine description

The Concept Virgin Coconut Oil Extraction Machine was designed using Solidworks Dassault 2023 version, the designed mechanism operates using a screw press type extraction process of the virgin coconut oil from the coconut meat. The Virgin coconut oil extraction machine's major components are the electric motor, the expeller, the feed screw extruder (screw blade shaft), the control panel, the hopper, the machine frame, the compression chamber, and the canvas collector. Power is generated from the 7.5 hp motor to the compression chamber. The compression chamber consists of the screw blade shaft and an extractor expeller. The extraction machine design consideration was based on the forces required to drive the shaft, the diameter of the screw blade shaft, the dynamic load on the bearing transmitted by the screw shaft, and the power needed to compact pulverized feedstock as well as extrude the resultant canvas from the die.

3.3. Material selection and specification

The virgin coconut oil extraction machine was designed using carefully selected materials to ensure durability, efficiency, and food-grade safety standards. Stainless steel is utilised in parts that come into direct contact with coconut products, such as the worm shaft, oil barrel, and hopper, since it is non-toxic, rust-resistant, and meets food safety standards, ensuring that the oil remains clean. Because mild steel is affordable and robust, even when coated to prevent corrosion, it is utilised for structural components like machine frames and extruders. During extended usage, the cast iron motor housing manages heat and mechanical strain, while the nylon castors provide effortless motion without adding bulk. While mild steel reduces costs without sacrificing structural requirements (Csernak & McCormac, 2012), stainless steel is more expensive but is used in crucial locations to ensure product quality. By putting hygiene, durability, and cost-effectiveness first, this method makes the machine reliable and usable in remote areas. Table 2 details the specifications of each major component. Figure 2 shows the 3D CAD model done on the SOLIDWORKS Software version 2023.

Table 2. Technical specifications of each part of the virgin coconut oil extraction machine

Part Name	Material Used	Specifications
Electric Motor	Cast Iron (Fan-cooled)	3-Phase Induction Motor, 1.5 kW (2HP), 1500 RPM, 50 Hz, 380V, IP55 Protection, Continuous duty (S1), 25 kg, TEFC Cooling
Feed Screw Extruder (Screw Blade Shaft)	Mild Steel	Rotating shaft with helical screw blade for conveying and compressing coconut meat
Machine Frame	Mild Steel	U-Channel frame designed to withstand machine weight in both idle and dynamic states
Hopper	Stainless Steel	Truncated rectangular pyramid shape, designed for bulk coconut meat accommodation
Oil Barrel	Stainless Steel	Used for collecting extracted coconut oil
Oil Outlet	Stainless Steel	An outlet for coconut oil extraction
Worm Shaft	Stainless Steel	Rotating shaft for pressing coconut meat
Grater Shaft	Stainless Steel	Used for grinding coconut meat before extraction
Industrial Bearing	Mild Steel	Supports rotating components
Bolt and Nuts	Mild Steel	Used for the assembly of machine components

Castor Roller	Nylon	Supports the mobility of the machine
Control Panel	-	Includes start/stop button, reverse/forward speed button, and gear selector

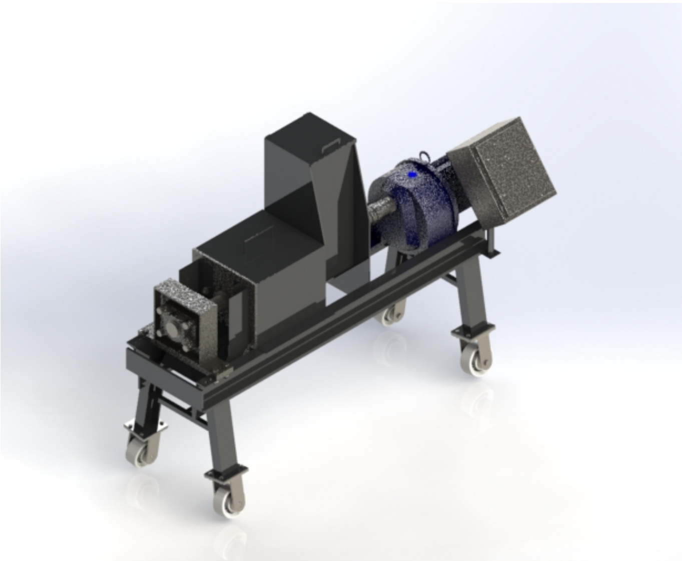

Figure 2. 3D CAD model of the virgin coconut oil extraction machine

3.5. Parametric modelling using buckingham's Pi theory

By identifying the dependent variables and independent variables of the virgin coconut oil (VCO) extraction machine, the developed parametric modelling such as the machine efficiency model, the thorough – put capacity model, the energy consumption model and the oil yield quality model will be used to optimize the virgin coconut oil extraction machine using Buckingham's pi theorem in this study. The dimensionless π-terms generated from Buckingham's π theorem are not just mathematical constructions, but also crucial instruments for optimising the virgin coconut oil extraction process. Each π-term isolates crucial interactions among operational factors, such as pressure, feed rate, grind size, and viscosity, which directly influence the machine's performance outputs, such as efficiency, throughput, and oil yield quality. For instance, π_1 connects pressure and viscosity with machine efficiency, π_2 reflects the impact of feed rate on throughput, and π_3 associate viscosity and grind size with oil yield. These equations simplify intricate variable interactions into more digestible forms, leading to enhanced understanding and focused optimization.

3.5.1. Assumptions in dimensional analysis

- Steady-state operation.
- Uniform material properties (e.g., consistent moisture content).
- Negligible heat loss or friction effects.
- Linear system behavior.

3.6. Model development

3.6.1. The machine efficiency model

The efficiency of the virgin coconut oil extraction machine "η" depends on the following factors; pressure (P), Grind size/ coconut meat size (d), moisture content of the coconut meat (%Cm), viscosity (μ), feed rate (Fr), Speed (S), and Temperature (°C). Therefore, the efficiency "η" in terms of dimensionless parameters, was expressed as:

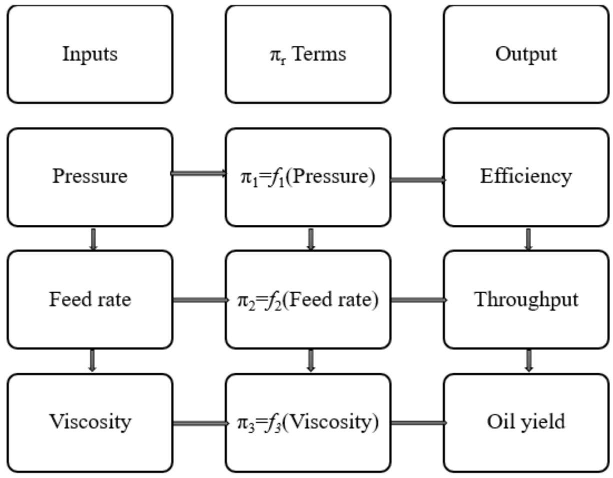

Figure 3. Conceptual diagram showing the role of π-terms in machine optimization

Table 3. Variables affecting the efficiency of the virgin coconut oil extraction machine

Variables	Symbol	Unit	Dimension
Pressure	P	Pa	$M^1L^{-1}T^{-2}$
Grind size	D	mm	L^1
Viscosity	μ	$N.s/m^2$	$M^1L^{-1}T^{-1}$
Efficiency	η	%	$M^0L^0T^0$
Moisture content	M_c	%	L^0T^0
Speed	S	m/s	L^1T^1
Temperature	K	°C	Θ
Feed rate	F_r	Kg/hr	M^1T^{-1}

η was a function of P, D, μ, M_C, S, Fr, and K

$\eta = f(P, D, \mu, M_c, S, Fr, K)$ ....(3.1)

Note that dependent variables = independent variables

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

$f = (P, D, \mu, M_c, S, Fr, K, \eta) = 0$ ....(3.2)

The total number of variables, n, is equal to 8

Number of fundamental dimensions for the problems = 4 (M, L, T, Θ).

Therefore, the number of π-term (ie. π_1, π_2, π_3, π......n)

n - m = 8 – 4 = 4

However, there will be for π_1, π_2, π_3, and π_4,

$\pi_1 = C_e f(\pi_2\ \pi_3\ \pi_4)$ ....(3.3)

where; C_e = Efficiency constant, π_1, π_2, π_3, π_4, = Pi terms to be determined.

$\pi_1 = D^{a1} \quad P^{b1} \quad \mu^{c1} \quad K^{d1} \quad (\eta)$ ....(3.4)

$\pi_2 = D^{a2} \quad P^{b2} \quad \mu^{c2} \quad K^{d2} \quad (F_r)$ ....(3.5)
$\pi_3 = D^{a3} \quad P^{b3} \quad \mu^{c3} \quad K^{d3} \quad (M_c)$ ....(3.6)
$\pi_4 = D^{a4} \quad P^{b4} \quad \mu^{c4} \quad K^{d4} \quad (S)$ ....(3.7)

Table 4. Dimensional matrix of variables for the machine efficiency model

Dimensional Unit	Variables							
	S	D	P	Mc	K	μ	Fr	η
	a	b	c	D	e	f	g	h
M	0	0	1	0	0	1	1	0
L	1	1	-1	0	0	-1	0	0
T	-1	0	-2	0	0	-1	-1	0
Ө	0	0	0	0	0	0	0	0

Considering equation 3.4,
$\pi_1 = D^a \quad P^b \quad \mu^c \quad K^d \quad (\eta)$
Substitute dimensions on both sides
$M^0L^0T^0\Theta^0 = L^a \quad (M^1 L^1 T^{-2})^b \quad (M^1 L^{-1} T^{-1})^c \quad M^0L^0T^0\Theta^0$
$M^0L^0T^0 = M^{b+c} \quad L^{a+b-c} \quad T^{-2b-c}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b. Where, b = 0 (from T-value)
Therefore, c = 0
Power of L = a + b − c = 0 (from the power of M, c = -b)
a + b − (-b) = 0
a + 2b = 0
a = -2b Where, b = 0 (from T-value)
a = 0
Power of T = -2b − c = 0
-2b − (-b) = 0 (from the power of M, c = -b)
-2b + b = 0
b = 0
substituting the power of the values a, b, c, in the 1st pi term 3.4,
$\pi_1 = D^0 \quad P^0 \quad \mu^0 \quad K^0 \quad (\eta)$
$\pi_1 = (\eta)$ ....(3.8)
from Eqn 3.5,
$\pi_2 = D^a \quad P^b \quad \mu^c \quad K^d \quad (F_r)$
Substitute dimensions on both sides
$M^0L^0T^0\Theta^0 = L^a \quad (M^1 L^1 T^{-2})^b \quad (M^1 L^{-1} T^{-1})^c \quad \Theta^0 \quad M^1T^{-1}$
$M^1T^{-1} = M^{b+c+1} \quad L^{a+b-c} \quad T^{-2b-c-1}$
Comparing the powers of M L T
Powers of M = b + c + 1 = 0
C = -b - 1 Where, b = 0 (from T-value)
Therefore, c = -1
Power of L = a + b − c = 0 (from the power of M, c = -b - 1)
a + b − (-b - 1) = 0
a + 2b + 1 = 0
a = -2b − 1 Where, b = 0 (from T-value)
a = -1
Power of T = -2b − c − 1 = 0
-2b − (-b - 1) − 1 = 0 (from the power of M, c = -b)
-2b + b + 1 - 1 = 0
b = 0
substituting the power of the values a, b, c, in the 2nd pi term 3.5,
$\pi_2 = D^{-1} \quad P^0 \quad \mu^{-1} \quad K^0 \quad (F_r)$
$\pi_2 = F^r/(D.\mu)$ ....(3.9)
Considering equation 3.6,
$\pi_3 = D^a \quad P^b \quad \mu^c \quad K^d \quad (M_c)$
Substitute dimensions on both sides
$M^0L^0T^0\Theta^0 = L^a \quad (M^1 L^1 T^{-2})^b \quad (M^1 L^{-1} T^{-1})^c \quad L^0T^0\Theta^0$
$L^0T^0\Theta^0 = M^{b+c} \quad L^{a+b-c} \quad T^{-2b-c}$
Comparing the powers of M L T
Powers of M = b + c = 0
C = -b. Where, b = 0 (from T-value)
Therefore, c = 0
Power of L = a + b − c = 0 (from the power of M, c = -b)
a + b − (-b) = 0
a + 2b = 0
a = -2b Where, b = 0 (from T-value)
a = 0
Power of T = -2b − c = 0
-2b − (-b) = 0 (from the power of M, c = -b)
-2b + b = 0
b = 0
substituting the power of the values a, b, c, in the 3rd pi term 3.6,
$\pi_3 = D^0 \quad P^0 \quad \mu^0 \quad K^0 \quad (M_c)$
$\pi_3 = (M_c)$ ....(3.10)
Considering equation 3.7
$\pi_4 = D^a \quad P^b \quad \mu^c \quad K^d \quad (S)$ ....(3.11)
Substitute dimensions on both sides
$M^0L^0T^0\Theta^0 = L^a \quad (M^1 L^1 T^{-2})^b \quad (M^1 L^{-1} T^{-1})^c \quad L^1T^1$
$M^1L^{-3}\Theta^0 = M^{b+c} \quad L^{a+b-c+1} \quad T^{-2b-c+1}$
Comparing the powers of M L T
Powers of M = b + c = 0
C = -b Where, b = 1 (from T-value)
Therefore, c = -1
Power of L = a + b − c + 1 = 0 (from the power of M, c = -b)
a + b − (-b) + 1 = 0
a + 2b + 1= 0
a = -2b + 1 Where, b = 1 (from T-value)
a = -1
Power of T = -2b − c + 1 = 0
-2b − (-b) + 1 = 0 (from the power of M, c = -b)
-2b + b + 1 = 0
b = 1
substituting the power of the values a, b, c, in the 4th pi term 3.7,
$\pi_4 = D^{-1} \quad P^1 \quad \mu^{-1} \quad K^0 \quad (S)$
$\pi_4 = (P.S)/D\mu$ ....(3.11)
Substituting the values of π_1, π_2, π_3, and π_4 in equation one
$f = (\eta, (F_r/(D.\mu)), (Mc), ((P.S)/(D.\mu)))$ ....(3.12)
$\eta = \Phi\ (F_r/(D.\mu), (Mc), (P.S)/(D.\mu))$ ....(3.13)
To determine the Ƞ-model, substitute the π values above into equation 3.3. However, the efficiency model can be expressed as:
$Ƞ = ((m_c.P.S.F_r)/(D^2.\mu^2))$ ....(3.14)

3.6.2. Thorough-Put Capacity Model

The thorough put of the virgin coconut oil extraction screw press machine "T_c" depends on the Machine efficiency Ƞ, Operating Parameters (Pressure P, Temperature K, Speed S, and federate F_r), Moisture content M_c, Grind size "G_s", Extruder size "E_s", Feeder screw diameter and length F_s, and Machine Uptime U. Therefore, the thorough put of the virgin coconut oil extraction machine "T_c" in terms of dimensionless parameters was expressed as:

Table 5. Variables affecting the throughput of the virgin coconut oil extraction machine

S/N	Variables	Symbol	Unit	Dimension
1	Speed	S	m/s	LT^{-1}
2	Machine efficiency	Ƞ	%	$M^0L^0T^0$
3	Thorough put	T_c	Kg/hr	M^1T^{-1}
4	Pressure	P	MPa	$M^1L^{-1}T^{-2}$
5	Temperature	K	°C	Θ^0
6	Feed rate	F_r	Kg/hr	M^1T^{-1}
7	Moisture Content	M_c	%	$M^0L^0T^0$
8	Grind Size	G_s	mm	L^1
9	Extruder Size	E_s	mm	L^1
10	Machine uptime	U	hr	T^1

Tc = f (S, K, Ƞ, P, Fr, Mc, Gs, Es, U) ....(3.15)
f (Tc, S, K, Ƞ, P, Fr, Mc, Gs, Es, U) = 0 ....(3.16)
The total number of variables, n is equal to 10
Number of fundamental dimensions = 4 (M, L, T, Θ)
Therefore, the number of π-term = n-m = 6
However, there will be for $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6$
Hence this eqn can be written as $f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6) = 0$ ....(3.17)
By choosing S, F_r, P, and K as repeating variables, we get π-terms as

$\pi_1 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d, \quad T_c$ ....(3.18)
$\pi_2 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad Ƞ$ ....(3.19)
$\pi_3 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad M_c$ ....(3.20)
$\pi_4 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad U$ ....(3.21)
$\pi_5 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad G_s$ ....(3.22)
$\pi_6 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad E_s$ ....(3.23)

Dimensional Unit	**Variables**									
	S	**K**	**Ƞ**	**Mc**	**Gs**	**Es**	**P**	**Fr**	**U**	**Tc**
	a	b	c	d	e	f	g	h	I	j
M	0	0	0	0	0	0	1	1	0	1
L	1	0	0	0	1	1	-1	0	0	0
T	-1	0	0	0	0	0	-2	-1	1	-1
Θ	0	0	0	0	0	0	0	0	0	0

First π-term

$\pi_1 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d, \quad T_c$ ....(3.24)
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad M^1T^{-1}$ ....(3.25)
$M^1T^{-1} = M^{b+c+1} \quad L^{a-c} \quad T^{-a-b-2c-1}$
Comparing the powers of M L T
Powers of M = b + c +1 = 0
c = -b – 1, Where, b = -1 (from T-value)
Therefore, c = -5/2
Power of L = a – c = 0 (from the power of M, c = -b)
a = -b - 1 Where, b = -1 (from T-value)
a = -5/2
Power of T = -a - b – 2c – 1 = 0
-(-b – 1) – b – 2(-b – 1) (from the power of M, c = -b – 1, from the power of L, a = c)
b + 1 – b + 2b + 2 = 0, 2b + 3 = 0
b = -3/2
substituting the power of the values a, b, c, in the 1st pi term,

$\pi_1 = S^{-5/2}, \quad F_r^{\,-3/2}, \quad P^{-5/2}, \quad K^0, \quad (T_c)$
$\pi_1 = (T_c/((S^2 \sqrt{}S.F_r \sqrt{}(F_r).P^2 \sqrt{}P)))$ ....(3.26)

Second π-term

$\pi_2 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad (Ƞ)$
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad M^0L^0T^0$ ....(3.27)
$M^0L^0T^0 = M^{b+c} \quad L^{a-c} \quad T^{-a-b-2c}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b, Where, b = 0 (from T-value)
Therefore, c = 0
Power of L = a – c = 0 (from the power of M, c = -b)
a = -b Where, b = 0 (from T-value)
a = 0
Power of T = -a - b – 2c = 0
-(-b) – b – 2(-b) (from the power of M, c = -b, from the power of L, a = c)

$b - b + 2b = 0,$
$b = 0$
substituting the power of the values a, b, c, in the 2nd pi term,
$\pi_2 = S^0, \quad F_r^{\,0}, \quad P^0, \quad K^0 \quad (\eta)$
$\pi_2 = (\eta)$ ....(3.28)

Third π-term

$\pi_3 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad M_c$
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad M^0L^0T^0$ ....(3.29)
$M^0L^0T^0 = M^{b+c} \quad L^{a-c} \quad T^{-a-b-2c}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b, Where, b = 0 (from T-value)
Therefore, c = 0
Power of L = a − c = 0 (from the power of M, c = -b)
a = -b Where, b = 0 (from T-value)
a = 0
Power of T = -a - b − 2c = 0
-(-b) − b − 2(-b) (from the power of M, c = -b, from the power of L, a = c)
b − b + 2b = 0,
b = 0
substituting the power of the values a, b, c, in the 4th pi term,
$\pi_3 = S^0, \quad F_r^{\,0}, \quad P^0, \quad K^0 \quad (M_c)$
$\pi_3 = (M_c)$ ....(3.30)

Fourth π-term

$\pi_4 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad U$
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad T^1$ ....(3.31)
$T^1 = M^{b+c} \quad L^{a-c} \quad T^{-a-b-2c+1}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b, Where, b = -1/2 (from T-value)
Therefore, c = ½
Power of L = a − c = 0 (from the power of M, c = -b)
a = -b Where, b = -1/2 (from T-value)
a = ½
Power of T = -a - b − 2c + 1 = 0
-(-b) − b − 2(-b) + 1 = 0 (from the power of M, c = -b, from the power of L, a = -b)
b − b + 2b + 1 = 0,
b = -½
substituting the power of the values a, b, c, in the 5th pi term,
$\pi 4 = S^{1/2}, \quad F_r^{\,-1/2}, \quad P^{1/2}, \quad K^0 \quad U$
$\pi 4 = (((\sqrt{(S.P)})U)/\sqrt{(F_r)})$ ....(3.32)

Fifth π-term

$\pi 5 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad G_s$
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad L^1$ ....(3.33)
$L^1 = M^{b+c} \quad L^{a-c+1} \quad T^{-a-b-2c}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b, Where, b = -1/2 (from T-value)
Therefore, c = ½
Power of L = a − c + 1= 0 (from the power of M, c = -b)
a = -b − 1 Where, b = -1/2 (from T-value)
a = ½
Power of T = -a - b − 2c = 0
-(-b − 1) − b − 2(-b) = 0 (from the power of M, c = -b, from the power of L, a = -b)
b + 1 − b + 2b = 0,
b = -½
substituting the power of the values a, b, c, in the 6th pi term,
$\pi 5 = S^{1/2}, \quad F_r^{\,-1/2}, \quad P^{1/2}, \quad K^0 \quad G_s$
$\pi 5 = (((\sqrt{(S.P)})G_s)/\sqrt{(F_r)})$ ....(3.34)

Sixth π-term

$\pi 6 = S^a, \quad F_r^{\,b}, \quad P^c, \quad K^d \quad E_s$
Writing dimensions on both sides, we have:
$[MLT\Theta]^0 = (L^1T^{-1})^a \quad (M^1T^{-1})^b \quad (M^1L^{-1}T^{-2})^c \quad L^1$ ....(3.35)
$L^1 = M^{b+c} \quad L^{a-c+1} \quad T^{-a-b-2c}$
Comparing the powers of M L T
Powers of M = b + c = 0
c = -b, Where, b = -1/2 (from T-value)
Therefore, c = ½
Power of L = a − c + 1 = 0 (from the power of M, c = -b)
a = -b − 1 Where, b = -1/2 (from T-value)
a = ½
Power of T = -a - b − 2c = 0
-(-b − 1) − b − 2(-b) = 0 (from the power of M, c = -b, from the power of L, a = -b)
b + 1 − b + 2b = 0,
b = -½
substituting the power of the values a, b, c, in the 7th pi term,
$\pi 6 = S^{1/2}, \quad F_r^{\,-1/2}, \quad P^{1/2}, \quad K^0 \quad Es$
$\pi 6 = (((\sqrt{(S.P)})E_s)/\sqrt{(F_r)})$ ....(3.36)

Summary of the π-terms

$\pi 1 = (T_c/((S^2\sqrt{S}.F_r\sqrt{(F_r)}.P^2\sqrt{P})))$
$\pi 2 = (\eta)$
$\pi 3 = (Mc)$
$\pi 4 = (((\sqrt{(S.P)})U)/\sqrt{(F_r)})$
$\pi 5 = (((\sqrt{(S.P)})G_s)/\sqrt{(F_r)})$
$\pi 6 = (((\sqrt{(S.P)})E_s)/\sqrt{(F_r)})$
Substituting the values of π1, π2, π3, π4, π5, π6 in equation one

$$f = \left(\frac{T_c}{(S^2\sqrt{S}.F_r\sqrt{F_r}.P^2\sqrt{P})}, \eta, (M_c), \frac{(\sqrt{S.P})U}{\sqrt{F_r}}, \frac{(\sqrt{S.P})G_s}{\sqrt{F_r}}, \frac{(\sqrt{S.P})E_s}{\sqrt{F_r}}\right) \quad ....(3.37)$$

$$T_c = f\left(\frac{1}{(S^2\sqrt{S}.F_r\sqrt{F_r}.P^2\sqrt{P})}, \eta, (M_c), \frac{(\sqrt{S.P})U}{\sqrt{F_r}}, \frac{(\sqrt{S.P})G_s}{\sqrt{F_r}}, \frac{(\sqrt{S.P})E_s}{\sqrt{F_r}}\right) \quad ....(3.38)$$

To determine the thorough-put/capacity (T_c) model, substitute the π values above into equation 3.15. However, the thorough-put/capacity model can be expressed as:
$T_c = ((S.F_r.P)/(\eta.M_c.U.G_s.E_s))$ ....(3.39)

3.6.3. Quality of Oil Yield Model

The quality of the virgin coconut oil yield model "Q" depends on moisture content (M_c) speed (S), pressure (P), feed rate (F_r), Grind size (G_s), extraction time (E_t), and machine efficiency (η). Therefore, the quality yield of the virgin coconut oil "Q" in terms of dimensionless parameters was expressed as:

Table 7. Variables affecting the quality of virgin coconut oil

S/N	Variables	Symbol	Unit	Dimension
1	Moisture content	M_c	%	$M^0L^0T^0$
2	Feed rate	F_r	Kg/hr	M^1T^{-1}
3	Quality yield	Q	Kg/litters	M^1L^1
4	Pressure	P	Pa	$M^1L^{-1}T^{-2}$
5	Grind size	D	mm	L^1
6	Efficiency	η	%	$M^0L^0T^0$
7	Extraction time	E_t	Min	T^1

$Q = f(M_c, D, P, F_r, \eta, E_t)$ ....(3.40)
$f(Q, M_c, D, P, F_r, \eta, E_t) = 0$ ....(3.41)
The total number of variables, n is equal to 8
Number of fundamental dimensions = 3 (M, L, T)
Therefore, the number of π-term = n-m= 7 − 3 = 4

However, there will be for $\pi_1, \pi_2, \pi_3, \pi_4$
$\pi1 = D^a \quad E_t^b \quad P^c \quad Q$ ....(3.42)
$\pi2 = D^a \quad E_t^b \quad P^c \quad M_c$ ....(3.43)
$\pi3 = D^a \quad E_t^b \quad P^c \quad F_r$ ....(3.44)
$\pi4 = D^a \quad E_t^b \quad P^c \quad \eta$ ....(3.45)

Table 8. Dimensional matrix of variables of the virgin coconut oil yield model

Dimensional Unit	D	P	Mc	Q	Fr	η	Et
	a	b	c	d	e	f	g
M	0	1	0	1	1	0	0
L	1	-1	0	1	0	0	0
T	0	-2	0	0	-1	0	1

First π-term

$\pi1 = D^a \quad E_t^b \quad P^c \quad Q$
$M^0L^0T^0 = L^a \quad (T^1)^b \quad (M^1L^{-1}T^{-2})^c \quad M^1L^1$ ....(3.46)
$M^1L^1 = M^{c+1} \quad L^{a-c+1} \quad T^{b-2c}$
The power of M; c + 1 = 0, c = -1
The power of L; a − c + 1 = 0 (but c = -1)
a + 1 + 1 = 0;
a = − 2
a = -2
The power of T; b − 2c = 0, (but c = -1)
b + 2 = 0
b = -2
substitute the value of the pi-term a, b, c
$\pi1 = D^{-2} \quad E_t^{-2} \quad P^{-1}\, Q$
$\pi1 = Q/(D^2.P.E_t^2)$ ....(3.47)

Second π-term

$\pi2 = D^a \quad E_t^b \quad P^c \quad M_c$ ....(3.48)
$M^0L^0T^0 = L^a \quad (T^1)^b \quad (M^1L^{-1}T^{-2})^c \quad M^0L^0T^0$
$M^0L^0T^0 = M^c \quad L^{a-c} \quad T^{b-2c}$
The power of M; c = 0
The power of L; a − c = 0 (but c = 0) a = 0
The power of T; b − 2c = 0, b = 0
substitute the value of the pi-term a, b, c in equation 3.59
$\pi2 = D^0 \quad E_t^0 \quad P^0 \quad M_c$
$\pi2 = M_c$ ....(3.49)

Third π-term

$\pi3 = D^a \quad E_t^b \quad P^c \quad F_r$
$M^0L^0T^0 = L^a \quad (T^1)^b \quad (M^1L^{-1}T^{-2})^c \quad M^1T^{-1}$ ....(3.50)
$M^1T^{-1} = M^{c+1} \quad L^{a-c} \quad T^{b-2c-1}$
The power of M; c +1 = 0, c = -1
The power of L; a − c = 0, a + 1 = 0 (but c = -1) a = -1
The power of T; b − 2c − 1 = 0, (but c = -1) b + 2 − 1 = 0, b = -1
substitute the value of the pi-term a, b, c in equation 3.61
$\pi3 = D^{-1} \quad E_t^{-1} \quad P^{-1} \quad F_r$
$\pi3 = F_r/(D.P.E_t)$ ....(3.51)

Fourth π-term

$\pi4 = D^a \quad E_t^b \quad P^c \quad \eta$ ....(3.52)
$M^0L^0T^0 = L^a \quad (T^1)^b \quad (M^1L^{-1}T^{-2})^c \quad M^0L^0T^0$
$M^0L^0T^0 = M^c \quad L^{a+b-c} \quad T^{b-2c}$
The power of M; c = 0
The power of L; a + b − c = 0 (but c = 0)
a + b = 0;
a = -b (but b = 0) a = 0
The power of T; -b − 2c = 0, b = 0
substitute the value of the pi-term a, b, c
$\pi4 = D^0 \quad E_t^0 \quad P^0 \quad \eta$
$\pi4 = \eta$ ....(3.53)

Summary of the π-terms

$\pi1 = Q/(D^2.P.E_t^2)$
$\pi2 = M_c$
$\pi3 = F_r/(D.P.E_t)$
$\pi4 = \eta$
The energy consumption model

$$= \left(\frac{Q}{D^2.P.E_t^2}, M_c, \frac{F_r}{D.P.E_t}, \eta\right) = \left(\frac{Q.M_c.\eta.F_r}{D^3.P^2.E_t^3}\right)$$

$$Q = f\left(\frac{M_c.\eta.F_r}{D^3.P^2.E_t^3}\right) \quad ....(3.54)$$

$$Q = \left(\frac{D^3.P^2.E_t^3}{M_c.\eta.F_r}\right)S_c \quad ....(3.55)$$

4. RESULTS AND DISCUSSION

4.1. Value of the constant

4.1.1. Determination of the efficiency constant

The efficiency constant was calculated using linearised expressions for π4 and π1, namely, [(P.S)/Dμ and η] extracted from the developed model. To determine the efficiency constant, linear regression analysis of π1 and π4 was plotted which gave a coefficient of regression of 0.0014.

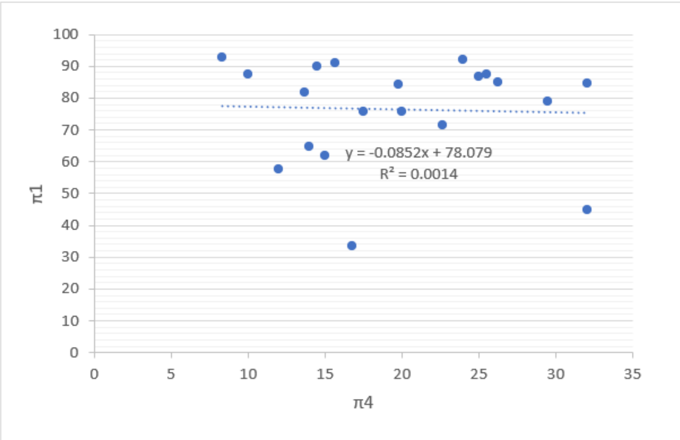

Figure 4. Determination of efficiency Constant

4.1.2. Determination of the thorough-put capacity constant

Simplified formulae for π6 and π1 were used to determine the throughput capacity, namely [T_c/((S^2 √S.F_r √(F_r).P^2 √P)) and ((√(S.P))E_s)/√(F_r)]. We developed a sophisticated model from which these equations were obtained. We employed a solid statistical methodology called the method of least squares, supported by the research of (Bolaji, 2008; Ikejiofor, 2016). We found an intriguing throughput constant result by analysing the data and determining the best-fitting line. Consequently, the regression coefficient, R^2, 0.0345, was determined, as illustrated in Figure 5.

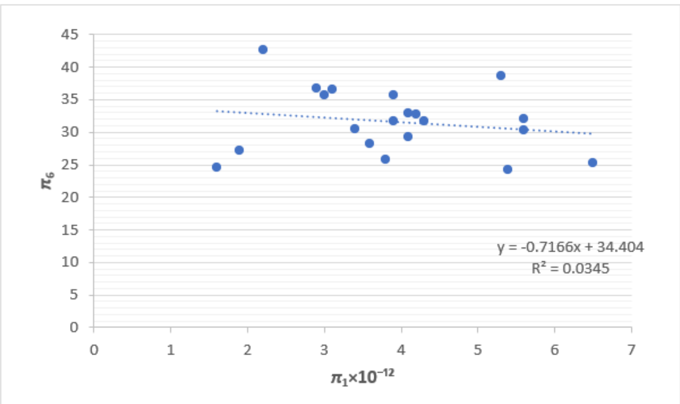

Figure 5. Determination of thorough-put capacity Constant

4.1.3. Determination of the oil yield constant

The linearised expressions for π4 and π1 namely [η and Q/(D^2.P.E_t^2)] that were extracted from the developed model were used to determine the oil yield constant. The oil yield constant was calculated by plotting linear regression analysis of π1 and π4. The process was carried out using the method of least squares, a statistical technique that is explained in the works of (Bolaji, 2008). However, as Figure 6 illustrates, the regression coefficient, R^2, obtained was 0.4009.

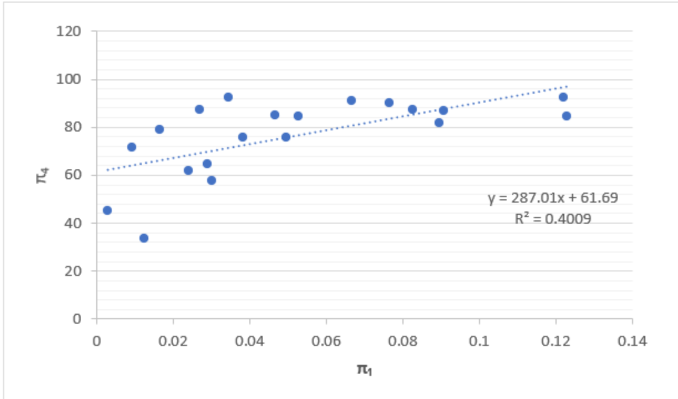

Figure 6. Determination of oil yield Constant

4.2. Design Validation

4.2.1. Efficiency validation

The predicted efficiency was estimated using the dimensional analysis model equation, and the actual value was obtained (Onyenanu *et al.*, 2025). Figure 7 depicts a graphical depiction of the predicted and actual numbers from the experiment for the machine's efficiency. The graph shows a significant degree of similarity between the predicted and actual values for the efficiency investigation (Onyenanu *et al.*, 2025).

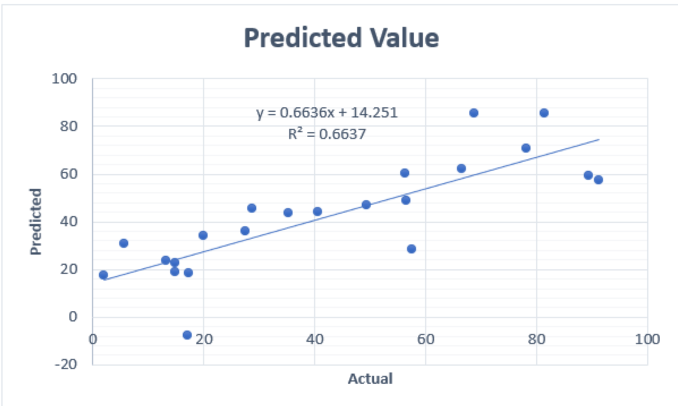

Figure 7. Relationship Between Predicted and Actual efficiency

4.2.2. Oil yield validation

Figure 8 provides a glimpse of both the predicted and actual oil yield. The results of this analysis demonstrated that the model corresponded well with the actual data collected from the developed virgin coconut oil machine (Onyenanu *et al.*, 2024). The value of R^2, which show how accurately the model fits the data, was determined to be 0.8804.

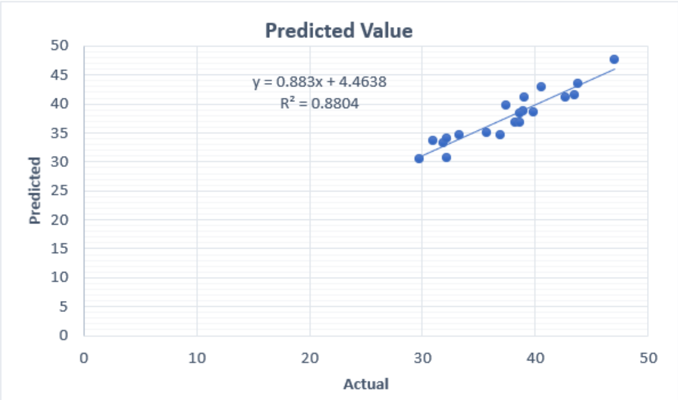

Figure 8. Measured efficiency versus computed efficiency

5. CONCLUSION

This study offers a fundamental strategy for enhancing design and operational performance of coconut oil presses, especially in environments with limited resources. Using dimensional analysis based on Buckingham's π theorem, a mathematical framework was created to forecast the virgin coconut oil press's efficiency, throughput capacity, and oil yield quality.

- The derived model equations which are $\eta = ((m_c.P.S.F_r)/(D^2.\mu^2))$ for efficiency, $T_c = ((S.F_r.P)/(\eta.M_c.U.G_s.E_s))$ for throughput capacity, and $Q=((D^3.P^2.E_t^3)/(M_c.\eta.F_r))S_c$ for oil yield quality were validated using experimental data from the virgin coconut oil extraction machine.
- The regression coefficients (R^2) obtained were 0.0014 for efficiency, 0.0345 for throughput capacity, and 0.4009 for oil yield quality, indicating varying degrees of predictive accuracy.

RECOMMENDATION

Although the model shows promise for streamlining the extraction of virgin coconut oil, more improvement could increase its accuracy. Future research should optimise the dimensionless parameters and add more experimental data to improve the models' forecasting accuracy. Furthermore, optimisation may be enhanced by combining dimensional analysis and machine learning methods. It is also advised to do additional validation in actual production environments to guarantee realistic applicability.

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