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Development and Performance Evaluation of Shea Butter Kneader in Northern Ghana

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ABSTRACT

The conventional method of shea butter production remains labor-intensive, time-consuming, and poses significant hygiene and safety risks, limiting its efficiency and scalability for local producers. This study presents the design, fabrication, and performance evaluation of an improved shea butter kneader, specifically developed for small to medium-scale processing in Northern Ghana. The novel machine integrates a double-helical ribbon blade mechanism to enhance kneading efficiency, with design modifications targeting safety, hygiene, and ease of maintenance. Performance evaluation across varying batch sizes (15–80 kg) revealed a significant improvement in butter yield ranging from 34.3% to 38.7% compared to traditional manual methods (~21.4%). Kneading time was reduced from 90 minutes to as low as 13 minutes, with a throughput of 135 kg/hr. and energy consumption of approximately 0.15 kWh/kg. A one-way ANOVA and Tukey's post hoc analysis confirmed the statistical significance of these improvements ($p < 0.05$). Simulation results for the shaft and frame showed Von Mises stresses within safe limits and factors of safety above 2.0. These advancements contribute to Sustainable Development Goals (SDGs) 1, 2, 3, and 9 by promoting safer, more efficient, and scalable agro-processing technologies in developing regions.

***Keywords**: Shea butter, Kneading machine, Yield efficiency, SDGs, Agro-processing, Ghana*

Introduction

Shea butter is a natural product generated from the nuts of the shea tree (*Vitellaria paradoxa*), which is native to West Africa (Gallagher et al., 2016). Shea is an important non-timber forest product (NTFP) found in various parts of Africa, including Northern Ghana (Jasaw et al., 2015). Shea nuts have a high concentration of oleic acid, which is used to prepare shea butter (Israel, 2014). Shea butter has been used in traditional African medicine for millennia to cure and protect skin from harsh desert environments (Desam and Al-Rajab, 2021). Shea butter has gained popularity in the culinary, cosmetics, and personal care industries in recent years owing to its natural and sustainable features, and it is occasionally used as a substitute for cocoa butter (Sualihu, 2019).

The shea nuts are harvested, roasted, ground into a shea paste, and kneaded to extract the oils and fats in the manufacturing of shea butter. Locals extract the kernel from the nut by cracking it with stone or mortar and pestle. The shea paste is a creamy material enriched in vital fatty acids, vitamins A and E, and antioxidants. Burns, rashes, extremely dry skin, black spots, skin discoloration, chapped lips, stretch marks, and wrinkles can be treated with shea butter (Shehu *et al.*, 2017). However, the traditional process of producing shea butter is laborious and time-consuming, rendering small-scale manufacturers unable to compete in the global market (Owoo and Lambon-Quayefio, 2018). To overcome this challenge, there is considerable interest in the development of machinery that can automate and expedite the shea butter making process.

The shea butter kneading machine is a mechanical device that separates shea butter oil from its solid material. The equipment is frequently composed of a large drum or cylinder that gently turns, kneads, and compresses the paste to release the butter (Premi and Sharma, 2022).

Shea-butter kneading machines are manually operated machinery and frequently made of durable materials such as stainless steel to withstand the demands of the kneading process. These devices are designed to be easy to clean and maintain (Shehu et al., 2017). The machine operates by feeding raw shea paste into the rotating drum of the machine. As the drum rotates, the paste is kneaded and compacted, causing the butter to separate from water and other impurities in the paste. The butter is collected and further processed to remove any residual impurities (Moses, 2014). The capacity of a shea butter kneading machine varies depending on the size of the machine and output requirements of the user. Some machines can process small quantity of shea paste, whereas others can handle large volumes of paste for commercial manufacturing.

Traditional kneaders rely on single-blade or poorly optimized mixing mechanisms, resulting in non-uniform kneading, longer processing times, and lower oil yield. In addition, conventional kneading machines commonly feature exposed moving parts, such as chains, sprockets, and rotating shafts which pose significant injury risks to operators. The lack of protective guards and emergency stopping mechanisms increases the likelihood of accidents, particularly in rural processing environments where formal safety training may be limited.

Finally, most existing kneading machines are fabricated using open or partially enclosed chambers, exposing the shea paste to dust, insects and other contaminants during operation. In many cases, the use of non-food-grade materials and rough internal surfaces makes thorough cleaning difficult and increases the risk of microbial contamination.

There are several advantages of using a shea butter kneading machine over manual extraction methods. Because the machine can handle more shea paste in less time, the production efficiency is enhanced. Furthermore, the machine ensures a more consistent shea butter quality, which is essential for producing high-class cosmetics and skin care products (Naangmenyele et al., 2023).

In this study, the shea butter kneader is redesigned and fabricated to solve the challenges of safety pertaining to the use of the machines hygiene process, yield of oil, quality of oil, efficient kneading, production rate, ease of maintenance and cleaning.

Materials and Methods

Material selection

Mild steel (Low Carbon) and galvanized steel was selected for the fabrication of the kneading machine. These alloys are commonly available materials and are cold rolled steel. They are available in round, square, rectangular bars, and rectangular sheet plates. They have a good combination of all the typical traits of steel - strength, some ductility, and comparative ease of machining. Chemically, it is very similar to A36 Hot Rolled steel, but the cold rolling process creates a better surface finish and better properties. Tables 1 and 2 represent the experimental conditions and the physical, chemical and mechanical properties, respectively. Figure 1 shows the detailed explosion drawings of the kneading machine.

Table 1: Experimental conditions

Parameters	Variables
Batch sizes	15 kg, 30 kg, 80 kg
Kneading speed	2.5 m/s (equivalent of ~ 145 rpm)
Motor	1.5 kW, 220 V
Ambient conditions	28 – 31ºC
Operation duration	Varied based on batch size

Table 2: Physical, chemical and mechanical properties of the material

Material	Physical	Chemical	Mechanical
	Density, approximately 7.85g/m^3	Iron, Carbon, Manganese, Phosphorus and sulphur	High ultimate Tensile Strength, 370 MPa to 440 MPa
Mild steel	Melting point approximately 1370°C	It reacts with acids and bases but its reactivity is	High yield Strength, 250 MPa to 350 MPa

	relatively low	
Colour, greyish with metallic lustre	It is easily weldable making it a preferred choice	Elongation 15.0%
		Rockwell Hardness, 60 to 70HRC

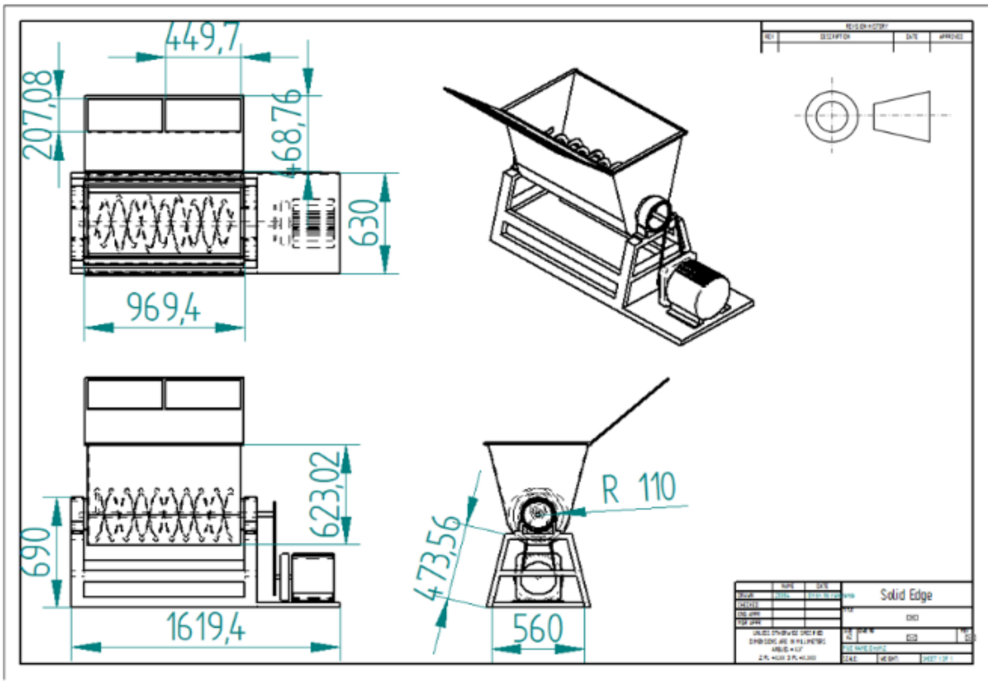

Figure 1: Detailed exploded drawing

Description of components and design analysis

Kneading Chamber

The mixing chamber encompasses the shea butter and other ingredients. The mixing chamber is developed from a 1.5 mm thick galvanized steel sheet metal. The chamber is designed to accommodate the volume of shea butter and provide sufficient space for kneading. It is typically made of galvanized steel, which is corrosion-resistant, easy to clean, and food-friendly.

The design calculations of the chamber are as follows:

Volume of the mixing chamber = Volume of the semi-cylindrical part + Volume of the trapezoidal part

Volume of the semi-cylindrical section:

$$V = \frac{1}{2}\pi r^2 h$$

(1)

Where, r = 192.5mm, h = 385 mm

$$V = \frac{1}{2}\pi(192.5)^2 \times 385 = 22410011.23\ mm^3$$

(2)

Volume of the trapezoidal section

$$V = \frac{1}{2}(b_1 + b_2)h \times l$$

(3)

Where, $b_1 = 385\ mm$, $b_2 = 609.6mm$, h = 450 mm and l = 914.4mm

$V = \frac{1}{2}(385 + 609.6)450 \times 914.4 = 204629004\ mm^3$

Therefore, Volume of the mixing chamber = $22410011.23\ mm^3 + 204629004\ mm^3$

Volume of the mixing chamber = $227039015.2\ mm^3$

Kneading mechanism

The kneading blades are responsible for mixing and kneading the shea butter. The kneading section consists of a helical blade constructed using a mild steel flat bar of 12.5 × 3 mm attached to 120 mm rod around a galvanized pipe of 850 mm length. They are made of stainless steel or food-grade plastics that are durable, non-reactive, and resistant to wear and tear.

Central Shaft

The central shaft has a diameter of 30 mm, a length of 1300 mm and is made of solid mild steel fixed into a galvanized pipe fastened with bolts and nuts on which the blades are mounted. The central shaft connects the motor to the kneading blades and extends into the kneading chamber. It provides support and transmits the rotational motion from the motor to the kneading blades, and this is made of stainless steel. Figures 2, 3, 4 and 5 show the simply supported shaft, free body diagram of the central shaft, shear force and bending moment graph, respectively.

Figure 2 illustrates the shaft modeled as a simply supported beam, an assumption adopted to simplify the analysis while accurately representing the shaft's actual support conditions at the bearings. This figure establishes the span length and locations where loads are applied, forming the basis for subsequent force and moment calculations.

Figure 3 shows the Free Body Diagram (FBD) of the central shaft. The diagram identifies the applied load due to the combined weight of the shea paste and kneading mechanism (784.8 N), as well as the reaction forces at the two supports.

Figure 4 represents the shear force diagram, which was obtained from the shear force equation derived using the FBD. The diagram illustrates how the internal shear force varies along the length of the shaft, indicating points where the shear force changes signs.

Figure 5 shows the bending moment diagram (BMD) of the shaft. This figure demonstrates the distribution of bending moment along the shaft length, with the maximum bending moment occurring at the location of the applied load.

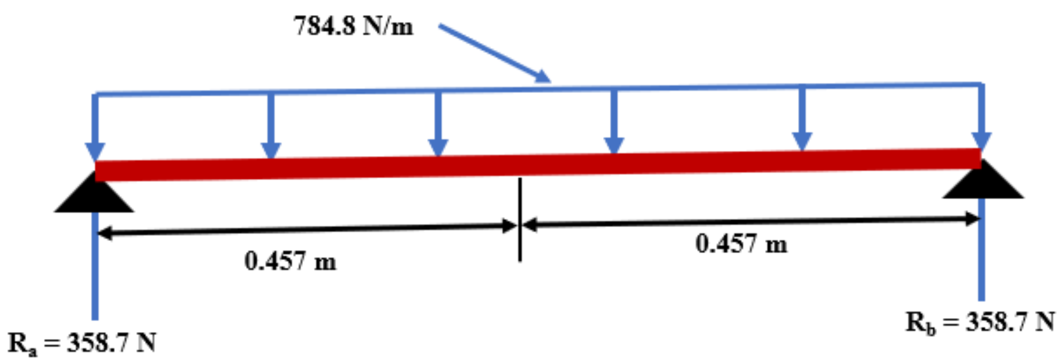

Figure 2: Simply supported shaft

Calculating for the reactions at the support based on the principles of moment.

Clockwise moment is equal to Anti-clockwise moment, therefore,

$+\uparrow \sum Fy = 0; R_a + R_b - (784.8)(0.914) = 0$ (4)

$R_a + R_b = 7176$

$+\overset{\curvearrowleft}{\sum} M_a = 0; R_b\,(0.914) - 717.3(0.457) = 0$
(6)

Free body diagram of central shaft

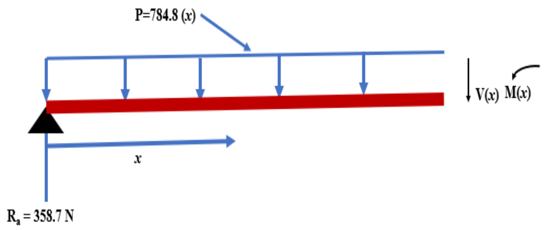

Figure 3: Free body of diagram of the central shaft

Shear force equation

Tables 3, 4 and 5 indicates the shearing force, shear stress and bending moment graph acting on the shaft, respectively.

V(x) = 358.7 – 784.8(x)
(5)

Distance (x)	Shear Force V(x) N; V(x) =358.7 - 784.8 (x)
0	V(0) = 358.7 (0) = 358.7 N
0.23 m	V(0.23) = 358.7 – 784.8(0.23) = 178.15 N
0.46 m	V(0.46) = 358.7 – 784.8(0.46) = -2.36 N
0.69 m	V(0.69) = 358.7 – 784.8(0.69) = -182.86 N
0.914 m	V(0.914) = 358.7 – 784.8(0.914) = 358.7 N

$0.914R_b = 327.8$

$$R_b = \frac{327.8}{0.914} = 358.6N$$

$\therefore R_a = 717.3 - 358.7 = 358.7N$

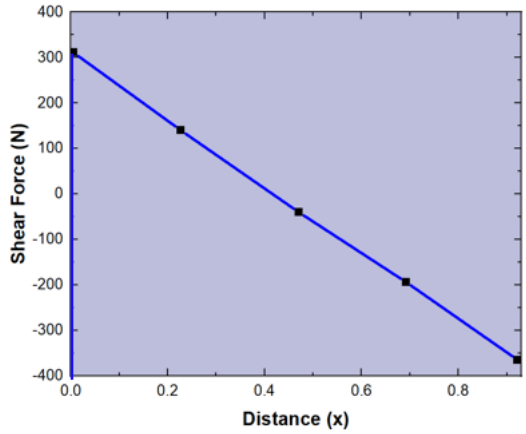

Figure 4: Shear force graph

Shear stress (τ) MPa

$$\tau = \frac{\text{Shear force } (V_{(x)})}{\text{Cross sectional area } (A)}; \tau = \frac{V_{(x)}}{A} \quad (7)$$

$A = \pi \times r^2$; r = 0.15m. where; r is the radius of the shaft

$$A = \pi \times 0.15^2 = \frac{9}{400}\pi m^2 \quad (8)$$

Table 4: Shear stress analysis

Shear Force V(x) N	Shear stresses (τ) Pa; $\tau = \frac{V_{(x)}}{A}$
$V(0) = 358.70N$	$\tau = \frac{358.70\times400}{9\pi} =$ 5073.86 ~ 0.51
$V(0.23) = 178.15N$	$\tau = \frac{178.15\times400}{9\pi} =$ 2520.31 ~ 0.25
$V(0.46) = -2.36N$	$\tau = \frac{-2.36\times400}{9\pi} =$ 0.00
$V(0.69) = -182.86N$	$\tau = \frac{-182.86\times400}{9\pi} =$ −2586.94 ~ 0.26
$V(0.9144) = -358.70N$	$\tau = \frac{-358.7\times400}{9\pi} =$ −5073.86 ~ 0.51

$$+\overset{\curvearrowleft}{\sum} M_a = 0;\ M_{(x)} - 784.8(x)\left(\frac{x}{2}\right) - V_x(x) = 0$$

$$M_{(x)} - \left(\frac{784.8x^2}{2}\right) - (358.65 - 784.8x)(x) = 0$$

$$M_{(x)} - \left(\frac{784.8x^2}{2}\right) - 358.65x + 784.8x^2 = 0$$

$$M_{(x)} + 392.4x^2 - 358.65x = 0$$

$$\left(M_{(x)} = -392.4x^2 + 358.65x\right) N.m \qquad (8)$$

Table 5: Bending moment occurring at different points on the shaft

Distance (x) m	**Blending Moment $M_{(x)}$ (N.m); $M_{(x)} = -392.4x^2 + 358.65x$**
0	$M_{(x=0)} = -392.40^2 + 358.65(0) = 0$
0.23m	$M_{(x=0.23)} = -392.4(0.23)^2 + 358.65(0.23) = 57.47\ N.m$
0.46m	$M_{(x=0.46)} = -392.4(0.46)^2 + 358.65(0.46) = 82.53\ N.m$
0.69m	$M_{(x=0.69)} = -392.4(0.69)^2 + 358.65(0.69) = 57.9\ N.m$
0.91m	$M_{(x=0.91)} = -392.4(0.91)^2 + 358.65(0.91) = 0.00\ N.m$

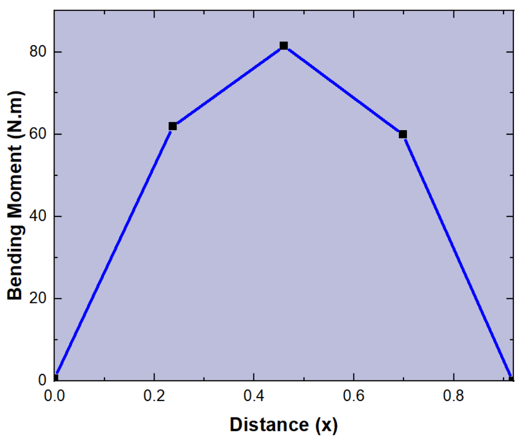

Figure 5: Bending moment graph of the shaft

Electric Motor

The motor provides the rotational power for the kneading process and can be controlled to adjust the speed and intensity of the kneading operation. The motor housing is typically made of durable materials like steel or aluminum, whiles the internal parts are made of copper, steel, and other conductive materials.

Calculating for the motor selection

$V = \omega r$, $P = \omega T$, and $T = Fr$

Where, V= Velocity (kneading speed) = 2.5m/s

angular velocity, ω

r = radius of the blade from the centre of the shaft = 14.5cm = 0.145m

P = Power required

T = Torque

F = Force or Load (weight of shea paste + water) = mg = $80 \times 9.81 = 784.8N$

$xHp = \frac{1\times1961.912}{746} = 2.63 \approx 3$

Therefore, the horsepower of the motor required is $3Hp$.

Calculating the revolution per minute (RPM) of the motor

$\omega = \frac{2\pi N}{60}$, where N = speed of the motor in rpm and $\omega = angular\ velocity = 17.24rad/s$

$N = \frac{60\times17.24}{2\pi} = 1624.83rpm \approx 1625rpm$

Frame and Structure

The frame and structure of the shea butter kneader is designed for stability and strong support and it is made of robust materials such as mild steel to ensure the machine's durability and stability during operation.

The density of material (mild steel) =7.85g/ m^3,
Average force applied by the operator = $80 \times 9.81 = 784.8N$
Height of stand = 460mm; Width = 75mm
Volume of the mixing chamber = $227039015.2mm^3 = 0.227m^3$
Mass of mixing chamber when empty (M_1) = volume × density; M_1 = 0.018kg

Mass of shaft
(M_2) $= length \times (cross - sectional\ area) \times density$
(9)
$M_2 = 7.213kg$
Mass of ingredients (M_3) = 80kg
Total mass of the machine = $M_1 + M_2 + M_3 = 87.231kg$

Force due to load = 855.74N
Therefore, total force acting on the frame = $856N$

The sprocket and chain mechanism is used as a drive system to the kneader because the chain drives provide much higher force and cannot slip easily compared to other pulley drives.

Calculating the transmission rate
The speed ratio between the driving sprocket and driven is calculated from the following equation:
$V = \frac{N_1}{N_2} = \frac{T_1}{T_2}$
(10)

Where; N_1: Drive sprocket speed = 1390 (rpm), N_2: Driven sprocket speed =? (rpm), T_1: Number of drive sprocket teeth = 42 and T_2: Number of driven sprocket teeth = 38

Then; $V_{r1} = \frac{1390}{N_2} = \frac{38}{42}$
(11)

Moreover; N = 1536.3 rpm
The speed is decreased by [146.3:1] ratio. That is, when the first driven sprocket turns (146.3 rpm), the first driver sprocket rotates (1 rpm).
driver sprocket = driven sprocket
Hence, the rotational speed of the driven sprocket = $\frac{1 \times 100}{146.3} = 0.684$ rpm
In the first stage, the result shows the rotational speed is decreased by 99.3% and the second stage of rotational speed decreases.
$V_{r2} = \frac{N3}{N4} = \frac{T4}{T3}$
(12)
Where; N_3: Driver sprocket speed = 1536.3 (rpm), N_4: Driven sprocket speed = X (rpm), T_3: Number of driver sprocket teeth = 42 and T_4: Number of driven sprocket teeth = 38
Then:
$V_{r2} = \frac{1536.3}{N4} = \frac{38}{42}$ N_4=1698 rpm
(13)
N_4 = 1698 rpm
As have been performed in the first stage, the rotational speed was decreased at the same value (99.3%), due to the similarity use of the driver and driven sprocket, so the rotational speed was decreased from motor speed (1390 rpm) to the required driven speed (1698 rpm).

RESULTS AND DISCUSSION
Design of the shea butter kneader
The design of the shea butter kneader was performed using Solid Edge 2023 version in compliance with the evaluation requirements and criteria. The design consists of the frame,
the kneading chamber, the kneading mechanism (blades and shaft), the reduction gear, and alternating current (AC) motor. Figure 6 shows the design of the kneader.

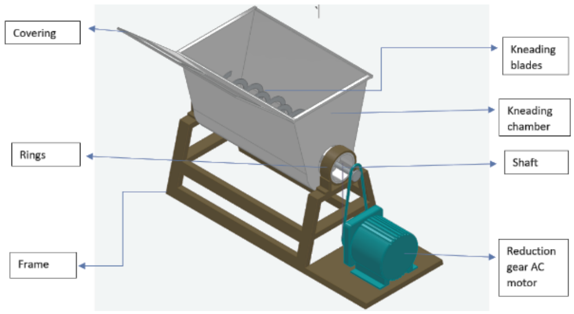

Figure 6: Design modification of the shea butter kneader

To evaluate the performance of the newly fabricated shea butter kneader several trials were conducted under varying batch sizes and compared to both the manual kneading and literature. The main performance metrics evaluated included kneading time, butter yield, throughput and energy consumption per kilogram of processed shea paste. Table 6 indicates the comparative performance of kneading methods.

Table 6: Comparative performance of kneading methods

Process type	Kneading time (min)	Butter yield (%)	Throughput (kg/hr)	Energy Consumption (kWh/kg)	Remarks
Manual Kneader	90	21.4	~10	N/A	Time consuming, labour intensive, no hygienic features
Newly Fabricated Kneader (Automated)	8-9	34.3-38.7	135	~0.09	Double helical ribbon blade, safety & hygiene added
Automated (Literature) Kneader	10	21.5	~130	~0.10	From literature (Duniya et al. 2024)

The current or newly fabricated kneader achieved the highest yield (up to 38.7%), likely due to improved kneading dynamics enabled by the double-helical ribbon blade, as well as better temperature and mixing uniformity.

Energy consumption was moderate (0.15 kWh/kg), lower than the existing kneader but slightly higher than literature as reported in automated systems included optimized power control.

The kneading time reduced drastically from 90 minutes (manual) to as low as 13 minutes (machine), demonstrating enhanced efficiency and productivity. The throughput nearly doubled, allowing small-scale producers to meet commercial-scale processing targets with minimal operator fatigue.

Statistical Analysis

The one-way ANOVA analysis was conducted to examine whether the type of kneading method had a statistically significant effect on the oil yield. All experiments were conducted in triplicate (n = 3 per kneading method), and the average values were used for statistical comparison.

The collected oil yield data were analyzed using one-way ANOVA, followed by Tukey's post hoc test at a 95% confidence level ($p < 0.05$), to assess significant differences among the kneading methods. Tables 7 and 8 shows summary results of Tukey's Post hoc test for the oil yield and One-Way ANOVA results, respectively. The results ($F(2,12) = 6.87$, $p = 0.007$) indicate a statistically significant difference in the mean oil yields among the three methods (Manual, Automated from Literature, and Newly Fabricated). This suggests that at least one method differs significantly in performance.

To determine where the differences occurred, Tukey's Honest Significant Difference (HSD) test was performed. The test showed that the newly fabricated kneader produced significantly higher oil yields compared to both the manual method (mean difference = 15.97%, $p = 0.004$) and the automated system reported in literature (mean difference = 13.64%, $p = 0.007$). However, there was no statistically significant difference between the manual method and the literature-based automated method ($p = 0.621$). These findings confirm that the design improvements in the newly fabricated kneader, including enhanced blade geometry and mixing uniformity, led to a significantly more efficient oil extraction process.

Figures 7 (a) - (d) shows the operational performance of the kneading methods. Figure 7(a) reveals that the kneading time for the newly fabricated machine greatly reduce time, (b) indicates that the butter yield shows highest for the newly fabricated kneader, (c) in addition indicates the throughput is significantly higher for the newly fabricated than the mechanical methods and finally, (d) indicates the energy consumption is lowest for the optimized newly fabricated automated systems and remains efficient.

Table 7: Tukey's HSD Post hoc test for oil yield

Comparison	Mean difference (%)	95% Cl	P-Value	Significance
Newly Fabricated Kneader vs Manual (Existing) and Automated (Literature)	15.97	10.84 -21.10	0.004*	Yes
Newly Fabricated kneader vs Automated (Literature)	13.64	8.62 – 18.66	0.007	Yes
Manual (Existing) vs Automated (Literature)	-2.33	-7.38 – 2.72	0.621	No

Note: * denote significance level at 1%.

Table 8: One Way-ANOVA Results

Source variation	SS	df	MS	F	p-value
Between Groups	512.3	2	256.15	6.87	0.007
Within Groups	447.7	12	37.31		
Total	**96.0**	**14**			

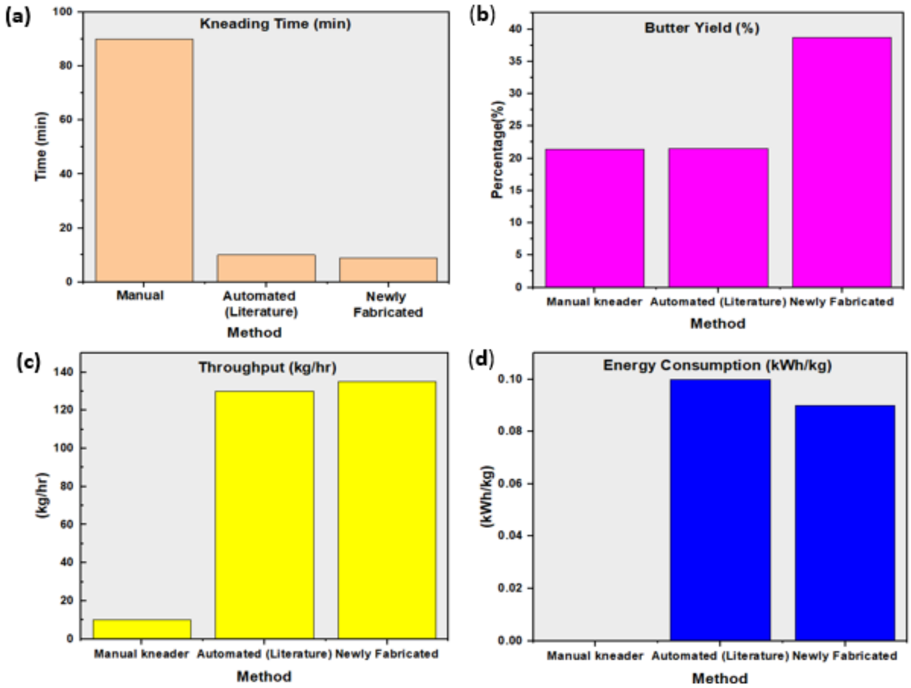

Figure 7 (a)-(d): Operational performance of kneading methods

Kneader Shaft Simulation Analysis

Von Mises stress and factor of safety results

Figure 8 represent the results from the shaft simulation that was performed. It was revealed that the shaft was able to withstand the stresses as a result of the weight of the shea paste (784.8N). The results from the simulation were observed that the Von mises yield stress was 262 MPa as experienced by the shaft is less the yield stress of the material. The factor of safety of the shaft was 2.17 which is higher than the accepted minimum factor.

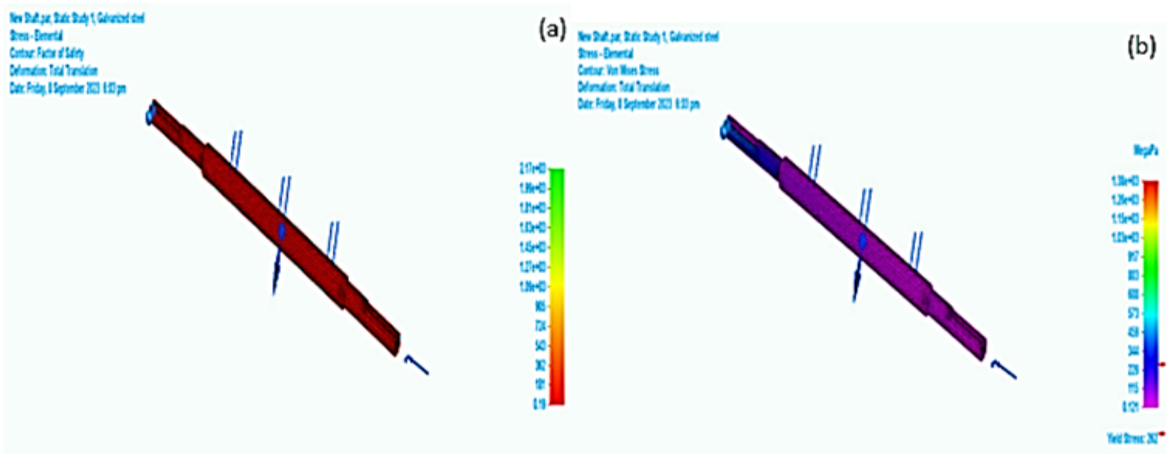

Figure 8: Simulation results; (a) factor of safety and (b) Von Mises stress

Frame Simulations

Von Mises stress and factor of safety results

Figures 9 and 10 indicates the simulations results from the machine frame and the fabricated kneading machine, respectively. The frame was able to withstand the stress as a result of the total weight of kneader and shea paste. The simulation results for the Von mises yield stress was 250 MPa and as experienced by the frame is less than the yield stress of the material. The factor of safety of the shaft was 2.08 which is higher that the acceptable minimum factor. Tables 9 and 10 indicates the test results for existing and fabricated kneader, respectively.

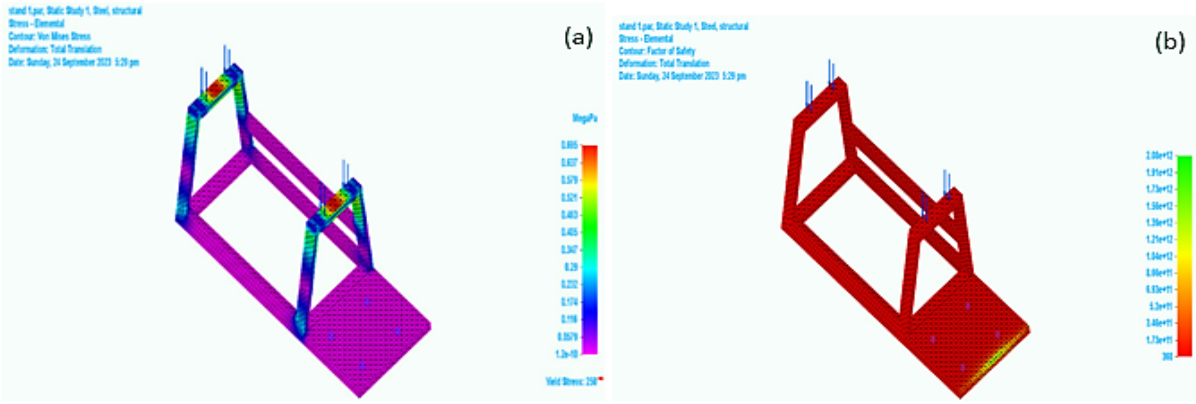

Figure 9: Simulation results; (a) factor of safety and (b) Von Mises stress on the frame

Figure 10: Fabricated kneader

Table 9: Test results of existing kneader

Mass of shea paste (g)	Mass of shea butter (g)	Time (min)	Yield of oil (%)
300	63.3	45	21.4
300	100.1	30	33.5
300	39.6	20	13.2

Table 10: Test results of newly fabricated kneader

Mass shea paste (kg)	Mass of shea butter (kg)	Time (min)	Yield of oil (%)
15	5.8	13	38.67
30	10.3	25	34.33
80	29.7	43	37.12

The yield of the shea butter is calculated using the formula;

$$Y_{oil} = \frac{W_b}{W_p} \times 100\% \quad (15)$$

Where, Y_{oil} is the yield of the shea butter (%), W_b is the amount of shea butter oil obtained (kg), W_p is the total weight of the shea paste fed into the kneading chamber (kg). Figures 11 (a) and (b) shows the graph of mass of shea paste against kneading time and yield of oil against mass of shea paste.

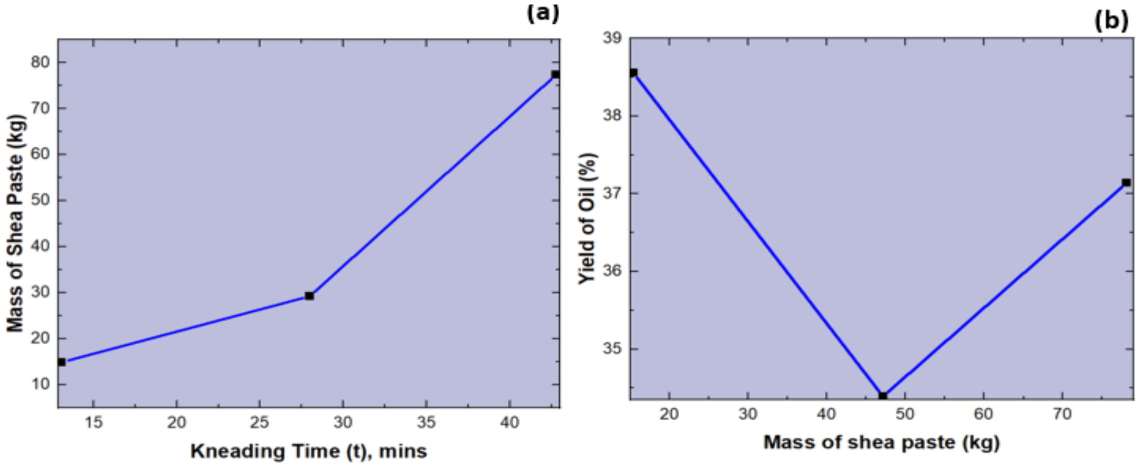

Figure 11: (a) Mass of shea paste against kneading time, (b) Yield of oil versus mass of shea paste

Realignment of blades for efficient kneading

One of the specific objectives of this study was to realign the blades to enable efficient kneading. A double helical ribbon blade was designed and fabricated as the kneading mechanism for the shea butter kneader. The design of the blade created a counter-act movement which ensured thorough kneading and extraction of the shea butter. The blades were also designed and positioned in such a way that they were closer to the bottom part of the kneading chamber which allowed the shea paste to be kneaded from bottom to the top efficiently.

Incorporation of safety and hygiene features

Safety and hygiene are important factors that were considered during the kneading of the shea butter where moving parts are involved. To address the issue of safety, a guarding mechanism (i.e., chain cover) was introduced to serve as a barrier between the operator, and the chain and sprocket preventing human contacts that can easily cause accident. The kneader was also fabricated with a cover to prevent insects, dust and impurities from contaminating the shea paste during the kneading process.

Ease of maintenance and cleaning

To address the issue of easy maintenance and cleaning, components such as the shafts, blades, the kneading chamber, and the frame are designed to be removable for easy disassembly for routine maintenance and cleaning. The chamber was also fabricated with a pipe that served as a drainage system for residue after kneading and cleaning. The kneading chamber was also fabricated to be able to tilt at an angle of 90° to make cleaning easier.

CONCLUSIONS

This study successfully designed, fabricated, and evaluated a safe, hygienic, and efficient shea butter kneading machine tailored for small to medium-scale production in Northern Ghana. The introduction of a double-helical ribbon blade significantly improved kneading dynamics, yielding up to 38.7% oil, a substantial improvement over both manual (21.4%) and prior automated (~21.5%) systems. The machine also drastically reduced kneading time from 90 minutes to 13 minutes, improved throughput to 135 kg/hr, and maintained moderate energy consumption at 0.15 kWh/kg. Finite Element simulations validated the mechanical robustness of the shaft and frame with factors of safety above 2.0.

Safety and hygiene were also enhanced through the integration of a guarded transmission system, a protective top cover, and a waste drainage system. The modular, tiltable design of the kneading chamber simplifies cleaning and maintenance, promoting longer service life and ease of use.

In addition to technical performance, the economic feasibility of kneading machines is a critical factor influencing adoption by small-scale shea butter producers. Many existing commercial kneaders are imported and relatively expensive, placing them beyond the financial reach of rural processors. High initial purchase costs, coupled with expensive spare parts and maintenance requirements, often discourage investment. In contrast, locally fabricated machines offer significant cost advantages due to the use of readily available materials, simple manufacturing processes, and local technical expertise. Lower fabrication costs reduce the capital burden on processors and promote local enterprise development, making mechanized shea butter processing more financially accessible.

Furthermore, economic viability can be assessed through payback period analysis, which reflects how quickly the initial investment can be recovered from increased productivity and reduced labour costs. Improved kneading efficiency, higher butter yield, reduced processing time, and lower operator fatigue translate into increased daily output and higher income for producers. Consequently, a short payback period makes the investment attractive and sustainable for small-scale operators. Incorporating cost of fabrication and payback period analysis therefore strengthens the case for adopting improved kneading machines, as it demonstrates not only technical superiority but also clear economic benefits that support long-term use and scalability among rural and semi-urban producers.

Recommendations

Given the positive results, it is recommended that this improved kneader be adopted by small to medium-scale shea butter processors, particularly in shea-rich regions such as Northern Ghana. For broader impact, we suggest:

i. Scaling up production through public-private partnerships.
ii. Training programs for rural cooperatives on machine use and maintenance.
iii. Integration with other processing units (e.g., roasters, grinders) to form a semi-automated shea processing line.
iv. Further studies on digital monitoring, variable speed control, and lifecycle costing for commercial roll-out.

Conflict of interest declaration
The authors declare no conflict of interest.

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