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Development of a Multi-Variant Grain Shelling Machine Using Locally Sourced Materials to Empower Smallholder Farmers in Nigeria

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K E Y W O R D S

Small-Scale Farmers
Innovative
Multi-Variant
Shelling
Grain Crops

A B S T R A C T

This paper presents the design, development, and performance evaluation of an innovative multi-variant grain shelling machine intended to support small-scale farmers in Nigeria. To mitigate the high cost of procuring specialized equipment, the machine was engineered for versatile application across major grain crop types, including maize and groundnut. Fabrication utilized locally sourced, cost-effective materials, aiming to improve accessibility and eliminate the intensive drudgery associated with manual shelling. The system's core components include a 1 hp electric motor, a V-belt drive, a hopper, and a shelling chamber with an appropriate sieve, all dimensioned based on established engineering equations. Performance evaluation used 5 kg grain samples, demonstrating high shelling efficiencies of 98% for maize and 90% for groundnut as against the commercially available shelling machines for maize and groundnut at shelling efficiencies of 99.9% and 98% respectively. These findings confirm the machine's efficiency, economic viability, and practical suitability for sustainable small-scale farming operations in Nigeria.

1. INTRODUCTION

Agriculture serves as the bedrock for many developing economies, in which most people depend on for employment and food. Agricultural grains are a critical staple food in Sub-Saharan Africa, containing essential nutrients for human survival (Xuan, 2024). However, despite high yields, farmers face significant post-harvest inadequacies, particularly in processing. Grains are better preserved when shelled, but traditional methods such as shelling with bare hands, beating with sticks, or using a mortar and pestle are tedious, laborious, time-consuming, and result in significant yield reduction (Adeoye and Alao, 2019).

This creates an urgent need for mechanization to add value to produce (Banji, 2022). Small-scale farmers in Nigeria, who are the backbone of the agricultural sector, are faced with a plethora of processing challenges. The inability to move beyond these archaic shelling methods is a huge setback for agricultural development in small-scale farming.

The creating of shelling machine can enhance agricultural productivity, reduce labour time, promote mechanization and support local farmers by providing an efficient and cost-effective shelling solution (Oaihimires, Abdulmaleeq and Victory, 2024). A major problem is that many existing shelling machines are tailored for a single, specific grain crop. This is a significant limitation, as it becomes too costly for a small-scale farmer to procure different machines for the various crops they cultivate.

This study aims to address these challenges by developing an innovative and user-friendly multi-variant grain shelling machine specifically for small-scale farming.

2. MATERIALS AND METHODS

2.1 Materials

The choice of materials for the multi-variant grain shelling machine significantly impacts its mode of operation, durability, cost-effectiveness, and ease of use that make up the machine (Mano *et al*, 2020). The materials used are; 2 mm mild steel plate, ½ inch mild steel angle bar, ½ inch mild steel square pipe, 8 mm round rod, 1 inch mild steel flat bar, Mild steel rings, Housing bearings (2), Bolts and nuts with washers, 4 mm mild steel plate (electric motor seating or housing), Belt (A54) 12.5 X 1425, Pulleys (2) – 7-12 inches(for the machine) and 4-6 inches (for the electric motor), Hinges (discharge layout), Electric motor (1hp).

2.2 Methods

2.2.1 Design Calculations

The machine components were designed using the following standard engineering design equations and specifications derived from (Khurmi, 2010) and (Sharma and Aggarwal, 2012), they are;

Volume of Hopper: $V = \frac{1}{2}(a + b) \times h \times L$ (1)

Where, V = volume of the hopper, a =length of the top base, b = Width of the bottom base, h = trapezoidal height, L= depth of the trapezoidal structure.

Weight of Shelling Mechanism: $W = m \times g$ (2)

Where, m= mass, g= acceleration due to gravity

Power: $P = T \times \omega$ (3)

Where, T= torque, ω= angular speed

Torque: $T = F \times r$ (4)

Where, F= force, r= radial distance

Shaft Diameter: $D^3 = \frac{16}{\pi Ss}\sqrt{[(K_b M_b)^2 + (K_t M_t)^2]}$ (5)

Where, K_b = combined shock and fatigue factor for bending moment, K_t = combined shock and fatigue for torsional moment, M_b = resultant bending moment (Nm), M_t = resultant torsional moment (Nm)

Speed Ratio: $N_1 D_1 = N_2 D_2$ (6)

Where; N_1 = speed of electric motor pulley, D_1 = diameter of the electric motor pulley, N_2 = desired speed of the shelling machine, D_2 = desired diameter of the pulley

2.2.2 Performance Evaluation

The fabricated machine was tested using measured quantities of maize and groundnut to evaluate its performance. The machine was powered by the 1 hp electric motor. Key performance parameters were calculated as follows:

$$Shelling\ Efficiency\ (\%) = \frac{Mass\ of\ shelled\ grains}{Total\ Mass\ of\ grains} \times 100 \quad (7)$$

$$Shelling\ \text{Capacity (kg/hr)} = \frac{Mass\ of\ shelled\ grains\ (kg)}{Time\ taken} \times 3600 \quad (8)$$

$$\text{Grain Damage } (\%) = \frac{Mass\ of\ damagedgrains}{Mass\ of\ shelled\ grains} \times 100 \quad (9)$$

The design calculations resulted in the final specifications for the multi-variant grain shelling machine, summarized in Table 1.

Table 1: Designed values of the Multi-variant Grain Shelling Machine

S/N	Parameters	Designed values
1	Motor capacity	1 hp
2	Angular speed	762.83 rad/s
3	Shelling drum weight	23.8 N
4	Weight of Shelling mechanism	39.12 N
5	Number shelling plates	78
6	Shaft diameter	12.47 mm
7	Volume of hopper	2.98×10^6 mm^3
8	Length of belt	1669.11 mm
9	Twisting moment	17885.66 Nmm
10	Performance efficiency	90 %
11	Shelling Rate	300 kg/hr

Table 2: Shelling Test operation on maize crop using the locally fabricated machine.

S/N	Mass of Grains Fed (kg)	Mass of Grains Shelled (kg)	Mass of Grains Unshelled (kg)	Shelling Efficiency (%)	Shelling Capacity (kg/hr)	Grain Damage (%)
1	5.0	4.9	0.1	98.0	150	2.00
2	10	9.7	0.3	97.0	300	3.10
3	15	14.2	0.8	94.7	450	5.64
4	20	18.5	1.5	92.5	600	8.11
5	25	22.5	2.25	90.0	750	10.00

3. RESULTS AND DISCUSSION

3.1 Experimental Results

The performance evaluation tests were conducted on varying masses of maize and groundnut. The results for shelling efficiency, shelling capacity, and grain damage are presented in Table

2 (Maize) and Table 3 (Groundnut) for the locally fabricated machine.

Fig 1: *Assembly Drawing Showing the Various Components of The Multi-Variant Shelling Machine.*

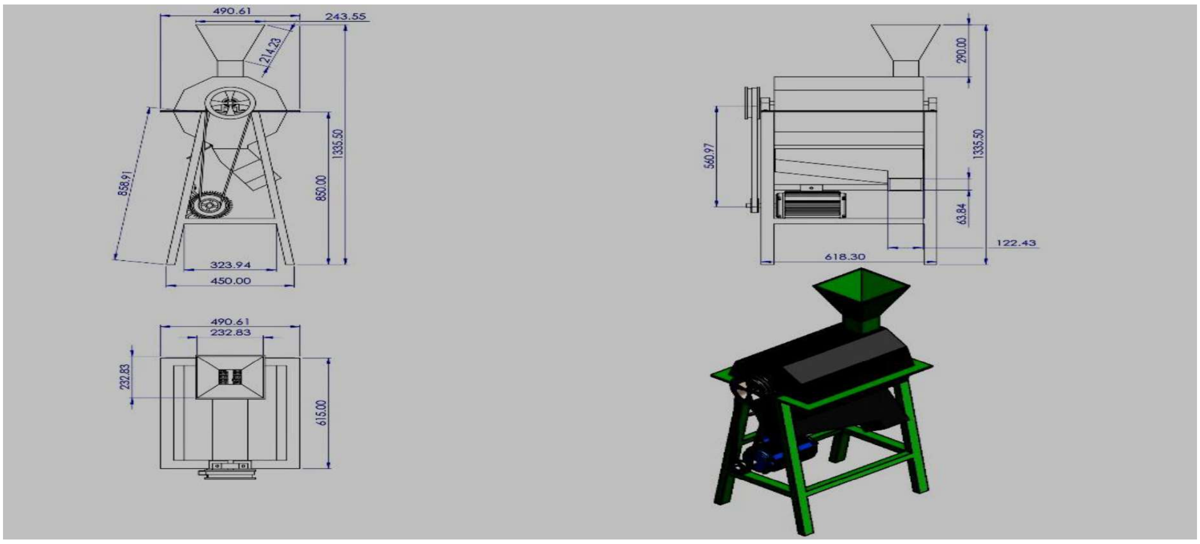

Fig. 2: 1st And 3rd Angle Projection of The Fabricated Multi-Variant Shelling Machine.

The relationships between the mass of grains fed and the corresponding unshelled grains, shelling rate, and shelling efficiency for maize and groundnut respectively are visualized in Figures 3-8.

Figure 3 illustrates that as maize input increases from 5 kg to 25 kg, shelled output rises from 4.5 kg to 18.5 kg, while unshelled output increases from 0.5 kg to 6.5 kg. This indicates strong shelling performance, with a slight reduction in efficiency at higher loads.

Figure 4 shows that the machine's shelling capacity increases proportionally with the quantity of maize fed into it. As input mass rises from 5 kg to 25 kg, capacity grows from about 150 kg/hr to 750 kg/hr, showing a strong linear upward trend. This indicates that the machine performs more efficiently and processes grain faster under higher feed rates.

Table 3: Shelling Test operation on groundnut grain using the locally fabricated machine.

S/N	Mass of Grains Fed (kg)	Mass of Grains Shelled (kg)	Mass of Grains Unshelled (kg)	Shelling Efficiency (%)	Shelling Capacity (kg/hr)	Grain Damage (%)
1	5.0	4.9	0.1	98.0	150	2.00
2	10	9.7	0.3	97.0	300	3.10
3	15	14.2	0.8	94.7	450	5.64
4	20	18.5	1.5	92.5	600	8.11
5	25	22.5	2.25	90.0	750	10.00

FOR MAIZE:

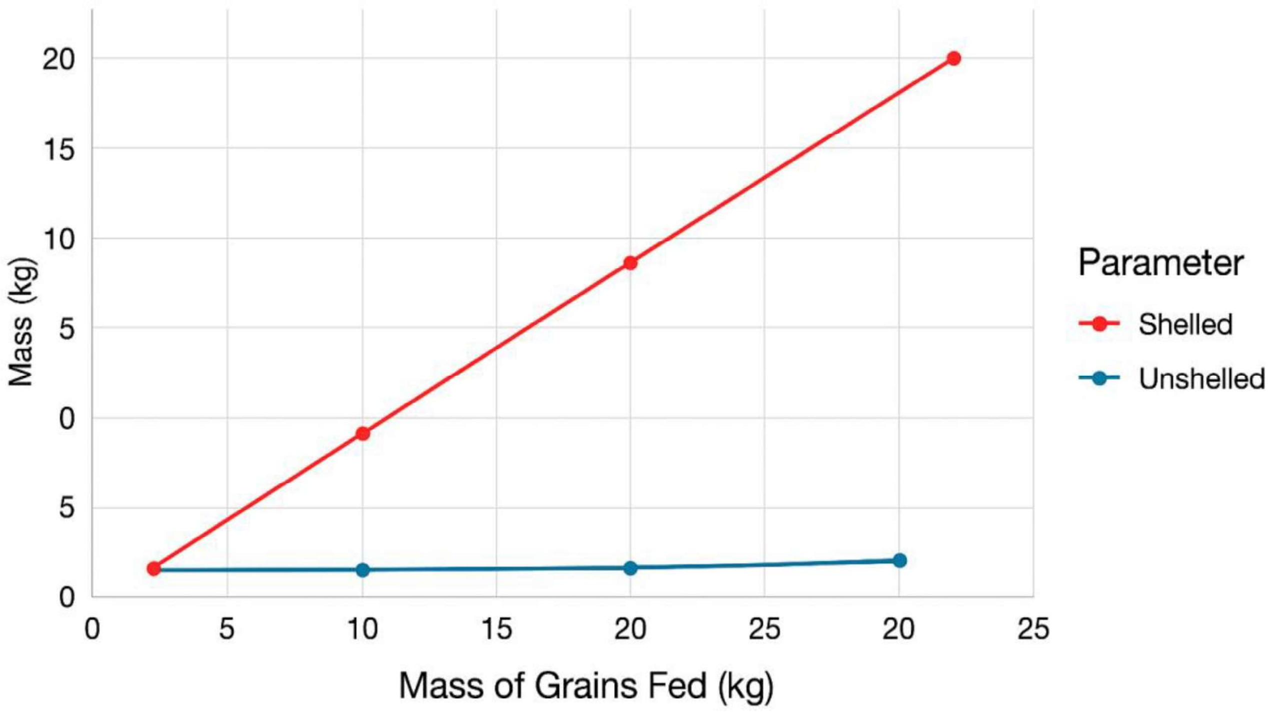

***Figure 3:** Shelled and Unshelled Grain vs Mass of Grains Fed*

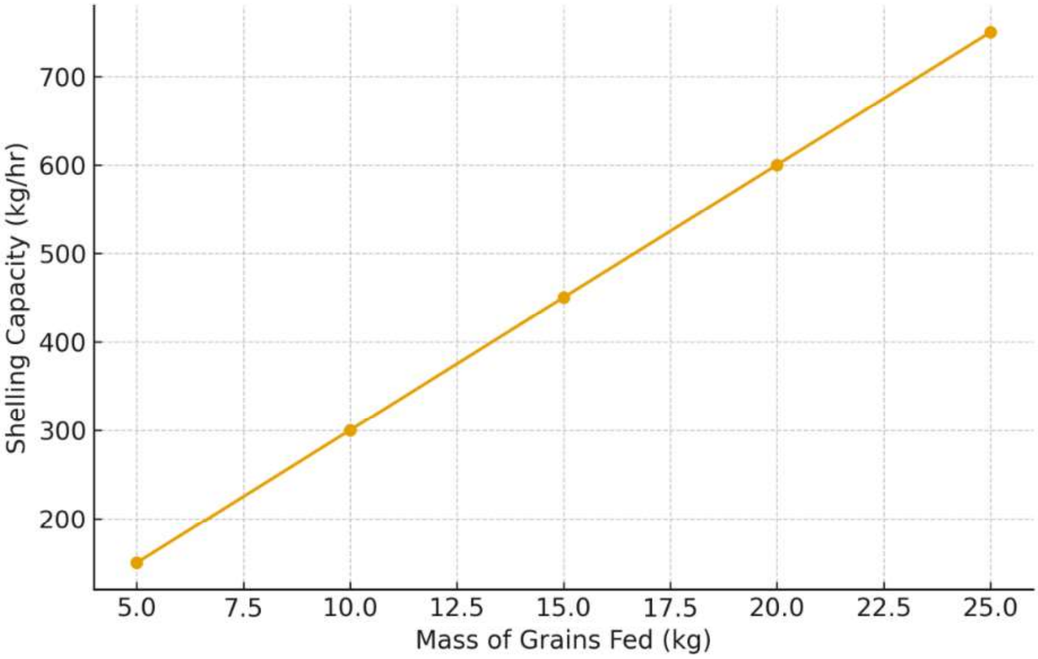

Figure 4: *Shelling Capacity vs Mass of Grains Fed*

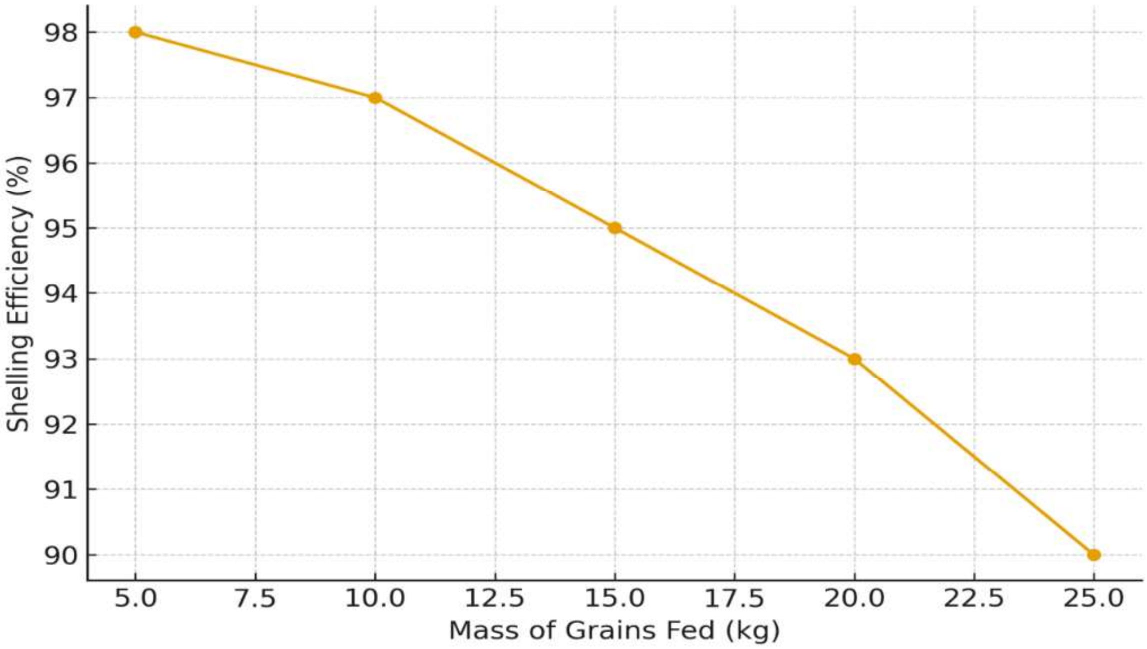

Figure 5: *Shelling Efficiency vs Mass of Grains Fed*

Figure 5 illustrates that the locally fabricated maize shelling machine's performance decreases as the quantity of maize fed into it increases. As the mass of grains fed increases from 5 kg to 25 kg, the shelling efficiency steadily drops from 98% to 90%. This declining trend indicates that the machine performs optimally at lower input masses. Higher grain loads appear to cause the machine to operate under strain, resulting in a reduction of its shelling effectiveness due to more unshelled grains.

FOR GROUNDNUT:

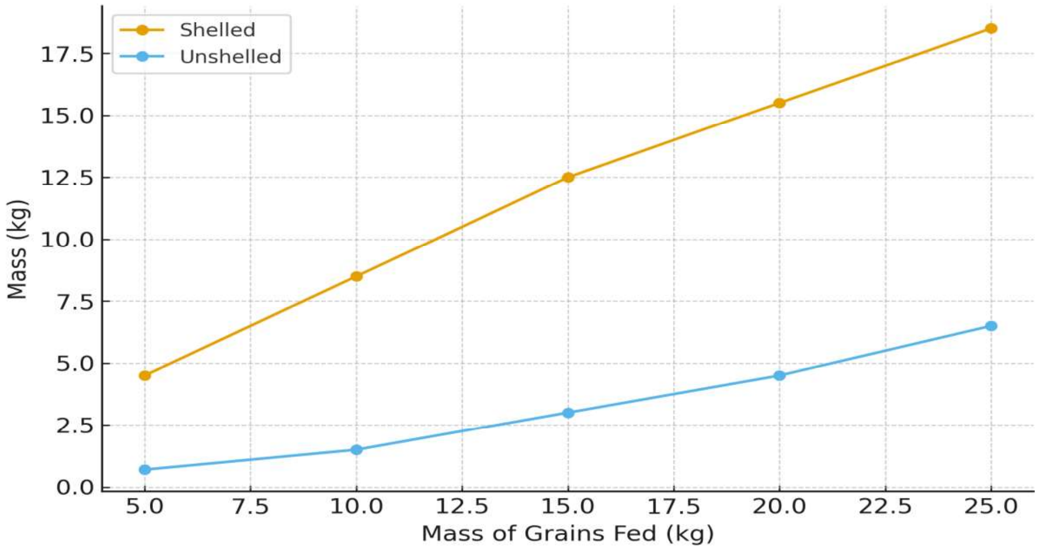

Figure 6: *Shelled and Unshelled Groundnut vs Grains Fed*

Figure 6 shows that both shelled and unshelled outputs increase as feed quantity rises from 5 kg to 25 kg, but the shelled mass grows more rapidly. This shows that a larger proportion of the grains is successfully shelled at higher feed rates, indicating improved separation efficiency as the machine processes more input.

Figure 7 shows that the machine's shelling capacity increases proportionally with the quantity of groundnut introduced. A clear linear upward trend is observed, with capacity rising from about 300 kg/hr at 5 kg input to approximately 1500 kg/hr at 25 kg. This demonstrates enhanced throughput at higher feed rates, indicating that the machine operates efficiently and maintains optimal performance when processing larger input volumes.

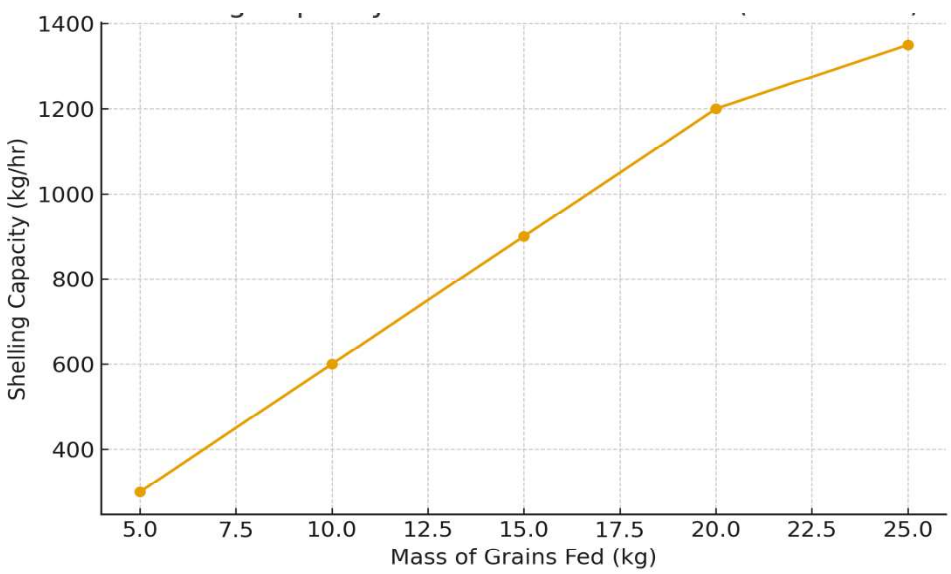

Figure 7: *Shelling Capacity vs Mass of Grains Fed (Groundnut)*

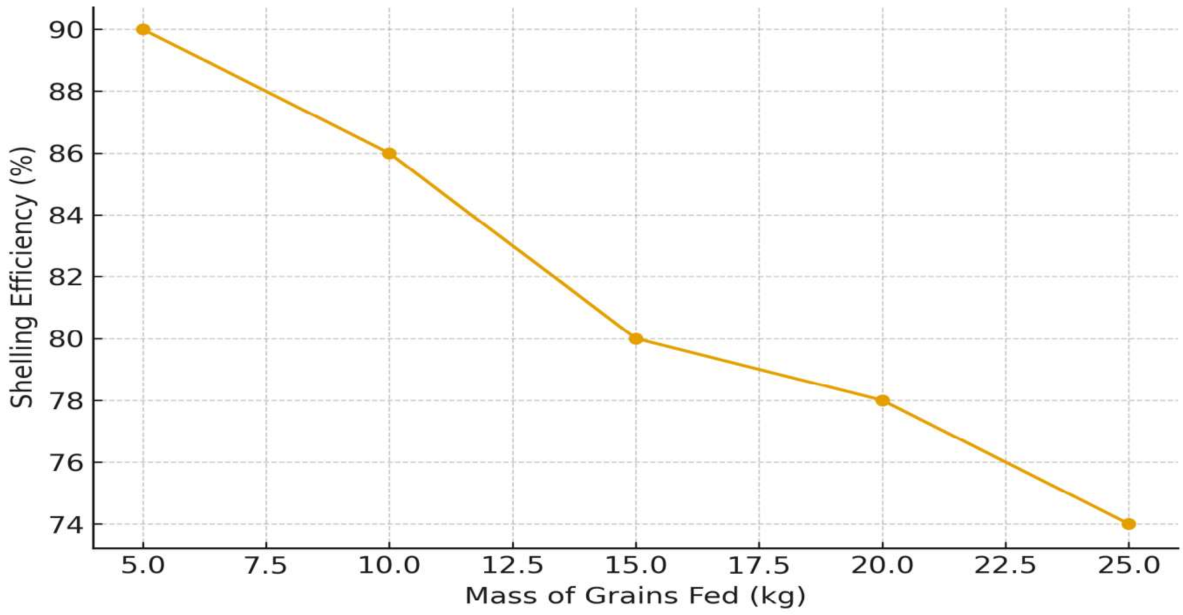

Figure 8: *Shelling Efficiency vs Mass of Grains Fed (Groundnut)*

Figure 8 shows Shelling efficiency decreases as feed quantity increases, dropping from about 90% at 5 kg to roughly 75% at 25 kg. This negative trend indicates reduced effectiveness at higher loads, suggesting possible performance limitations when the machine is heavily fed.

3.2 Comparative Performance Analysis: Local fabricated multi-variant grain shelling machine and Commercially available Shelling machine (maize and groundnut)

This analysis compares the performance of a locally fabricated 1 HP multi-variant shelling machine, which demonstrates high efficiency at low feed rates for both maize and groundnut, against the established benchmarks of commercially available, dedicated machines.

The performance evaluation demonstrates the successful operation of the multi-variant grain shelling machine. At the 5 kg test level, the machine achieved a shelling efficiency of 98% for maize and 90% for groundnut. These results are high and fall within the 85-95% efficiency range reported in the literature for other small-scale shellers, confirming the design's effectiveness. The slightly lower efficiency for groundnut is likely due to the smaller grain size and greater variability in shell hardness and texture compared to maize cobs.

Grain damage was minimal for maize at 2%, which is well within acceptable standards for food processing. The 10% damage rate for groundnut is higher but still represents an improvement over manual methods, which often have high breakage rates from inconsistent force. The mild steel beaters and concave sieve design provided the necessary impact and friction for shelling while minimizing kernel breakage.

During operation, the machine ran smoothly without excessive vibration or misalignment. This indicates a stable design, attributed to the rigid mild steel frame and proper alignment of the shaft and bearings. The 1 hp motor and pulley system provided adequate power without belt slippage.

A primary strength of this study is the reliance on locally sourced mild steel and standard components. This strategy significantly reduced the fabrication cost, making the machine affordable for its target users smallholder farmers. Compared to traditional manual shelling, the developed machine offers a 5-6 times faster shelling rate, a significant reduction in labor (requiring only one operator), and higher shelling uniformity. This confirms the machine is a practical, efficient, and labor-saving solution for rural agricultural applications.

Table 4: Comparative Performance Analysis of a Local fabricated multi-variant grain shelling machine and Commercially available Shelling machine (maize and groundnut).

Performance/Operational Metric	Locally Fabricated Multi-Crop Sheller (Maize & Groundnut)	Commercial/Industrial Shelling Machine (Dedicated Crop)
Shelling Capacity (kg/hr)	Moderate 150-750 kg/hr for Maize; 300-1500 kg/hr for Groundnut based on the previous graphs and typical local designs	High to Very High Typically >1000 kg/hr for commercial medium-scale; up to 23 MT/hr for industrial scale.
Shelling Efficiency (η_s) (Max)	Good to High ≈ 85-98% for Maize; ≈ 75-90% for Groundnut.	Very High Often 98% to 99.9%.
Grain Damage/Loss	Higher Lack precision to minimize breakage; losses often include unseparated kernels in the cob/chaff outlet.	Low/Optimized Designed with specific crop properties and precision clearance for minimal mechanical damage.
Maintenance & Spares	Low Cost; Parts are Locally Sourced/Fabricated Easy and quick to repair.	High Cost; parts are often specialized and may require Importation.
Crop Versatility	High Modified to process both maize and groundnut.	Low (Usually dedicated to a single crop for specialized performance).
Design Basis	Empirical/Experience-based, using locally available materials (Often lacks consideration of precise engineering properties of crops).	Engineering Design Based on material science and complex crop properties (Optimized for performance).

4. CONCLUSION

This study successfully designed, fabricated, and evaluated an innovative multi-variant grain shelling machine. The careful selection of locally sourced materials, such as mild steel and cast iron, resulted in a machine that is efficient, durable, cost-effective, and easy to maintain.
The machine, powered by a 1 hp electric motor, demonstrated a high performance for small-batch (5 kg) processing, achieving a shelling efficiency of 98% for maize and 90% for groundnut. It recorded shelling capacities of 150 kg/hr (maize) and 300 kg/hr (groundnut), with low grain damage rates of 2% and 10%, respectively. These results are within acceptable industry standards and represent a significant improvement over manual method.

The simplicity of operation, low power consumption, and low fabrication cost make the machine practically applicable and widely acceptable for small-scale farmers in Nigeria and other developing regions. This technology successfully bridges a gap by providing an affordable, multi-crop solution that increases productivity, reduces post-harvest labor, and preserves grain quality.

NOMENCLATURE

V	Volume (m^3)
a	length of the top base
b	width of the bottom base
h	trapezoidal height
l	depth of the trapezoidal structure
m	mass (kg)
g	Acceleration due to gravity (m/s^2)
W	weight (N)
P	Power (W)
F	force
R	radial distance
T	Torque (Nm)
D	Diameter (mm)
N	Rotational speed (rpm)
S	Allowable stress (MPa)
M	Moment (Nmm)
T	Twisting moment (Nmm)
K	Combined shock and fatigue factor

Greek Symbols

ω	Angular speed (rad/s)
η	Efficiency

Subscripts

s	shear
b	bending
t	torsion
s	Shelling

1	electric motor
2	Shelling shaft

Superscripts

*	Corresponding author
a	first author/ affiliation
b	second author/ affiliation
3	cubic root
2	square root

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