





Research Article

Development and Performance Evaluation of a Hand Operated Maize Sheller

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ABSTRACT

Maize is a popular food crop of the world. After harvest, maize is shelled traditionally by small holders of farms. This method has not proved to be effective due to drudgery attached, kernel breakage and poor shelling capacity. Over time, motorized shellers have been introduced to address the challenges faced by processors; they have not gained widely adoption due to unaffordable cost of owning one. There is the need to design a cost effective and eco-friendly solution that will suit the need of subsistence farmers in the industry. This work focuses on development of a hand-operated maize sheller. A major component is the lever arm fitted to a ball bearing to transfer rotational motion to stripping chute. The machine uses the principle of abrasion to shell maize. Model ($Y=54.92+ 0.248 X1-2.68 X2 \pm 1.187$) obtained from evaluation reveals that shelling capacity is a function of two predictors, speed ($X1$) and moisture content ($X2$). For every unit increase in cranking speed at a particular moisture content (23.2%, 18.5% or 14%) shelling capacity increases considerably. When the experiment is run at much lower moisture content (18.5%) shelling capacity increases significantly. The machine reached highest shelling capacity (60 kg h⁻¹) at lowest moisture content (14%) and highest speed (120 rpm). The machine was developed at affordable cost of \$61. Shelling efficiency is also a function of speed and moisture content at which it is processed. For this condition, maximum shelling efficiency is achieved at lowest moisture content possible (14%) and terminal speed of 80 rpm. Mechanical damage resulted when the speed and moisture content are inconsiderably high. The machine is suitable for use by small and medium scale processors; it can efficiently replace the manual shelling methods as it is affordable, less stressful and easy to maintain.

Keywords: Crank, Stripping chute, Sheller, Multivariate data, Shelling capacity

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INTRODUCTION

Maize is one of the most prominent cereal crops of the world. In Nigeria, it is a staple food of choice largely consumed for its nutritional benefits. The grain crop serves as a key input in many manufacturing companies and poultry industry. Empirical facts gathered reveals that 60 percent of Nigeria's maize is used for the production of poultry feeds, 25 percent is used up by the food and beverage industry while the remaining is consumed by households (Okojie, 2022).

Nigeria is mainly susceptible to shocks that affect global agriculture grain supplies (Boluwade and Smith 2022). According to USDA (2022), maize importation into Nigeria doubled from 500,000 metric tonnes to one million metric tonnes between October 2019 and October 2020. This rise made incumbent administration to halt use of foreign exchange for border trade of cereal to boost domestic production of maize and other cereal products. The ripple effect of the policy has made maize to be sold at prohibitively exorbitant price in the recent time. From the forgoing, there is need for stake holders at all levels of maize production to be actively involved to bridge the gap between the increasing demands and production capacity (Okusanya and Oladigbolu, 2020).

Maize shelling involves removal of maize kernel from cob through impact or abrasion. It is one of the most important postharvest operations in maize production line. Report by Amare *et al.* (2017) reveals that maize shelling is difficult at moisture content above 25% as it makes stripping efficiency to be low, thereby causing mechanical damage to the seed. Danilo (2003) further stressed that maize is more efficiently shelled when the moisture content is in the range of 13 to 14%. After harvesting and de-husking, shelling is the next operation in the production line. Maize is shelled manually by hands or other traditional means like rubbing, beating or treading with animals. This method is not only primitive and drudgery laden; the output from the process does not justify effort input.

Over the years, improvement has come over the crude method of maize processing to reduce the burden of grains loss and damage caused by traditional method. Different designs of motorized shellers have been introduced to overcome these difficulties, but those designs have not gained wide adoption by marginal farmers due to prohibitive cost and failure of the shellers to meet the expectation of the processors in terms of design capacity and high efficiency under continued use in the field. Those who even use them by economy of scale cannot afford their high cost of maintenance.

This research endeavour is geared towards designing and fabricating a hand operated maize sheller for farmers in the remote areas of the economy and stake holders who are holder of small farms. This will serve to improve on the activities of maize production and processes in the industry.

MATERIALS and METHODS

Design Philosophy

The assembly uses simple machine principle of lever arm or crank system to supply rotational power through the wheel of the arm to the transmission shaft attached to the stripping chute. The lever experiences applied force on one end while the fulcrum

is close to the other end. The fulcrum (ball bearing) is between the applied force on the arm and the load of the chute on the tail end of the transmission shaft.

Design Consideration

Some relevant factors were considered in the design and development of the hand operated shelling machine. Such factors include power requirement, ease of replacement of various components, labour requirement, ease of mobility, possibility of machine duplication, safety of operation of parts, cost of construction, types of load and stresses, machine kinematics and cost of maintenance. The machine will be very easy to maintain as it does not require mechanical power like oil engine to operate. Mild steel plate of 3 mm thickness was considered for the construction to avoid shearing of parts or machine failure while in operation. The spiral chute operated by lever arm linked to the transmission shaft impacts strong abrasive force to bring about stripping effect as materials are fed in.

Materials Selection

Table 1 shows the list of materials used for the development of all the minor and major components the machine. The components include transmission shaft, stripping chute, bearing, bearing housing, lever arm, material outlet and top cover. The criteria for material selection of each component of the machine assembly were stated with their specifications and dimensions.

Table 1. Major components of the maize sheller assembly.

Machine Element	Criteria for Material Selection	Materials Selected	Dimension	Remark
Transmission Shaft	Machinability, high tensile/compression strength, low notch sensitivity factor, ductile, torsional rigidity, stiffness, etc.	Low carbon steel Iron rod	Ø 25mm, 220mm long	Machined
Stripping chute/Shelling drum	Ability to withstand vibration and abrasive force	Mild steel of 3 mm thickness	Ø 82mm tapered inward	Fabricated
Bearing	Compressive strength, fatigue strength, thermal conductivity, corrosive resistance, etc.	Stainless steel	Øb 68mm Øs 25mmH – 30mm	Bought readymade
Lever Arm/Crank		mild steel rod	Ø 25 mm, 200 mm long	Machined
Support Frame	Compression strength	Galvanized hollow pipe Ø 34 mm	Tripod stand, each being 312 mm long	Constructed
Material Outlet	Must allow free flow of material	Mild steel plate 3 mm thick	249 mm x 37 mm x 3 mm	Constructed
Bearing Housing	Must be strong enough to withstand bearing pressure and protect the bearing from outside particles	Mild steel plate 3 mm thick	Ø 60mm x 70 mm long	Constructed
Top Cover	High shear strength and ability to sustain large permanent deformation to the point of fracture	Mild steel plate 3 mm thick	Ø 86mm(curvature), 81.9mm x 236.5mm	Constructed

Design Calculations

Input power requirement

The input power can be determined from the name plate information of a prime mover used to power the machine. It can also be determined from the drive for the transmission shaft of the machine. In this endeavor, the input power for the sheller was found from the Mathematical model by [Belonio \(2004\)](#) on human power estimation for farm work. It is as stated in Equation 1.

$$P_g (Hp) = 0.35 - 0.092 \text{Log}t (min) \quad (\text{Belonio, 2004}) \quad (1)$$

Human power is given as $P_g (Hp) = 0.35 - 0.092 \text{Log}t (min)$

To find P_g when $t = 1 \text{ h} = 60 \text{ minutes}$

$$P_g = 0.35 - 0.092 \log 60 = 0.35 - 0.092 \times 1.7782$$

$$P_g(Hp) = 0.35 - 0.1636 = 0.1864 \text{ HP} = 0.139 \text{ kW} = 139 \text{ W}$$

Hence, human power requirement by one labourer on the sheller for one hour is 139 W.

If the highest material throughput from the machine is 60 kg h^{-1} and maximum yield from one hectare of land is 1.69 tonnes ([IITA, 2020](#)), it will take the following number of operators to shell maize from one hectare of farm land in one hour:

$$60 \text{ kg} \rightarrow 1 \text{ h}$$

$$1.69 \times 1000 \text{ kg} \rightarrow x$$

$$x = \frac{1.69 \times 1000}{60} = 28.17 \text{ h} \approx 30 \text{ h}$$

It simply implies 30 of such machines are needed to shell harvested maize from one hectare in 1 hour.

Also, one machine can finish the work in 4 days of 8 hours' work per day.

Power requirement for one hectare of maize farm is:

$$P = 30 \times 139 = 4.17 \text{ kW}$$

Load Requirement

$$\text{Power, } P = F \times \omega r = F \times v = \frac{F \times \pi DN}{60} \quad (2)$$

Where F is stripping force on the maize cob, ω is angular velocity of the lever arm and r is radius of the lever arm, v is linear velocity of the transmission shaft.

$$F = \frac{P}{v} \quad (3)$$

It is assumed that Power, P transferred to the tripping chute is constant.

Given the following parameters: $\omega = 120 \text{ rpm}$, $D = 280 \text{ mm} = 0.28 \text{ m}$, stripping force, F can be found.

$$\text{At } 120 \text{ rpm, } F = \frac{P}{v} = \frac{P}{\frac{\pi DN}{60}} = \frac{139}{\pi \times 0.28 \times \frac{120}{60}} = 78.98 \text{ N}$$

$$\text{At } 40 \text{ rpm, } F = \frac{139}{\pi \times 0.28 \times \frac{40}{60}} = 237.03 \text{ N}$$

Torque Requirement

Torque, $T = \text{Stripping force } F \times \text{radius } r \text{ of the stripping chute}$

$$\text{Torque, } T = F \times r \quad (4)$$

If $F = 237.03$ and $r = 80 \text{ mm}$, then:

$$\text{Torque, } T = 237.03 \times 0.08 = 18.96 \text{ N m}$$

Also, at $F = 78.98 \text{ N}$,

$$\text{Torque, } T = 78.98 \times 0.08 = 7.82 \text{ N}$$

Machine Description and Operation

The hand operated maize sheller has four main components; the shelling unit, the cranking unit, material outlet and member frame. The selling unit has tripping chute that can accommodate maize cob of varying geometries. The chute on the other hand has four set of blades arranged in a way to create little or no clearance for the cob. The abrasive force generated in the process assists in stripping maize kernel out of the cob, leaving stripped cob behind as waste product of the process. As soon as a batch is completed, another cob is peaked to continue the operation until all kernels are stripped off the cob. The cranking unit is the section of the machine assembly that provides rotational power to the transmission shaft driving the stripping chute. Human power is used to propel the lever arm of the cranking unit. The crank unit is made of 25 mm mild steel rod and two bearings housed by mild steel plate of 4 mm thickness. Material outlet on the other hand provides passage for flow of shelled maize kernels into sack or container provided. The outlet is tilted at an angle to provide free flow of materials by gravity. The member frame is the support for the entire assembly. The design of the frame is in form of a tripod stand. Two mild steel bars of 12 mm diameter assist to hold the tripod in place. The legs of the operator are placed on both sides of the tripod to further strengthen the firmness of the machine while in operation. See figures 1, 2, 3 and 4 for details on all the units of the machine assembly.

Cost Estimation of the Hand Operated Maize Sheller

Cost of engineering products can broadly be grouped under direct or indirect cost. Direct cost is the cost of factors which are directly attributed to the manufacture of a specific product (i.e. materials and labour costs). Indirect cost on the other hand is that indirectly attributed to the manufacture of a specific product, such as overhead cost (usually expressed in percentage of direct labour cost), (Ajav *et al.*, 2018). The costing of the newly designed and fabricated maize Sheller was based on the detailed factorial estimate method. This is because fabrication of the machine is complete and

detailed breakdown and estimation of component parts is possible. The cost analysis of the machine is as shown in Table 2.

Table 2. Bill of Engineering Measurement and Evaluation (BEME).

S/N	Materials	Quantity	Unit Price (₦)	Total (₦)
1	Bearing Ø 22mm (internal Ø)	2	1 500	3 000
2	Rod Ø 22mm& 110 mm long for shaft	¼	8 000	2 000
3	Hollow pipe for body frame Ø 35mm	½	6 000	3 000
4	Mild steel plate 3 mm thickness	¼	28 000	7 000
5	Braising Rod for support 12 mm	½	4 000	2 000
6	Consumables (Electrode, paint & cutting disc)			2 500
7	Transportation			1 000

Note : 1 US Dollar = ₦ 447.52

Sub-total = ₦ 20,500.00 = \$ 45. 81

i. **Materials Cost** : = ₦ 20 500.00 = \$ 45. 81

ii. **Direct Labour Cost:**

(Machining of Main Shaft Bending, welding, painting) = ₦2 500 = \$ 5. 59

iii. **Indirect/Overhead Cost:** = 20% of ₦ 20 500.00 = ₦4,100 = \$ 9. 16

Grand-total = Material cost + Labour cost + Overhead cost = ₦27 100 = \$ 60. 56 ≈ \$61. 00

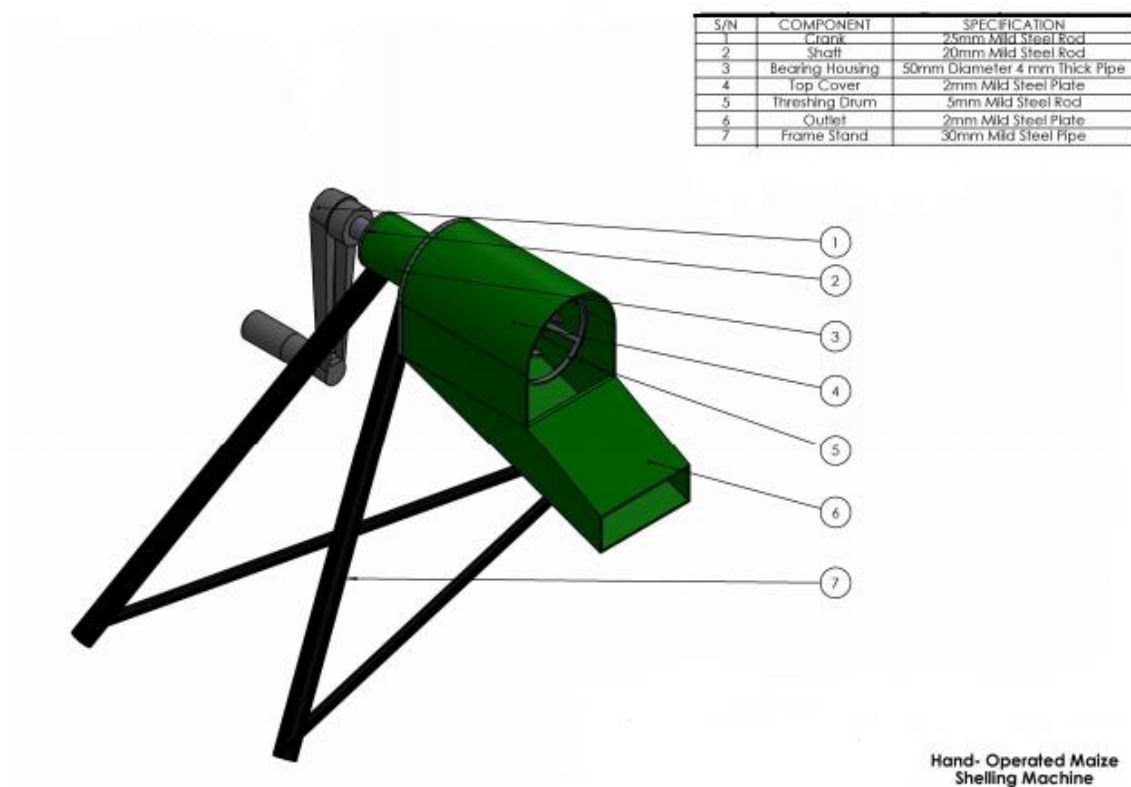


Figure 1. Pictorial view of the machine.

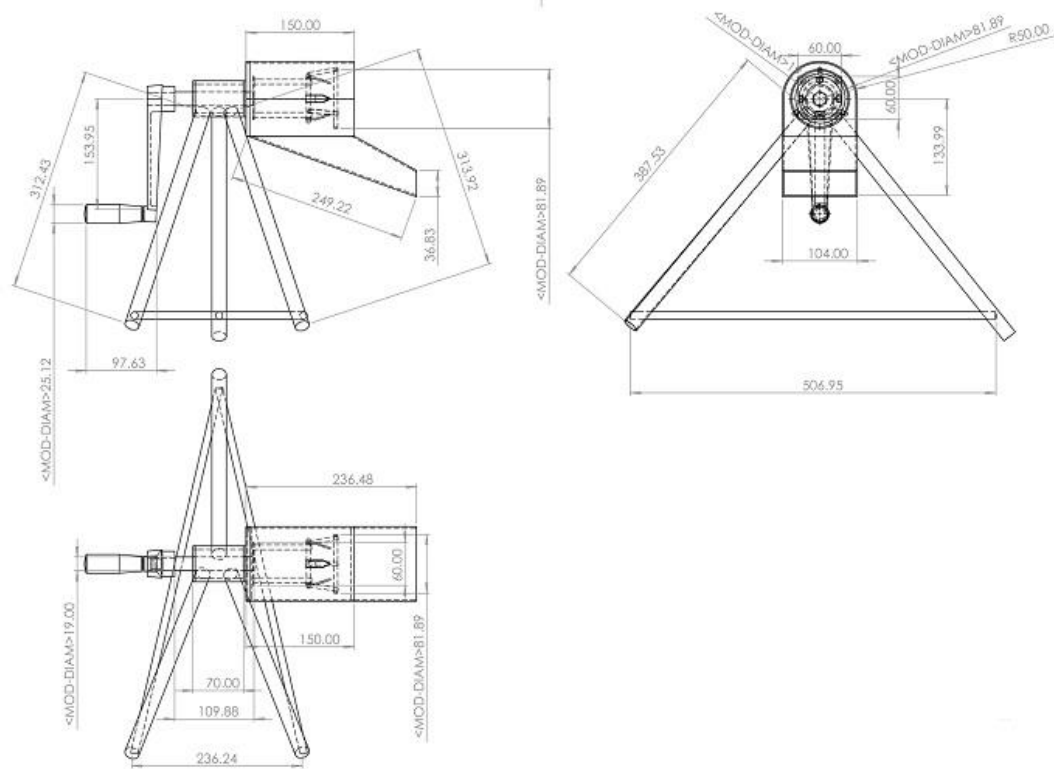


Figure 2. Autographic projection of the machine.

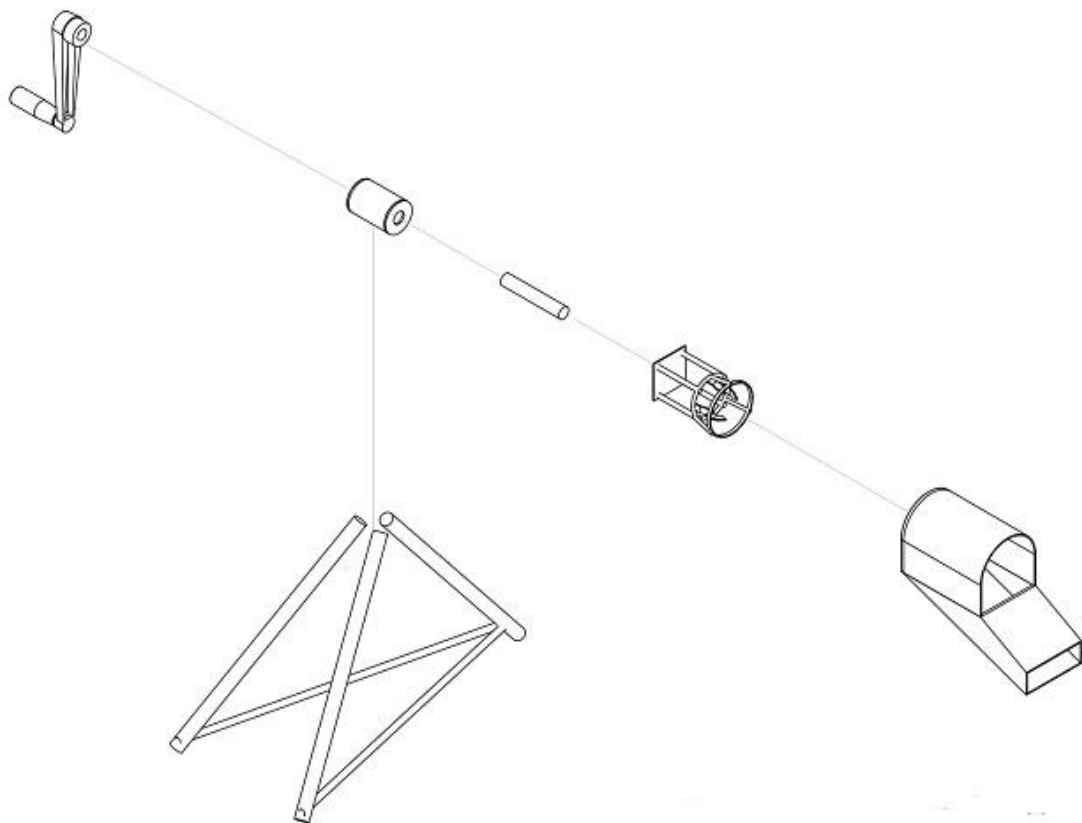


Figure 3. Exploded view of the machine.

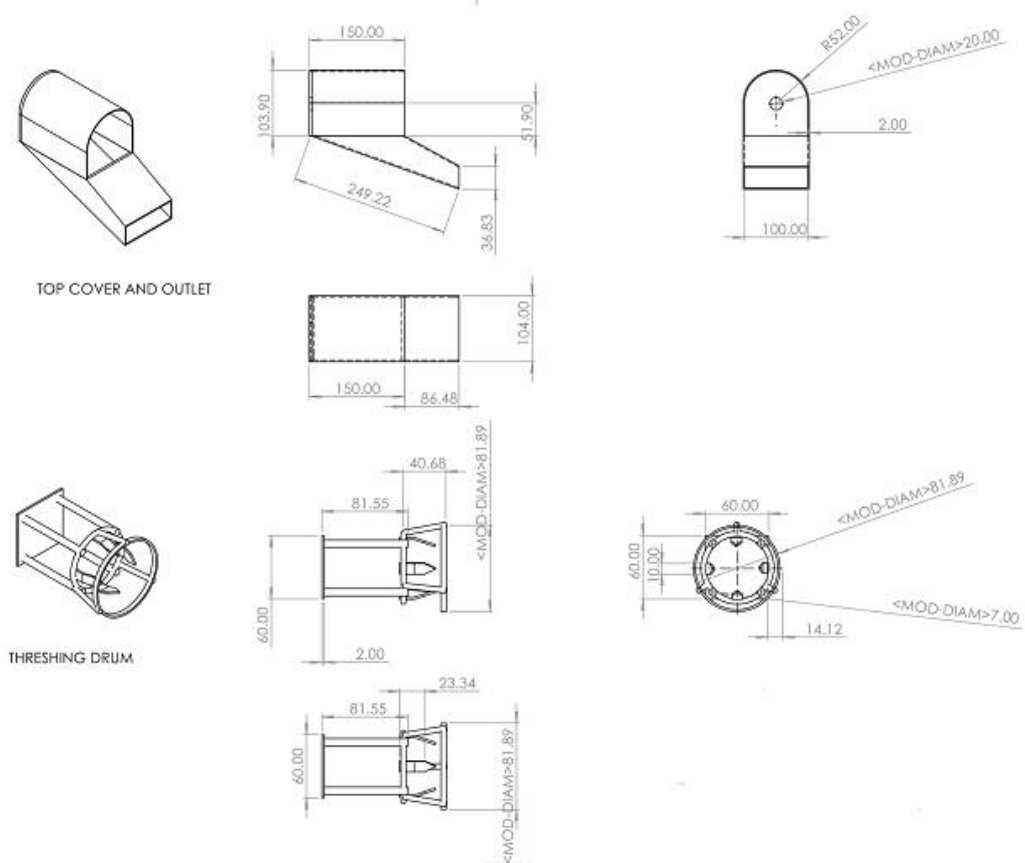


Figure 4. Part drawing of the machine.

Figures 1 and 2 are respectively the pictorial view and autographic projection of the machine assembly while Figures 3 and 4 are the exploded view and part drawing of the machine assembly. The dimensions of each component or subcomponents are shown as well. The components include threshing drum, bearing housing, support frame, grain outlet, crank arm, etc.

Statistical Method for Analysis

Null hypothesis for variables considered is $H_0: 0.5 \leq r \leq 1$; while alternative hypothesis is $H_1: r < 0.5$. For H_0 in the range of values stated above. The regression line in Equation 5 and 6 can be determined using statistical method of multiple linear regression by hand using dependence techniques, machine learning algorithm of any applicable application software like excel. A relationship is established between two or more predictors and a response variable for bivariate data (Equation 5). Multivariate linear regression was the statistical model used to understand the relationship between two explanatory variables (speed and moisture content) and a response variable (materials throughput). For the multivariate data, Equation 6 is used. y is response variable, β_0 is intercept on y axis, X_1/X_n is the predictor and β_1/β_n is the regression coefficient and ε is the model error. Microsoft Excel Data Analysis tool pack for multiple regressions was used for analysis of the data.

$$y = bx + a \quad (5)$$

$$y = \beta_0 + \beta_1 X_1 + \beta_n X_n + \varepsilon \quad (\text{Zach, 2020}) \quad (6)$$

Materials for Evaluation

Materials used for evaluation of the sheller are unshelled maize at various MC (14%, 18.5%, and 23.2%), the hand operated sheller, sensitive measuring scale, stop watch, recording materials, veneer caliper, moisture meter. Variables considered during evaluation are material throughput, moisture content, speed of rotation of the crank, stripping force, shelling efficiency, shelling methods and percentage of broken kernel. Equations 7, 8, 9 and 10 below were used for results estimation of the machine evaluation ([Azeez et al., 2017](#)).

$$\text{Materials Throughput} = \frac{\text{Weight of material processed (kg)} \times 60}{\text{Time (minutes)}} \quad (7)$$

$$\text{Percentage of unshelled grains (\%)} = \frac{\{\text{Weight of unshelled kernels (kg)}\}}{\{\text{Total Kernel input (kg)}\}} \quad (8)$$

$$\text{Shelling Efficiency} = 100 - \text{percentage of unshelled kernels} \quad (9)$$

$$\text{Kernel Damage (\%)} = \frac{\{\text{broken grain (kg)}\}}{\text{Weight of shelled maize kernel (kg)}} \quad (10)$$

RESULTS AND DISCUSSION

Maize sheller developed was evaluated using unshelled maize at various moisture content and speed of rotation of the crank arm to determine the efficiency, shelling capacity and kernel damage. The results of the analysis are as shown in Figures 5 and 6 and Tables 3, 4, and 5.

Tables 3, 4 and 5 show the results of evaluation of the developed maize sheller at various moisture content (MC) ranging from 14% to 23.2%. The results show kernel breakage reduces as the moisture content of various maize samples used for machine evaluation reduces. Also, highest material throughput (60 kg h⁻¹.) was obtained at lowest MC (14%) and highest angular speed of rotation. The efficiency of shelling was seen to be highest at lowest MC and time (6-10 seconds).

Table 3 shows reduction in efficiency of shelling from 100 to 94 percent as the speed of rotation increases from 40 rpm and 120 rpm. It can be inferred that the operation of the machine should be kept at barest minimum level to be able to experience optimum shelling efficiency. Also, kernel damage can reduce significantly if the hand operated sheller is kept at optimally low speed while in operation.

Table 3. Machine evaluation at moisture content (MC) of 23.2% and time range of 16-22 seconds.

S/N	Material's throughput (kg h ⁻¹)	Speed (rev min ⁻¹)	Shelling efficiency (%)	Kernel damage (%)
1	18.61	120	94	0.95 ± 0.01
2	16.52	100	95	0.72 ± 0.01
3	15.72	80	97	0.41 ± 0.01
4	13.85	60	99	0.23 ± 0.01
5	12.00	40	100	0.12 ± 0.01

Table 4 shows reduction in efficiency of shelling from 100 to 95 percent as the speed of rotation increases from 40 rpm and 120 rpm. Kernel breakage also reduced when compared to parameters in Table 3. This could be due to reduction in moisture content of the maize evaluated. It was 23.2% in Table 3 and 18.5% in Table 4. The time it took to shell the same quantity of maize under similar condition also reduced. This shows that the dryer the material to be shelled is, the lesser the time it will take to shell it.

Table 4. Machine evaluation at moisture content (MC) of 18.5% and time range of 8-12 seconds for each maize cob.

S/N	Shelling capacity (kg h ⁻¹)	Speed (rev min ⁻¹)	Shelling efficiency (%)	Kernel damage (%)
1	27.00	120	95	0.31 ± 0.005
2	22.50	100	96	0.25 ± 0.005
3	18.00	80	97	0.14 ± 0.005
4	15.88	60	100	Nil
5	14.21	40	100	Nil

Table 5. Machine Evaluation at MC of 14.0 % and time range of 6-10 seconds for each maize cob.

S/N	Shelling capacity (kg h ⁻¹)	Speed (rev min ⁻¹)	Shelling efficiency (%)	Kernel damage (%)
1	60.00	120	96	Nil
2	50.50	100	97	Nil
3	40.00	80	99	Nil
4	30.17	60	100	Nil
5	19.89	40	100	Nil

The result in Table 6 shows various values of shelling capacity at different shelling methods ranging from manual to motorized shelling. The table compared the shelling capacity of the methods. Motorised sheller has the highest capacity (125.0-701.4 kg h⁻¹) when compared to all other methods. It can be inferred that what the hand operated sheller does not have in shelling capacity is compensated for in overhead cost - running cost (fuel and maintenance cost).

Table 6. Shelling capacity using different shelling methods.

S/N	Shelling method	Shelling capacity (kg h ⁻¹)	Remarks
1	Rubbing maize against each other	3.0 – 4.0	Evaluated
2	Hand shelling	3.5 – 5.0	Evaluated
3	Hand operated maize shell	18.6 – 60.0	Evaluated and reported by: Rajender et al. (2018) ;
4	Motorized maize sheller	125.0 – 701.4	Reported by: Sedara et al. (2021) ; Dagninet et al. (2008) ;

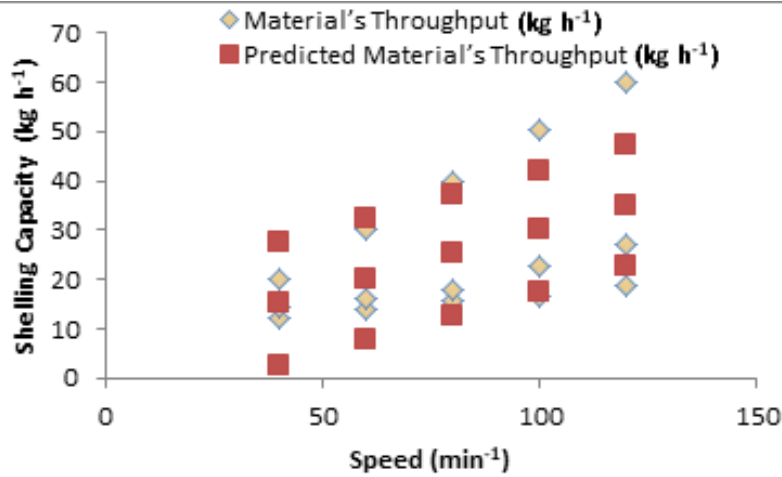


Figure 5. Chart of a predictor (speed) and response variable (Shelling Capacity).

In Figure 5, shelling capacity increases as the speed of rotation of cranking arm increases. The highest value was obtained (60 kg h⁻¹) at highest speed of rotation (120 rev min⁻¹).

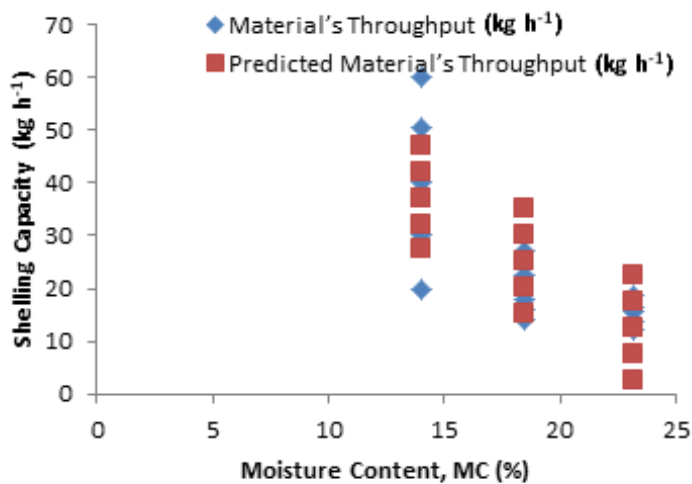


Figure 6. Chart of a predictor (moisture content) and response variable (Shelling Capacity).

Figure 6 is the plot of response variable with one of the predictors (MC). Highest value of materials throughput is obtained at lowest MC (14%) possible.

The relationship between the variables also provides the values predicted by the model and the difference between the actual value of the dependent variable and its predicted values by the regression model for each data point.

Results of analysis in Tables 7 and 8 explain the strength of relationship and level of confidence between the two independent variables and the response variable. The results presented in Table 7 shows that 15 observations were used for the model of the predictors and the response variable. The coefficient of determination, R square being 0.777 implies 77.7% of the variation in the materials throughput can be explained by speed of rotation of the crank arm and the moisture content at which the maize was shelled. The multiple R value, 0.883 reveals that there is strong level

of correlation or linear relationship between the two explanatory variables (predictors) and that null hypothesis defined is within acceptable limit. The standard error, 7.35 is larger than the coefficients of the two predictors (speed and MC) which are respectively 0.25 units and 2.68 units. On the average, the observed values of predictors fall 7.35 units from the regression line.

Table 7. Regression parameters.

Multiple Regression Statistics	
Multiple R	0.8813
R Square	0.7767
Adjusted R Square	0.7395
Standard Error	7.3511
Observations	15

Table 8 shows the analysis of variance (ANOVA) of the regression statistics. From the table, it can be deduced that the number of independent variables in the model is 2 as regression degree of freedom (df) is 2. F value in the table is 20.87 and the Significance F is 0.00124. The F value assists in testing the hypothesis that the slope of the independent variable is zero. The Significance F is otherwise called the p value for the null hypothesis that assists in confirming that the coefficient of the independent variable is zero. Since the p-value is below 0.05, it implies there is 95% confidence that the slope of the regression line is not zero. Hence, there is significant linear relationship between the explanatory variables (speed and MC) and the response variable (material throughput). For individual p - value in Table 8, it can be deduced that each explanatory variable is statistically significant – meaning the two predictors are applicable for the model.

Coefficients and intercept presented in Table 8 can be used to express linear regression model stated in Equation 6. The response variable, y can be established from the parameters in the table. β_0 is 54.92 kg h⁻¹, β_1 is 0.248 rpm, β_2 is - 2.68 % and ε being the model error has value of 1.187 kg h⁻¹. Therefore, response variable y is expressed as: $Y = 54.92 + 2.68X_1 - 2.68X_2 \pm 1.187$ (kg h⁻¹).

Table 8. Model parameters.

	Coefficients	Standard Error	t Stat
Intercept	54.92	10.97	5.00
Speed (rev/min)	0.25	0.07	3.69
MC (%)	-2.68	0.51	-5.30

Variable X_1 in the model is speed of rotation of the crank arm; variable X_2 is the moisture content of maize under evaluation; and variable Y is the material throughput. For example, for every unit increase in cranking speed of the machine at particular moisture content, material throughput increases commensurately. When the experiment is run at much lower moisture content, material throughput increases significantly. The negative sign in the coefficient of variable X_2 indicates that there is inverse relationship between material throughput and moisture content of maize under process. Every unit increase in moisture content will decrease material throughput. The machine reached highest material throughput

(50 kg h⁻¹. – predicted, 60 kg h⁻¹ – estimated) at lowest moisture content (14%) and optimum speed of rotation (80 rpm). From the foregoing, it can be inferred that what the machine does not have in shelling capacity is compensated for by low overhead/running cost when compared to motorized sheller. The machine also has comparative advantage over traditional shelling as it is less stressful to operate; it has shelling capacity higher than any traditional method ever reported (see tables 6 for more details). The shelling capacity (60 kg h⁻¹) is also higher when compared to pedal operated maize sheller (40.22 kg h⁻¹) reported by [Rajender et al. \(2018\)](#).

CONCLUSION

From the result of various analysis and evaluations carried out on the machine, it can be deduced that the sheller has comparative advantage over traditional shelling methods ever reported, in terms of shelling capacity, efficiency and shelling drudgery (see Table 4). The hand held Maize Sheller reduces the time required for traditional shelling by more than 10 times and it also protects from injury to fingertips. Also, what the machine does not have in shelling capacity is compensated for by low overhead/running cost when compared to motorized sheller. The operation of the machine should be kept at barest minimum level of speed to be able to experience optimum shelling efficiency. Kernel damage can reduce significantly if the hand operated sheller is kept at optimally low speed while in operation. The moisture content of maize to be shelled play significant role on shelling efficiency, shelling capacity and kernel breakage estimation of the machine. Therefore, maize shelling by the machine is effective when the moisture content is in the range of 10 to 14% the dryer the material to be shelled is the lesser the time it will take to shell it. The machine can be given wide publicity to encourage wide adoption especially among small and medium scale farmers in the rural communities. In view of the federal government policy of local production of grain crops to enhance food sufficiency and security, heavy investment on commercialization of the machine is recommended since it is cost effective and easily affordable.

DECLARATION OF COMPETING INTEREST

We hereby declare that we have no conflict of interests

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Muyiwa Abiodun Okusanya conceptualized this project, did investigation, design and fabrication of the machine.

Francis Ehis Agbongiaban contributed to the methodology, data collection/analysis performance evaluation review and editing of the write-up.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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