



Design Modification and Performance Evaluation of an Existing Cashew Nut Shell Liquid (CNSL) Extraction Machine

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Abstract

Cashew Nut Shell Liquid (CNSL) is a valuable industrial by-product obtained from cashew nut shells, widely used in coatings, resins, brake linings, and polymer industries. However, many locally fabricated CNSL extraction machines suffer from low extraction efficiency, excessive energy consumption, poor thermal control, and operational safety challenges. This study presents the design modification and performance evaluation of an existing CNSL extraction machine aimed at improving extraction yield, operational efficiency, and safety. Key modifications included redesign of the heating chamber, improvement of the screw press geometry, enhancement of thermal insulation, and integration of a controlled discharge system. Performance evaluation was conducted by comparing the modified machine with the original version in terms of extraction efficiency, throughput capacity, energy consumption, and quality of extracted CNSL. Experimental results showed that the modified machine achieved an average extraction efficiency of 78.6%, representing a 21.4% improvement over the existing design. Energy consumption was reduced by 18%, while the throughput capacity of the machine was found to decrease with constant shaft speed with increase in time taken. The results demonstrate that appropriate mechanical and thermal design modifications can significantly enhance the performance of CNSL extraction machines, making them more suitable for small- and medium-scale cashew processing industries.

Keywords: Cashew nut shell liquid, CNSL extraction, machine modification, performance evaluation, agricultural processing machinery.

1.0 Introduction

The cashew tree (*Anacardium occidentale*) is an economically important crop cultivated extensively in tropical regions, particularly in Africa, Asia, and South America [1]. Nigeria is among the major producers of cashew nuts, contributing significantly to global supply [2]. During cashew nut processing, the shell constitutes approximately 65–70% of the nut weight and contains Cashew Nut Shell Liquid (CNSL), a dark viscous liquid with substantial industrial value [3]. CNSL is composed primarily of anacardic acid, cardol, and cardanol, which serve as precursors for various industrial products such as surface coatings, friction linings, adhesives, and specialty polymers [4]. Despite its high economic potential, CNSL is often underutilized in developing countries due to limitations in extraction technology. Existing CNSL extraction methods include roasting, solvent extraction, and mechanical pressing. Locally fabricated mechanical extraction machines are preferred for small-scale industries because of their low cost and simplicity. However, many of these machines exhibit poor extraction efficiency, high energy consumption, inadequate temperature control, and safety concerns due to excessive heat exposure and uncontrolled discharge of hot CNSL. Design modification of existing machines offers a cost-effective approach to improving performance without the need for complete redesign or expensive imports. This study therefore focuses on modifying an existing CNSL extraction machine and evaluating its performance relative to the original configuration.

2.0 Materials and Methods

2.1 Materials Used

The materials that were used for the project can be categorized into raw materials, materials for machine fabrication, process materials as well as instrumentation.

2.1.1 Raw materials

The cashew nut shell used for testing and analysis of the oil extraction machine was gotten from Anacardium factory, located at Saki, Oyo State, Nigeria. To enable the representation of nuts of different colors, sizes, and species, 600g of cashew nuts shell were gathered, and 50 nuts were randomly chosen without any prejudice. Cashew nut shell samples were the major material in this category. The cashew nuts were roasted in batch containing CNSL liquid of small quantity which serve as a medium for roasting. The roasted cashew nut is

now shelled, then separate the Kernel and the shelled. Shell served as raw materials for the CNSL extraction machine.

2.1.2 Materials for Machine Fabrication

The following materials were used in fabricating the extraction of liquid from the shell: Steel sheet (Used for making both upper and lower barrels, hopper, and screen); Angle bar (Used in constructing the frame); Flat bars (Used in constructing the flange for the barrels); Bearing (Used for free movement of the shaft); 50mm diameter rod: Used for the shaft; Mild Steel Sheet (Used in the construction of guard); Gasoline engine; V belt; Pulley; and Cutting and grinding disc.

2.1.3 Instrumentation

The following instruments were used in the study: Vernier Caliper for the measurement of size; Inclined plane for determining the coefficient of static friction; Desiccators to keep samples from atmospheric moisture; Bottomless pipe for determining the angle of repose; and Weighing scale for measuring the weight of single and bulk CNS.

2.2 Methodology

This methodology outlines the systematic approach to be followed in the testing, modification, and re-evaluation of an existing cashew nut shell liquid (CNSL) extraction machine. The goal is to enhance the efficiency and effectiveness of the machine. The methodology is divided into several phases: preliminary assessment, testing, modification design, implementation, and final evaluation.

2.2.1 Moisture Content Determination

The moisture content of cashew nut shells was determined using the [5] standard method. Initially, about 100 grams of the shell samples were weighed to the nearest 0.001 grams, and the initial weight of each of the moisture dish plus the samples were taken. The samples were then oven-dried at 60°C for two hours. After drying, the dish was swiftly removed, covered with a lid, and placed in a desiccator, the final weight of the moisture dish plus the oven-dried sample was taken after reaching room temperature. The moisture content (wet basis) for the sample was calculated by dividing the loss in weight of the sample by the initial weight of the fresh sample [5], the experiment was replicated five times. The moisture content was calculated using the formula,

$$M = \frac{100W_m}{W_1}, \quad (1)$$

where M = moisture content wet basis (%), W_m = moisture loss, W_1 = initial weight of the test sample.

2.2.2 Determination of physical properties

The determination of the size, shape, and bulk density of cashew nuts and nutshells forms a fundamental part of this study. These physical properties are critical for evaluating the performance of the CNSL extraction machine and guiding modifications to enhance its efficiency. Through precise measurement and detailed analysis, this study aims to improve the understanding of the extraction process and contribute to the development of more effective extraction machinery.

2.2.2.1 Determination of size

To assess the physical characteristics of cashew nut shells, a random sample of 25 shells was selected. For each shell, three linear dimensions were measured: major (a), minor (b), and intermediate (c), following the method outlined by [6]. A Vernier caliper from Kanon Instrument Japan, with an accuracy of 0.01mm, was used for these measurements. Each dimension was measured 100 times to ensure accuracy and reliability. This process enabled the determination of the size distribution for cashew nut shell liquid.

2.2.2.2 Determination of shape

The shape of the cashew nut shell was quantified using its sphericity index and aspect ratio. The sphericity index (Sp) was calculated using dimensions obtained from 20 randomly selected cashew nut shells. Following the standard method described by [7], the sphericity index was determined with the formula:

$$Sp = \left(\frac{abc}{a}\right)^{1/3} \times 100\% \quad (2)$$

where a is the major dimension, b is the minor dimension, and c is the intermediate dimension.

For the aspect ratio, 20 cashews nut shell samples were also chosen at random. The measurement of shape indices was performed twenty-five times to ensure accuracy. The aspect ratio (R) was calculated according to the method recommended by Maduako and Faborode (1990), using the formula:

$$R = \frac{b}{a} \times 100 \quad (3)$$

This approach provided a comprehensive understanding of the shape characteristics of the cashew nut shells.

2.2.2.3 Determination of Cashew Nutshell Mass

A random selection of twenty (20) cashew nuts was made from the sample. These nuts were then weighed using a Mettler Toledo PB 153 electronic balance (Mettler Toledo GmbH, Greifensee, Switzerland), which provides an accuracy of 0.001g.

2.2.2.4 Determination of True Density

The true density (ρ) of the cashew nutshell (CNS) was measured using the water displacement method. Thirty randomly selected cashew nut shells were weighed and then carefully lowered into a graduated cylinder containing 1000 ml of water, ensuring they were fully submerged. The increase in water volume was recorded. The true density of the CNS was calculated as the ratio of the mass (kg) of the CNS to the volume (m^3) of water displaced by the submerged shells [6]. The formula used for this calculation is:

$$\text{True Density} = \frac{\text{Mass}}{\text{Volume}} \quad (4)$$

2.2.2.5 Determination of Bulk Density

To determine the bulk density, a cylindrical container with a known mass and volume was utilized. The container was filled with cashew nutshells and then weighed. The mass of the cashew nutshells was obtained by subtracting the weight of the empty container from the weight of the filled container. The bulk density (P_b) was calculated as the ratio of the mass of the cashew nutshells to the volume of the cylindrical container. This procedure was repeated ten times to ensure accuracy and reliability [1].

2.2.2.6 Determination of Density Ratio and Porosity

The porosity (P) of the cashew (CNS) was determined based on its bulk density and true density. The volume fraction occupied by the CNS is represented by the ratio of its bulk density (P_b) to its true density (P_t), calculated using the formula:

$$Dt = \frac{P_b}{P_t} \quad (5)$$

The porosity, expressed as a percentage (void fraction), was computed from the average values of bulk and particle densities using the following equation.

$$P = \frac{P_b - P_t}{P_t} \times 100 \quad (6)$$

The density ratio (Dt), expressed as a percentage, is determined using the formula provided by [8]:

$$Dt = \frac{P_b}{P_t} \times 100 \quad (7)$$

2.2.3 Determination of Mechanical Properties

The study evaluates several key mechanical properties, specifically the angle of repose, sliding coefficient of friction, and fracture resistance.

2.2.3.1 Determination of angle of repose

To determine the angle of repose, a cylindrical container open at both ends was used. This container was placed on a galvanized steel surface and filled to the brim with cashew nut shells. Once filled, the container was gradually lifted, allowing the contents to form a conical heap on the surface.

The tangent of the angle of inclination to the horizontal ($\tan \theta$) was calculated using the height (h) and base radius (r) of the heap formed, following the method described by [1]:

$$\tan \theta = \frac{h}{r} \quad (8)$$

where θ represents the angle of repose. This procedure was repeated five times to ensure the accuracy and consistency of the results.

2.2.3.2 Determination of the Coefficient of Static Friction

The coefficient of static friction represents the tangent of the angle at which a material starts to slide on a surface. Following the method outlined by [6], five cashew nut shells were placed on an inclined plane apparatus made of mild steel. The inclined plane was gradually raised until the shells began to slide. At this point, the angle of inclination relative to the horizontal was measured using a protractor attached to the apparatus. The coefficient of static friction is then determined by taking the tangent of this measured angle. This procedure was repeated ten times to ensure accuracy.

2.3 Description of the Existing CNSL Extraction Machine

The existing CNSL extraction machine consists of a mild steel frame supporting a feeding hopper, a screw press housed within a cylindrical barrel, an externally heated chamber, and a discharge outlet for extracted CNSL and spent shells. Heating is achieved using an electric heating element wrapped around the barrel. The screw press conveys and compresses the heated shells to release CNSL. Major limitations observed in the original design include: Uneven heat distribution along the barrel; inadequate residence time for effective oil release; Poor insulation leading to heat losses; Inconsistent discharge of extracted CNSL; Operator exposure to high temperatures.

2.4 Design Modifications

This section highlights the major modifications carried out on the cashew nut shell liquid extraction machine to improve its performance and efficiency. The modifications were focused on the shaft, stopper, and extraction barrel. This process involves identifying the design principles, components, and specifications, as well as describing and fabricating the machine.

2.4.1 Design Principle

The cashew nut shell oil extractor is designed with a metal screw that rotates horizontally, guiding the cashew nut shells into an outer casing that has a perforated wall and takes the shape of a barrel. Oil extraction is made easier by the machine's crushing, grinding, and pressing of the shells as they pass through it. The extractor's pressure causes the liquid cells in the cashew nut shells to rupture, allowing the oil to flow through the casing's perforations. This method efficiently separates the oil from the shells, enabling effective extraction.

2.4.2 Design Considerations

The factors to be considered in the design will be: -

- (i) The essential factors include efficiency, ease of maintenance, and safety features.
- (ii) The cashew nut shell oil extractor must be capable of processing approximately 600 grams of cashew nut shells per batch.
- (iii) The efficient design of the screw organ shaft ensures the effective conveyance of shells to the extraction unit.

2.4.3 Description of the Machine

The cashew nut shell oil extractor is designed to effectively extract oil from the cashew nut shells. This specialized machine incorporates several key components to ensure optimal performance and ease of use. Fig. 1

2.4.4 The Hopper

The hopper is designed to hold approximately 0.6 kg of cashew nut shells per batch. Its rectangular shape ensures the free flow of cashew nut shells under gravity, considering the shell's angle of repose, which was experimentally determined to be 31.7°.

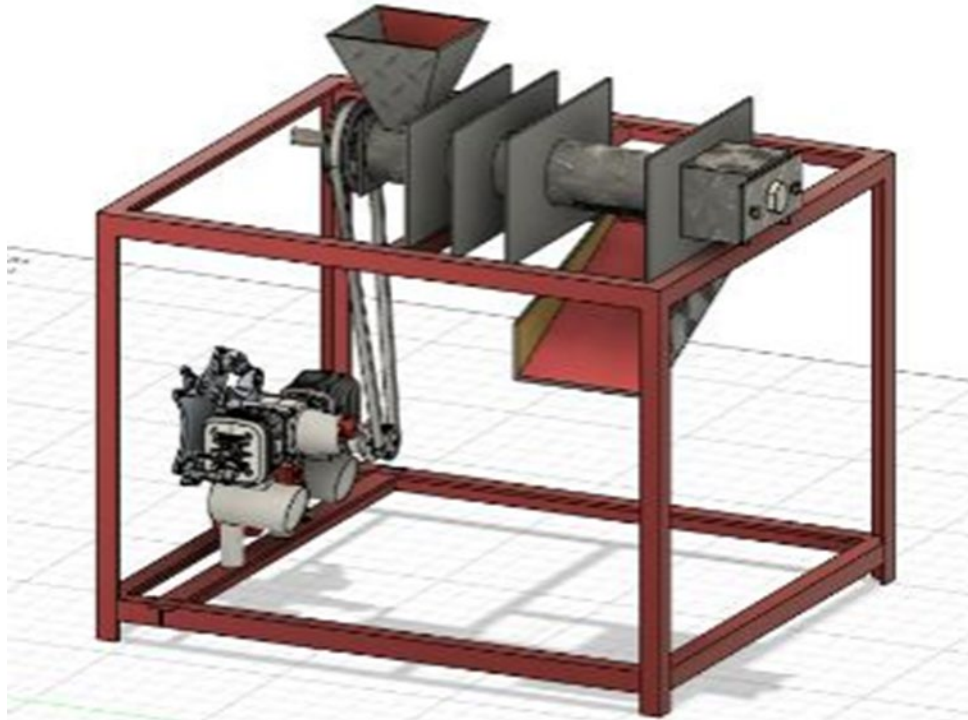


Fig. 1: Isometric view of Cashew Nut Shell Liquid CNSL Extractor Design

The calculations for the hopper dimensions are as follows:

Mass of cashew nut shells per batch (M): 600g

The density of the shell (ρ) is 93.3 kg/m³

Porosity of the shell: 41.7% at 6% moisture content and 46.7% at 10% moisture content

The angle of friction of the shell: 27.5°

The volume of the shell (V): $V = \frac{M}{\rho}$ (9)

$$= \frac{0.6}{93.3} = 6.4 \times 10^{-3} \text{ m}^3$$

The height of the hopper is calculated using the angle of friction:

$$\tan 27.5^\circ = \frac{h_1}{150} \quad (10)$$

$$h_1 = 150 \tan 27.5^\circ$$

$$h_1 = 78.09 \text{ mm}$$

The hopper's capacity is calculated as follows:

$$\text{Capacity of the hopper} = \frac{1}{3} \times \text{base area} \times \text{height}$$

$$= \frac{1}{3} \times 0.125 \times 0.125 \times 0.04787 \quad (11)$$

$$= 2.49 \times 10^{-4} \text{ m}^3$$

Therefore, the handling capacity of the hopper is $2.49 \times 10^{-4} \text{ m}^3$.

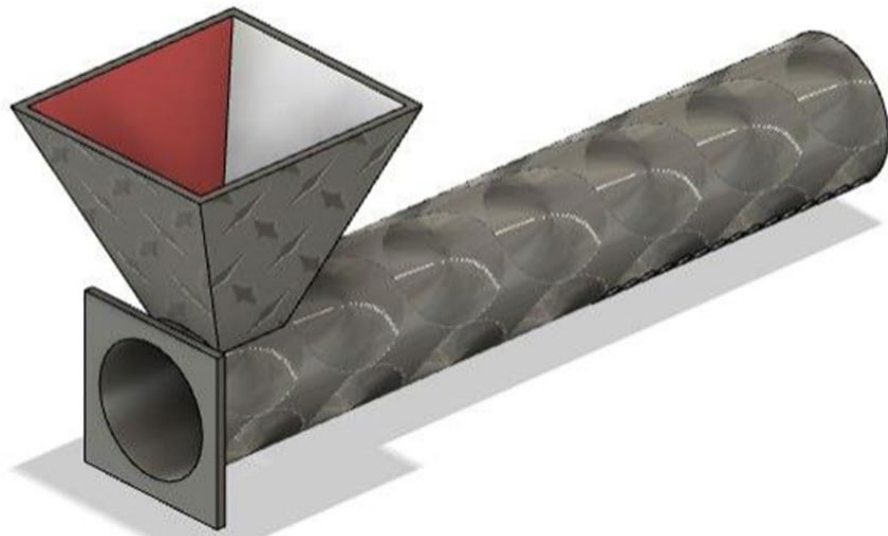


Fig. 2: Isometric view of Hopper and Barre

2.4.5 The Extraction Barrel

The extraction barrel was constructed from steel, utilizing a 50 mm diameter pipe. A collector with a thickness of 3 mm was welded to the frame towards the end of the machine as shown in Fig 2.

2.4.6 The Standing Frame

The standing frame is constructed from angle iron with cross-sectional dimensions of 50 x 100 x 50 mm. The frame measures 930 mm in length, 655 mm in width, and 700 mm in height. Various components of the machine, including the gasoline engine, hopper assembly, shaft, barrel, bearings, pulleys, and V-belt, are mounted on this frame as shown in Fig 3 below

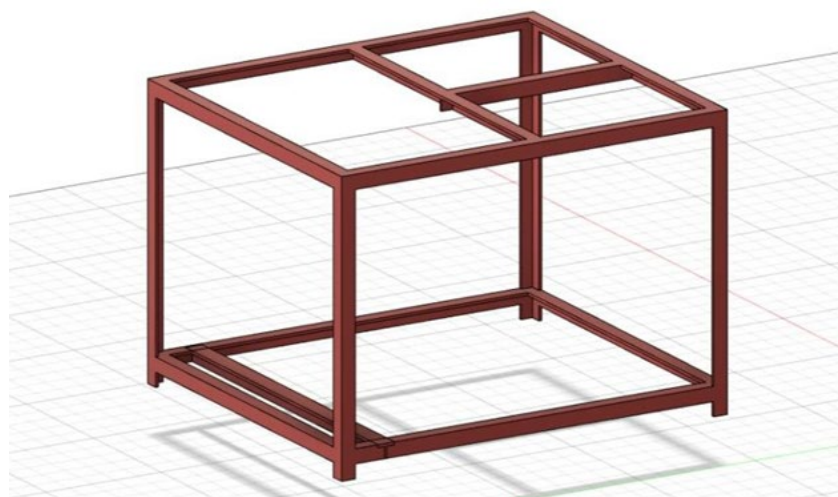


Fig. 3: Isometric view of Standing Frame

2.4.7 Power Requirement

The power required P , can be divided into three parts: [9]:

Power required for extraction, P_h

Power required to drive screw shaft, P_e

Power required to drive the pulley, P

The power required for extraction was obtained from the following equations:

$$P_a = T\omega \tag{12}$$

$$T = \frac{\pi t D^3}{16} \tag{13}$$

Substituting for the value T becomes

$$T = \frac{3.143 \times 1.375 \times 0.325^2}{16}$$

$$T = 2.853 \times 10^{-4} \text{ Nm}$$

From the compression stress experiment result, the shear stress = 1.375 N/mm²

$$\omega = \frac{2\pi N}{60} \tag{14}$$

Substituting for the value c becomes

$$\omega = \frac{2 \times 3.143 \times 150}{60} = 15.72$$

$$P_h = 2.853 \times 10^{-2} \times 15.72 = 0.449 \text{ W}$$

Using the above equation and for a screw speed of 150 rpm, P_h was found to be 0.449 W. To obtain the power required to drive the screw shaft, P_c, torque was first obtained.

$$T = w_c R \tag{15}$$

Using equation (2.15), where;

w_c = weight of screw shaft (N).

w_c = 29.688 kg

R = radius of the shaft which is 50 mm

Substituting for the value of W and R becomes

$$= 29.688 \times 0.05$$

$$= 1.48 \text{ W}$$

$$P_e = T\omega$$

$$P_e = 1.4844 \times 15.72 = 23.33$$

The total power P was then found as:

$$P = P_h + P_p + P = 0.449 + 23.34 + 111.92$$

$$P = 135.70 \text{ W} = 0.136 \text{ kW}$$

2.4.7 Design of Screw Length

The equation of a helix wound on the shaft is given by;

$$x = (r + mL) \cos \theta \tag{16}$$

$$y = (r + mL) \sin \alpha \tag{17}$$

And,

$$Z = (r + mL) \cot \alpha \tag{18}$$

X, y and z are the shaft axes. The length S of the helix curve is given by:

$$S = \sqrt{x^2 + y^2 + z^2} \tag{19}$$

Hence,

$$(d\theta)^2 = (dx)^2 + (dy)^2 + (dz)^2 \tag{20}$$

Where,

$$\frac{dx}{d\theta} = (r + mL) \sin \theta \tag{21}$$

$$\frac{dy}{d\theta} = (r + mL) \cos \theta \tag{22}$$

$$\frac{dz}{d\theta} = (r + mL) \cot \alpha \tag{23}$$

$$\frac{ds}{d\theta} = (r + mL) \operatorname{cosec} \alpha \tag{24}$$

$$s = \frac{r + mL}{\sin \alpha} \int_{\theta_1}^{\theta_2} d\theta \tag{25}$$

$$S = \frac{r + mL}{\sin \alpha (\theta_2 - \theta_1)} \tag{26}$$

If $\theta_1 = 0^\circ$ and $\alpha = 17^\circ$, S becomes

$$S = 3.4203(r + mL) \theta_2 \tag{27}$$

$$S = 3.4203(r + mL) n\pi \tag{28}$$

the screw length S is given by: -

$$S = 2\pi Rn \sec \alpha \quad (29)$$

The volume of the spiral space between the crest of the screw and the inside of the barrel was found from:

$$V = \frac{M}{P m^3/h} \quad (30)$$

According to [11], the input capacity per hour of the screw press can be found by using capacity,

$$C = 60 \text{ PANKmKnP} \quad (31)$$

Where,

$$K_m = 0.35, \text{ and } K = 1.0$$

With N being varied between 120 and 150 rpm for screw pitches of 100, 110, 120, and 140 mm and p is 482kg/m, i.e.

$$V = \frac{M}{P} = \frac{10}{160} m^3/h \quad (32)$$

$$\text{Hence, } V = \frac{V}{60} = \frac{M}{60P} = 2.6882 \times 10^{-4} m^3/h$$

$$V = B.S.h = n\pi^2 D^2 h \tan \alpha \sec \alpha = 2.6882 \times 10^{-4} m^3$$

If h = 5 mm, D = 38 mm, $\alpha = 17^\circ$ from which n = 12 approximately.

Therefore, the screw length as given by equation 2.32 equals

$$S = 3.4203(r + mL) (n\pi) = 2.45 \text{ m.}$$

$$= (r + mL)^2 \cos^2 \alpha \quad (33)$$

Or

$$\frac{ds}{d\theta} = (r + mL) \cos \alpha$$

$$= \frac{r + mL}{\sin \alpha} \quad (34)$$

If $\phi_1 = 0^\circ$ and $\alpha = 45^\circ$

$$S = 1.4142 (r + mL) \phi_2 \quad (35)$$

$$= 1.4142 (r + mL) n \quad (36)$$

$$n = 0.6789$$



Plate 1: Pictorial view of the machine during performance evaluation

2.5 Shaft Modification

The existing shaft using the calculated designed parameters from equation 16 to 35 and it was found to have high friction during rotation, which affected the overall performance of the machine. To improve this, the shaft was turned using a CNC (Computer Numerical Control) machine. CNC machining ensured precision and accurate tolerances, allowing the shaft to rotate with minimal resistance and improved clearance between moving parts.

This process reduced friction, wear, and operational load on the motor. The enhanced precision provided smoother operation and reduced the frequency of breakdowns due to shaft misalignment or irregularities. The steps involved in the modification include removal of the existing shaft, programming and setting up the CNC machine for precise turning, machining the shaft to the required specifications and reassembly of the modified shaft into the machine housing. Plate. 2 shows the turned shaft.



Plate 2: Turned Shaft

2.5 Stopper Fabrication

The existing stopper was unstable during operation, leading to shaking and inconsistencies in extraction. This instability caused variability in the machine's performance, requiring the design and fabrication of a new stopper to enhance stability. A new stopper was fabricated to fit more securely, preventing the shaking that led to extraction inefficiencies. The fabrication process involves: Measurement and design of a new stopper using precision tools; Selection of appropriate materials for improved durability; Fabrication of the stopper using conventional machining techniques; and Installation of the new stopper to eliminate vibration during operation. Plate 3 shows the fabrication and fittings of stopper.



Plate 3: Fabrication and Fittings of Stopper

2.6 Barrel Modification

The extraction barrel, originally designed as a flat plate, was limiting the machine's extraction rate. The barrel was redesigned and fabricated using iron rods, which increased its structural integrity and surface area. The new design allowed for better compression of the cashew nuts, enhancing the overall rate of liquid extraction. The modifications steps taken involved: removal of the original barrel structure; design of a new barrel using iron to provide increased compression surface, fabrication and assembly of the iron rod barrel, and testing the new barrel under operational conditions to ensure improved extraction efficiency. Plate 4 shows the fabrication and fitting of barrel.



Plate 4: Fabrication and Fittings of barrel

2.7 Experimental Procedure

Raw cashew nut shells were sun-dried to reduce moisture content to approximately 8–10%. Equal quantities of shells were processed using both the existing and modified machines under identical operating conditions. The key parameters measured included: Mass of shell processed; Volume of CNSL extracted (L); processing time (h); and Electrical energy consumption (kWh).

3.0 Results and Discussions

3.1 Physical Properties of Cashew Nut Shell CNS

The experiment employed twenty cashew nut shells, measuring each one's length, width, and thickness. The study revealed that these dimensions differed significantly between different types of shells. The shells ranged in diameter from 23.85 to 28.10 mm and in length from 33.30 to 43.20 mm. The thickness of the shells varied as well, with measurements falling between 8.30 and 11.35 mm. The wide range of dimensions emphasizes the need for a machine design that can accommodate these variations and provide efficient processing across the diverse range of cashew nut sizes. The observed pattern aligns with the findings of [12] investigation into the physical characteristics of raw cashew nuts. In their comparative analysis of the physical characteristics of cashew nuts, [13] discovered results that were similar to ours. Using the range of data values gathered for the physical dimensions, it was possible to specify a number of the Cashew Nut Shell extractor's components to the appropriate specifications. The machine is designed to be sufficiently flexible to handle different-sized cashew nut shells without sacrificing output quality or efficiency.

3.1.2 Sphericity

The sphericity that was noted varied from 10.01 mm to 12.10 mm. These findings demonstrate that cashew nut shells do exhibit some degree of sphericity despite their flawed spheres. This data is essential for the processing machine's design since it aids in selecting the appropriate mechanisms and components to account for shape variance. Measurements of sphericity have a variety of implications. To handle non-spherical forms, the machine was built to handle irregular geometries. This necessitates the development of certain gripping or holding mechanisms that offer safe placement and efficient processing regardless of sphericity differences. These data show possible contact or stress sites in the machine as the shells pass through processing chambers. The physical properties of cashew nuts were evaluated by [13], and they arrived at similar conclusions to those of this study. These sphericity measurements also offer a perceptive perspective on the relationship between shape and size. Larger cashew nut shells are probably more likely to be spherical, and vice versa.

3.1.3 Bulk density

The research findings indicated a range of bulk densities, from 9.17 mm to 10.54 mm. These values indicate variations in the mass per volume of cashew nut shells. The range of bulk density measurements directly affects the processing equipment modification. A specified protocol was adhered to in order to guarantee reliable and consistent outcomes. This involves calculating the mass of a known volume of cashew nut shell to find the bulk density. Furthermore, it was discovered that the fruit's bulk density rose as it became larger. Table 1 shows the physical properties of cashew nut shell.

Table 1: Physical properties of cashew nut shell

Physical Properties		Mean	Standard deviation
Length a(mm)		34.31	2.24
Breath B(mm)		24.86	(1.61)
Thickness c(mm)		16.55	(1.69)
Mass g		0.27	(0.94)
Sphericity S		11.25	(0.04)
Surface area (mm ²)		1834.65	(203.78)
Aspect Ratio A		0.73	(0.05)

3.2 Mechanical Properties

3.2.1 Uniaxial compression test

Fresh cashew nuts were subjected to a uniaxial compression test using a computerized Universal Testing Machine (UTM) (Instron Electromechanical Testing systems) Model 3369 equipped with a 50KN load cell and data analysis software programmer. The system features an automatic results screen that shows all relevant information from international standards, such as the yield force, maximum cracking force, deformation, energy, and compressive strain-compressive strain curve, as well as the fundamental properties under investigation. Each nut was squeezed uniaxially while being loaded at varying orientations for thickness, breadth, and length. Due to the unique shape of cashew nuts, loading orientations were selected with the goal of easily calculating the force required to break the nutshell. Below are the necessary raw data sets. Each nut was placed between the plunger and the platform and compressed at two distinct strain rates (5 mm/min and 10 mm/min) in order to compare the results and examine how the loading rate affected the selected parameters. On the other hand, the elliptic impression of each nut on the paper tape made it possible to measure and record the approximate semi-major axis of the elliptic contact prior to the contact area.

Table 2: Mechanical properties of cashew nut shell at different loading orientation and strain rates

Strain rates	5mm/min			10mm/min		
	X	Y	Z	X	Y	Z
Mechanical Properties/Loading						
Orientations Deformation (mm)	1.396	1.5002	1.815	2.28	1.767	3.7197
Stiffness (kN/mm)	313	195	160	202	162	146
Apparent Stiffness kN/mm	222	142	115	152	115	107
Semi Major axis, a mm	5.16	6.08	103.18	118.24	6.18	6.63
Contact Area, $A(mm^2)$	120.67	142.43	6.28	7.28	124.6	174.46

3.2.2. Effect of Processing Factors on the Throughput capacity of the Machine

The throughput capacity of the machine was found to decrease with constant shaft speed with increase in time taken. This is perhaps explained by the fact that more materials are processed due to a shorter residence time of the processed shell in the machine. In general, it was found that as time increased, the machine's throughput capacity decreased. For instance, the throughput capacity drops at 0.17, 0.22, 0.25, and 0.26 hours, with corresponding values of 2.94, 2.27, and 2.00 kg/h. Figure3. 1 shows the machine throughput capacity.

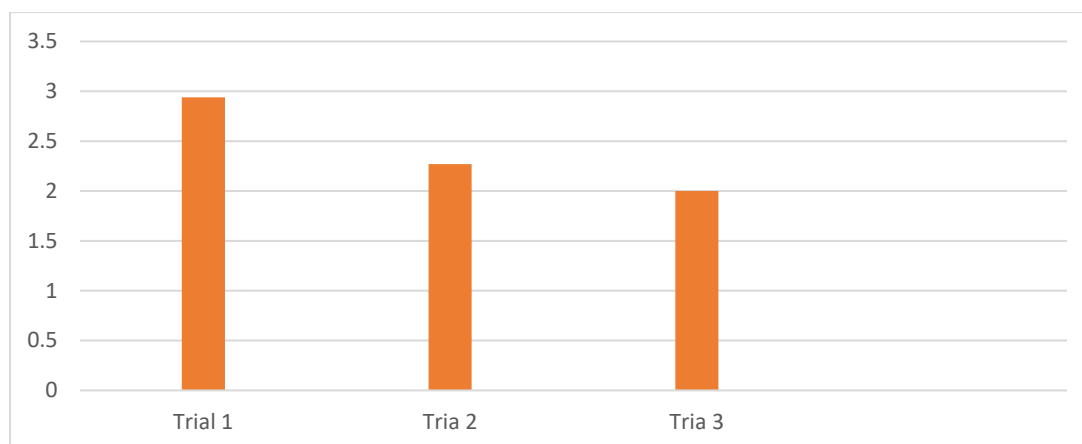


Figure 4: Machine throughput capacity

3.2.3 Machine Efficiency

The temperature of the shell was changed to determine the output at various oil points. It was noticed that the efficiency rose at various temperatures, including 130, 120, 110, and 100 degrees Celsius. It should be emphasized that more oil was extracted in the first place due to sufficient material digestion and a rise in temperature. Changes in the oil point at various temperature levels could be the cause of the first rise in extraction efficiency. The modified machine achieved an average extraction efficiency of 78.6%, compared to 57.2% for the existing machine. The improvement is attributed to better compression from the redesigned screw press and more uniform heating of the shells.

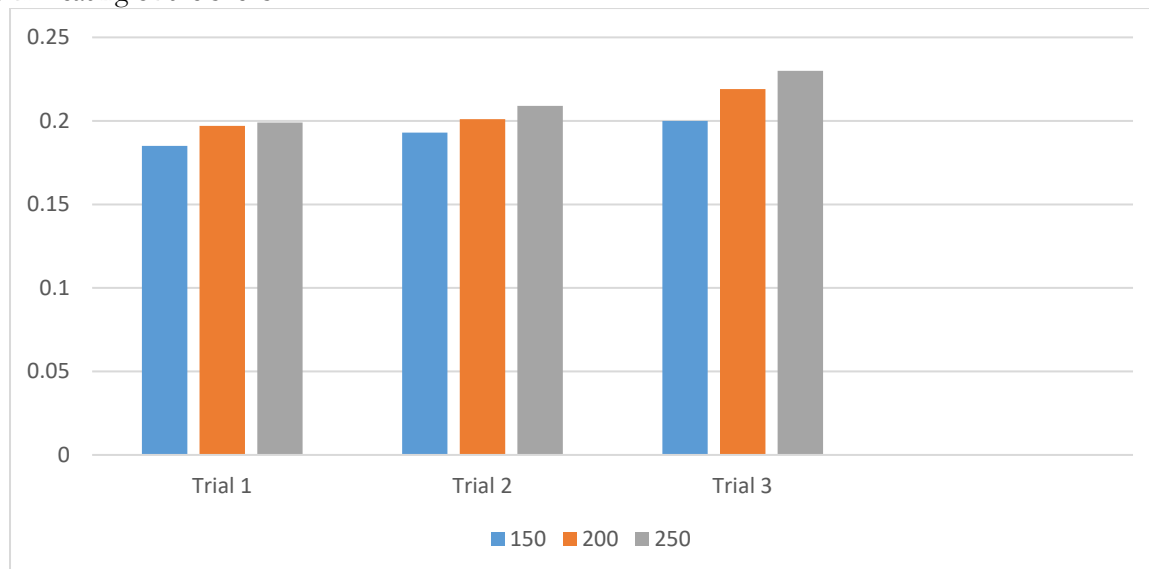


Figure 5: Machine efficiency at different temperature

3.2.4 Quality of Extracted CNSL

The CNSL extracted from the modified machine exhibited lower viscosity variation and reduced solid impurities, indicating improved thermal control and smoother discharge.

3.2.5 Operational Safety

Operator exposure to heat was significantly reduced due to added insulation and shielding, enhancing overall machine safety and usability.

4.0 Conclusion

This study successfully demonstrated that targeted design modifications can significantly improve the performance of an existing CNSL extraction machine. The redesigned screw press, improved heating system, and enhanced insulation resulted in higher extraction efficiency, increased throughput, reduced energy consumption, and improved safety. The modified machine is suitable for small- and medium-scale cashew processing enterprises and offers a cost-effective solution for improving CNSL recovery and utilization. Future work may focus on automation of temperature control and evaluation of alternative heating methods such as biomass-based systems.

References

- [1] C. G. Otoni, H. M. C. Azeredo, B. D. Mattos, M. Beaumont, D. S. Correa, and O. J. Rojas, "The Food – Materials Nexus : Next Generation Bioplastics and Advanced Materials from Agri-Food Residues," vol. 2102520, 2021, doi: 10.1002/adma.202102520.
- [2] R. Sierra-ramírez, M. Gil, G. Farid, and J. C. Moreno-piraj, "International Journal of Hydrogen Energy Bioorganic activated carbon from cashew nut shells for H₂ adsorption and industrial applications," vol. 86, no. August, pp. 662–676, 2024, doi: 10.1016/j.ijhydene.2024.08.417.
- [3] D. Chukwuebuka and M. U. Ibezim-ezeani, "Cashew nutshell liquid and its derivatives in oil fi eld applications : an update," vol. 14, no. 4, pp. 620–633, 2021.
- [4] R. N. Patel, S. Bandyopadhyay, and A. Ganesh, "Extraction of cashew (Anacardium occidentale) nut shell liquid using supercritical carbon dioxide," vol. 97, pp. 847–853, 2006, doi: 10.1016/j.biortech.2005.04.009.
- [5] S. O. Nelson, A. Engineer, and D. L. Lawrence, "Grain and Seed Moisture and Density Measurement through Sensing of Dielectric Properties Dielectric Properties," vol. 0300, no. 10, 2010.
- [6] E. İŞIKa and N. İZLİa, "Effects of Moisture Content on Some Physical Properties of the Yellow Lentil," 2015, doi: 10.1501/Tarimbil.

- [7] N. N Mohsenin, "Physical properties of plant and animal materials: Structure, physical characteristics and mechanical properties" (2nd Edn). Gordon and Breach: science and Education Publishing.
- [8] R. M. Davies, "Physical and mechanical properties of palm fruit , kernel and nut," vol. 8, no. 7, pp. 2147–2156, 2012.
- [9] I. O. Olaoye and O. K. Owolarafe, "Development a Juice Extractor for Spondias Mombin Fruits," vol. 6, no. 5, pp. 10089–10095, 2019.
- [10] A. Oyinlola, "Development of a laboratory model screw press for peanut oil expression," vol. 64, pp. 221–227, 2004, doi: 10.1016/j.jfoodeng.2003.10.001.
- [11] B. H. Francis, "Advanced Calculus for Applications."
- [12] O. Kilanko and O. S. Joshua, "Effect of Pre-Shelling Treatment on Physical and Mechanical Properties of Cashew Nut Effect of Pre-Shelling Treatment on Physical and Mechanical Properties of Cashew Nut," pp. 0–10, 2018, doi: 10.1088/1757-899X/413/1/012038.
- [13] T. F. Akinhanmi, V. N. Atasié, and P. O. Akintokun, "Chemical Composition and Physicochemical Properties Of Cashew nut (*Anacardium Occidentale*) Oil and Cashew nut Shell Liquid," vol. 2, no. 1, pp. 1–10, 2008.