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Development of a Shea Nut Sheller for Rural Communities of Northern Ghana

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ABSTRACT: Conventional manual deshelling techniques are tedious and inefficient, frequently causing kernel damage that diminis hes their market value. This research involves the development, construction, and assessment of an enhanced shea nut shelling ma chine designed to meet the needs of rural areas in northern Ghana and empower women in economic activity. The 35 kg machin e consumes only 0.214 liters of fuel to process 1.672 kg of shea nuts and functions without electricity, making it ideal for use in remote communities inaccessible by the national grid. Performance evaluation indicates a 77.03% shelling efficiency, 52.39% shea yield, 1.672 kg processing capacity, and a processing time of 10.99 seconds. These results demonstrate a substantial improvement over manual methods, enabling smallholder women involved in shea nut processing to significantly reduce labour costs. Statistical analysis shows high accuracy (1.14% margin of error) and moderate variability (1.3% coefficient of variation), while structural ana lysis confirms the durability and stability of the components under working conditions. Overall, the machine effectively addresses key challenges in existing shelling methods by enhancing efficiency and reducing manual effort. Nevertheless, the observed 28% c ore breakage rate suggests the need for further design optimization. Enhancements such as incorporating shock-absorbing materials or adjusting rotational speed could help reduce kernel damage while maintaining high shelling and cleaning efficiency. Its adoption fosters the economic empowerment of rural women and advances the attainment of Sustainable Development Goals (SDGs) 1 and 5.

KEYWORDS: Conventional, manual, Ghana, smallholder, Sustainable Development Goals (SDG) 1&5

1. INTRODUCTION

The shea-nut tree, native to sub-Saharan Africa is an important commercial and traditional resource, especially for rural communities in 19 countries, like Ghana, Burkina Faso, Mali and Nigeria [1]. The kernels are utilized in the production of shea butter, a versatile substance abundant in fatty acids (such as linoleic and oleic acids), glycerol, and fat-soluble vitamins. These properties make it an essential raw material for the cosmetic and pharmaceutical industries[2]. Shea butter functions as a nutritional ingredient, a traditional medicinal agent with antimicrobial qualities, and a base material for producing soaps, candles, and herbal treatments used to relieve sprains and minor pains[2]. The shells of shea nuts are also employed in construction as waterproofing materials, providing protection against wind and rain-induced erosion. The rising global demand for shea butter, fueled by its application in personal care and food products, has greatly improved the livelihoods of rural women and children involved in its collection and processing within the informal sector[3], [4].

In Ghana, shea trees occupy approximately (77,670 square kilometers) across areas including Tamale and its adjoining communities, Walewale, Damongo, Salaga, with an estimated 9.4 million trees yielding over 60,000 metric tons of shea nuts each year highlighting the significant economic value of the crop. Shea nut processing especially the shelling stage is essential for obtaining high-quality shea butter, yet it continues to be a major challenge because of the ineffectiveness of traditional methods. Labour intensive methods, including the flat stone and pestle-and-mortar approaches, are highly labour-demanding and time-consuming, often resulting in significant kernel breakage and contamination, which in turn lowers productivity and compromises the quality of the extracted butter[2], [5]. These female-dominated traditional methods yield a low processing rate of about 5-10 kg of kernels per person per day and cause up to 25% kernel damage, thereby reducing the quality and market value of the final product[6].

The manual nature of shelling places considerable physical stress on workers, leading to hand injuries and musculoskeletal problems. These risks are heightened by inadequate ergonomic design and the lack of appropriate protective equipment. Moreover, socio-demographic constraints, including restricted access to credit and limited educational opportunities, impede the adoption of modern processing technologies and continue to reinforce economic and social disparities[7]. In response to these challenges, mechanized shea nut shelling machines have been designed to increase productivity and lessen physical labor. Nevertheless, most current machine operates with electric motors that provide insufficient rotational velocity, resulting in less effective shell cracking. In some shelling machines, smaller nuts remain uncracked because of short and widely spaced beaters. Additionally, their dependence on electricity makes them unsuitable for rural communities where power supply is limited or unavailable. Existing mechanized designs, such as the universal nut sheller and indigenous shellers, also face challenges including inconsistent

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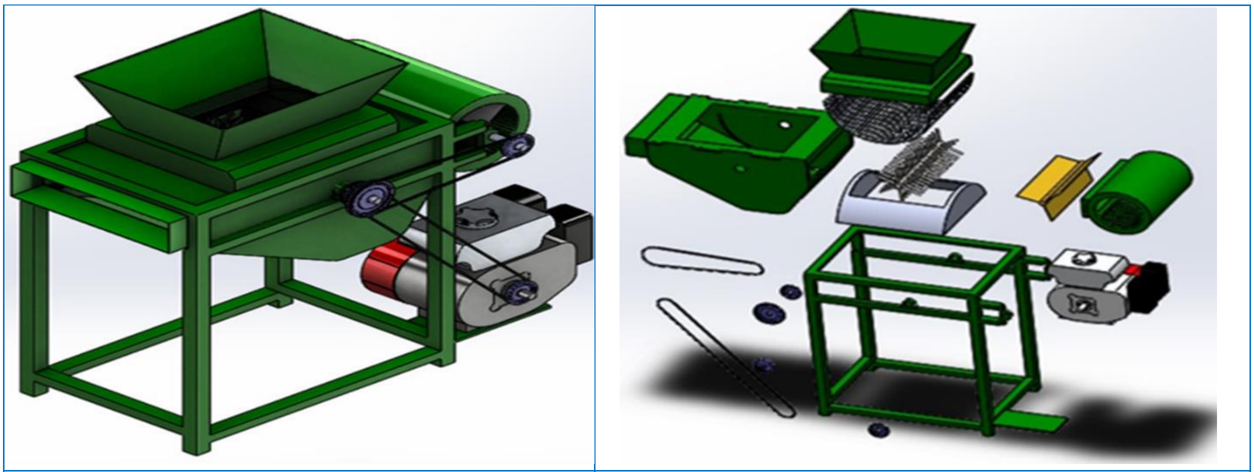
performance across regional nut variations, and lack of effective shell-kernel separation mechanisms[8]. These limitations highlight the need for a redesigned sheller tailored to the specific needs of rural processors in Ghana.

2. MATERIALS AND METHODS

The machine was designed using SolidWorks software to ensure the creation of accurate and precise components. Fabrication of the sheller was carried out at the School of Engineering workshop in Nyankpala.

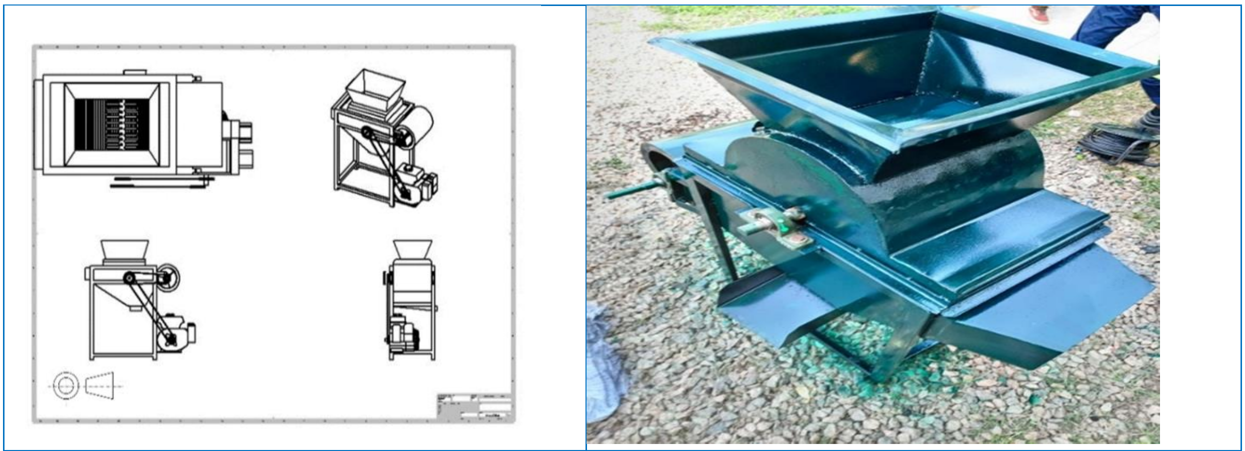
The prototype shea nut sheller comprises three main subsystems: the frame, the shelling system, and the transmission system. The frame includes a sturdy structure and hopper, both fabricated from mild steel to ensure structural integrity and operational stability. Figs. 1 (a) and (b) illustrate the design of the shea nut sheller and its exploded view, respectively, while Figs 2 (a) and (b) present the fabricated prototype and its first-angle orthographic projection.

The study focuses on rural communities in the Northern Region of Ghana, where shea nut processing is a vital economic activity, particularly for women in the informal economy. Nyankpala and Tamale's market served as the source for shea nuts and fabrication materials.



(a) Designed Shea Nut Sheller **(b) Exploded view of the sheller**

Fig. 1 CAD drawings of sheller



(a) Orthographic view **(b) Fabricated Machine**

Fig. 2 Orthographic projection and final fabricated machine

2.1 Numerical simulation procedure

2.1.2 Design Calculations

In the design of the shea nut sheller for analysis and performance evaluation the following mathematical equations were developed based on the fundamental engineering principles.

Volume of hopper (V) = $\frac{H}{3} \times (A + B + \sqrt{A \times B})$ (1)

where H = height between the two rectangular faces of the hopper

Speed of beater shaft, v = $\frac{2\pi r N}{60}$ (2)

Impact Force of beaters exerted on nuts, F F= $\frac{mv}{\Delta t}$ (3)

Torque on the beaters, T = F $\times$ r (4)

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Power required by beaters, $P = \frac{2\pi NT}{60}$ (5)

Torsional shear stress of beaters, $\tau_{beaters} = \frac{T \times r}{J}$ (6)

Minimum pressure required by the blower, $p = \frac{1}{2}\rho v^2$ (7)

Length of belt = $L = \frac{\pi}{2}(D1 + d2) + 2C + (\frac{D1+D2}{4C})^2$ (8)

where L = Belt length, D1 and D2 = diameter of engine pulley and machine pulley, C = center spacing of the machine and engine pulleys = 0.14 m

Standard Variation (SD) = $\sqrt{\frac{\Sigma\,(\text{Efficiency} - \text{Mean})^2}{(n-1)}}$ (9)

$SD = \sqrt{\text{Variance}}$ (10)

Error margin (with 95% confidence) = $\frac{z \times SD}{\sqrt{\text{number of tests}}}$ (11)

Co-efficient of Variation (CV) = $\frac{SD}{\text{Mean}} \times 100$ (12)

3. CONSTRUCTIONS

3.1 The Hopper

The hopper was built using thick steel sheet material and formed a hollow half-cylinder with a frustum shape of 0.0616 m^2 at the bottom, 0.1606 m^2 at the top, and 0.20 m high as illustrated in Fig. 3.

Hopper

Fig.3 Fabricated Hopper

3.2 The Shelling Unit

The shelling system comprises of a horizontal shaft, that has beaters attached and rotates rapidly within the shelling drum or concave chamber. The shells crack and break as the nuts are crushed against the concave surface (the sieve) by the revolving beaters as they are fed into the chamber through the hopper. The beaters are arranged helically on the shaft to ensure uniform nut impact. A total of 14 beaters were evenly distributed to balance the shaft dynamically and minimize imbalance during rotation with a spacing of 0.09 m apart. It is made with mild steel and fabricated by arc welding. Figs. 4 (a) and (b) show the concave sieve and the beaters, respectively.

(a) Concave sieve **(b) Beater arrangement**

Fig. 4 Fabrication of concave sieve and beater

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3.3 Blower Design and Operation

A centrifugal blower is preferred for stable high-pressure airflow. It includes a volute casing (blower chamber), mounted downstream of the shelling unit to direct airflow into the outlet duct as shown in Fig. 5. The volute casing is 342 mm long, with an inner diameter of 114.5 mm and an outside diameter of 145.5 mm. The shaft in the chamber has a total of four backward curved rectangular blades that rotates at a maximum speed to generate enough air to blow away the shells. As the airflow is directed towards the outlet duct, it blows away the cracked shells through the air chamber to allow for the shea kernels to fall due to gravity into the collector, through the trough.

Fabricated Blower

Fig. 5 Blower

Table 1. Shear value of nut sheller

S/N	Parameter	Symbol	Value	Unit
1	Torsional shear stress of beaters	$\tau_{beaters}$	63	MPa
2	Torque on the beaters	T	34. 895	Nm
3	Power on the beaters	P	3288.78	kW
4	Impact Force of beaters on nuts	F	317.230	N
5	Speed of beater shaft	v	10.367	m/s
6	Volume of hopper	V	0.0214	m3
7	Length of belt	L	0.78	m
8	Minimum pressure for blower	p	135	Pa

3.4 Structural Analysis Procedure

The beaters and the blower were simulated to investigate operational failures as a result of the displacement, strain and stresses induced. Three-dimensional CAD models of the beaters (attached to a shaft), fan blades (blower) were created, using mild steel properties. The assigned material was Steel, with a density of 7833 kg/m³, modulus of elasticity of 199,947.953 MPa, Poisson's ratio of 0.29, yield strength of 262.001 MPa, and an ultimate strength of 358.527 MPa. Fixed constraints were applied to the ends of the rotating shafts. The models were meshed with tetrahedral elements and loads included impact forces from shear nut, 20 N and 100 Nm torque, with fixed constraints at shaft and hub connections. Liner static structural analyses using NX Nastran (2312.0) solver computed von Mises stress and displacement.

4. RESULTS AND DISCUSSIONS

Bowls of uncracked shea nuts, each weighing 1.672 kg were shelled with the speed of the engine set at 750 rpm. The sheller was evaluated for shelling efficiency, kernel damage, kernel recovery efficiency and fuel consumption. Shelling outcomes were categorized as unshelled (intact nuts), fully shelled without damage (whole kernels), fully shelled with damage (cracked or broken kernels), and partially shelled (incompletely separated shells). Additionally, fuel consumption (litres per kg of nuts processed) and time taken to process a known mass of nuts were calculated. Fully shelled (N1), fully shelled with unbroken kernels(N2), partially shelled (N3), unshelled (N4), and fully shelled but with broken kernels (N5) were recorded separately as shown in Table 2 and Fig. 6.

4.1 Shelling Efficiency and Kernel Recovery Efficiency (KRE)

Shelling efficiency was calculated as the weight of input nuts that were fully shelled (with or without damage), 1.288 kg relative to the total input mass, 1.672 kg. KRE is the percentage of undamaged kernels recovered relative to the total kernel content in the input nuts. At 750 rpm, the shea

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nut sheller achieved an efficiency of 77.03 % and a significant KRE of 52.39%. However, the kernel damage was significant, 28% while 0.60% of the shea nuts were unshelled prompting the necessity for optimization.

4.2 Fuel Consumption and Shelling rate

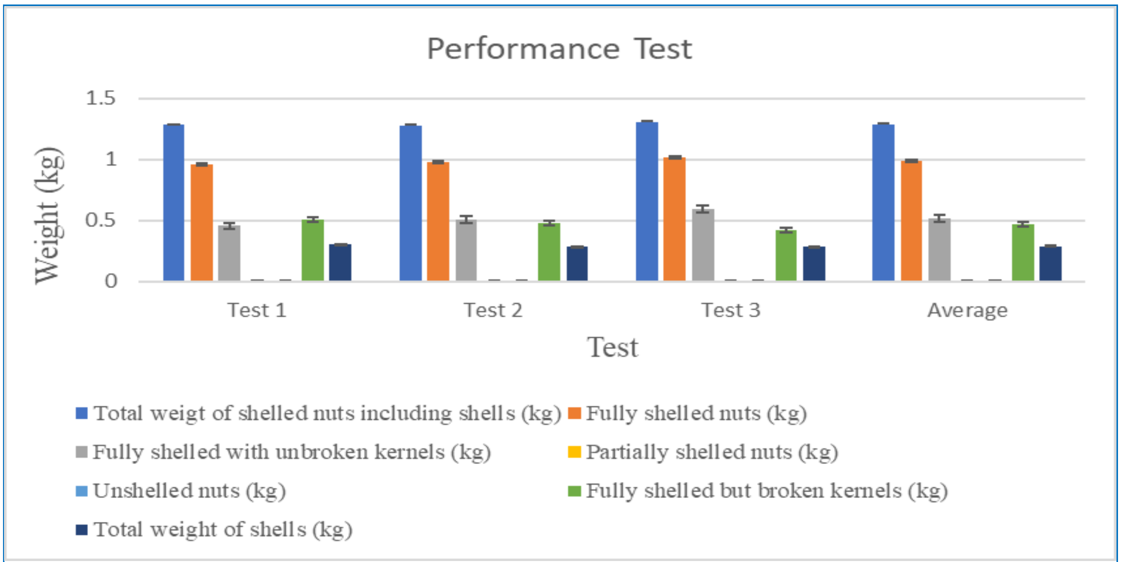
The fuel consumption of the shea nut sheller was evaluated during a controlled test to determine the efficiency of fuel usage per bowl of shea nuts (equivalent to 1.672 kg) processed. The sheller consumed a total of 0.214 litres of petrol over a total operating time of 806 s. The time required to shell an equivalent 1.672 kg of shea nut was measured at 10.99 seconds compared to 20 minutes average time recorded for traditional hand-cracking methods. This shows that the sheller effectively reduced manual labour and shelling time by 99%.

4.3 Statistical Analysis

The variance and standard deviation (SD) were computed to assess consistency. The variance and deviation achieved were 1.0111 and 1.0055 respectively. Co-efficient of variation was 1.3% indicating moderate variability. The error margin was 1.14% indicating high precision, reliability and greater confidence in results.

Table 2: Performance data for shea nut sheller

Test	Weight of shelled nuts (kg)	Fully shelled nuts (kg)	Fully shelled with unbroken kernels (kg)	Partially shelled nuts (kg)	Unshelled nuts (kg)	Fully shelled but broken kernels (kg)	Total weight of shells (kg)
1	1.282	0.962	0.454	0.009	0.010	0.508	0.301
2	1.275	0.981	0.503	0.005	0.006	0.478	0.283
3	1.307	1.012	0.591	0.007	0.003	0.421	0.285
Average	1.288	0.985	0.516	0.007	0.006	0.469	0.290



(a) Performance test

Fig. 6 Graphical presentation of performance tests

4.4 Structural Analysis Results

4.4.1 Stress Analysis

The Maximum and Minimum Von-Mises stresses induced in the shaft (with beaters attached) was 0.0497 MPa and 0.003 MPa respectively. At the minimum stress, it indicates that, vast portions of the shaft and the beaters are experiencing virtually no stress. With the blower, the maximum and minimum Von-mises stress from the analysis was 30 MPa and 0.01 MPa. The result shows that maximum stress occurs at the point of contact between the shaft and the blower blades while minimum stress occurred at the extreme ends of the blades as shown in Figures 6 (a) and (b), respectively. The yield strengths were 220.6 MPa which is well greater than the maximum stresses indicating that, the materials are well within their elastic region and will not permanently deform or break due to the impact of applied loads.

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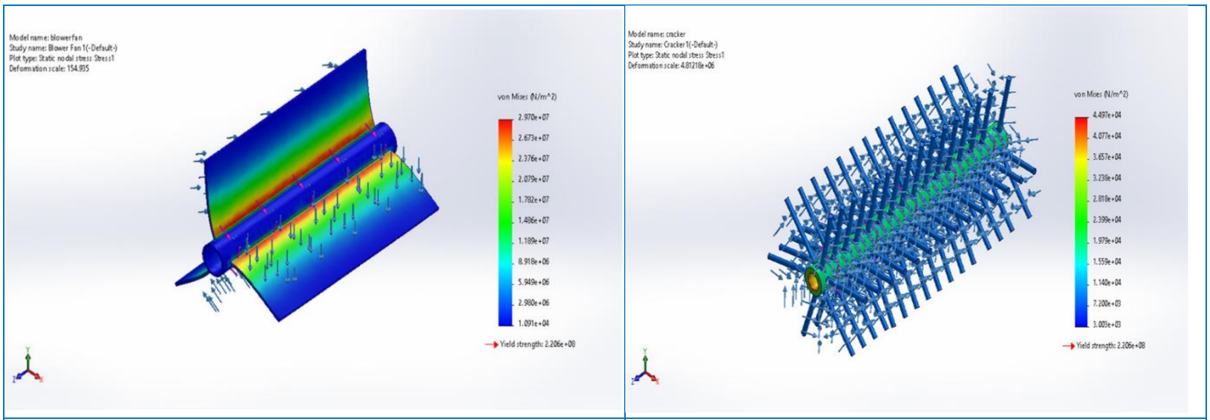
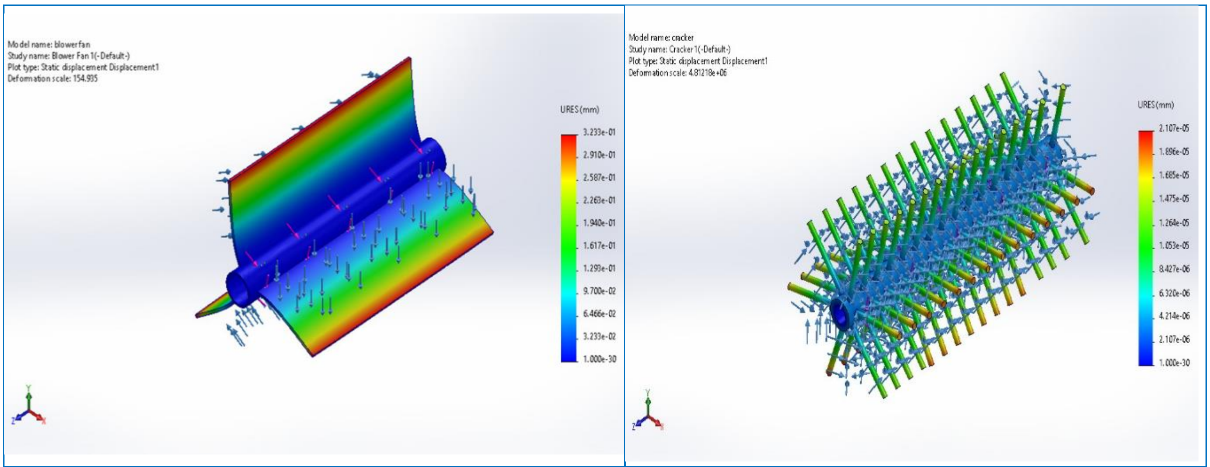


(a) Stress analysis on blower | (b) Stress analysis on beater

Fig. 6 Stress Analysis

4.4.2 Displacement Analysis

The displacement analysis conducted on the beaters and blower showed maximum and minimum values of 2.107×10^{-5} mm and 1.00×10^{-30} mm for beaters and 3.22×10^{-1} mm and 1.00×10^{-30} mm for the blower. The maximum displacements occurred at the tips of the beaters and blower blades as shown in Figs. 7 (a) and (b), respectively, which are very minimal, indicating minimal deflections during operations.



(a) Displacement analysis on blower | (b) Displacement analysis on beater

Fig. 7 Displacement Analysis

Performance testing revealed that the designed beaters, with uniform length and optimized spacing, effectively cracked both large and small nuts, addressing existing designs' issue of smaller nuts passing through uncracked due to short, widely spaced beaters. The precision in beater design contributed to a shelling efficiency of 77.03% and a kernel recovery efficiency (KRE) of 52.39% represent a substantial advancement, reducing labour and increasing marketable kernel yield by approximately 23% based on manual KRE of 40%[2].The KRE also remained below the 80-90% reported for top performing mechanical shellers[3], [6] indicating room for improvement. Also, the observed kernel breakage rate of 28%, while lower than manual methods, indicates that the impact energy exceeds the kernels' fracture threshold, reducing the economic value of the output due to the higher market value of intact kernels. These results indicate that additional optimization, such as integrating shock-absorbing materials or fine-tuning rotational speeds, could minimize kernel breakage while sustaining high shelling efficiency, in line with existing research on adjustable shelling mechanisms[9]. Overall, the improved shea nut design demonstrates a substantial advancement over traditional techniques and earlier designs, providing improved efficiency, better suitability for rural areas, and fewer operational challenges. However, the balance between shelling efficiency and kernel breakage underscores the need for further refinements to optimize impact forces and enhance kernel recovery efficiency (KRE).

5. CONCLUSIONS

The shelling machine was designed using SolidWorks 2024 version and manufactured using locally available materials. A performance analysis was conducted to test the time taken for the sheller to shell nuts, the rate of fuel consumption and the shelling efficiency of the machine.

In comparison to the traditional method of shelling, manual shea nut shellers and other automated shea nut shellers, the shea nut sheller shells a significant quantity of shea nuts in a short time, and increases the work rate using less effort and also offers a separation of shells from kernels respectively. However, the significant kernel damages and moderate kernel recovery efficiency present a need for optimization. By addressing these challenges, the sheller can better support rural communities, particularly women, who rely on shea nut processing for their livelihoods,

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contributing to sustainable practices and economic empowerment in the face of growing global demand for shea butter.

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