Development of a Low-Cost Hammer Mill Machine for Food Processing

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Authors' contributions

This work was carried out in collaboration among all authors. Author ITA wrote the first draft of this manuscript and played a part role in the modelling of the machine. Author JAO wrote the second draft of this manuscript and was in charge of the working drawings of the machine both as a model and in the manuscript. Author OAO played a pivotal role in the development of the machine on the workshop floor and supervised the development of the machine on the workshop floor. Author ITO ensured the machine met Author OK was the final supervisor of the modelling and development. Author AKO was in charge of the final approval of the project and ensured that the Machine was developed to conform to the organizational standards expected by the necessary standards regulation. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

This hammer mill was fabricated from locally sourced and available materials for grinding of large sized grain particles such as SORGHUM, maize, millet, guinea, etc. into small sizes enough to pass through the holes of the cylindrical sieve positioned beneath the hammer assembly. Hammer mills have enjoyed major use in the pulverization and/or grinding of granular objects or similar solid materials into smaller sizes or particles. Major parts of the Conventional hammer mills are shaft, free swinging hammers, sieve, hopper, electric motor, and discharge chute amongst other component parts. Functional hammer mills operated within the urban settlements in Nigeria are

mostly imported and expensive to acquire by rural farmers thus the need to develop one that can be easily acquired by the rural farmers as well as ease of maintenance. The grinding process is achieved using a hammer in beating the material fed into fine particles; the fineness aimed depends on the beating operation that happens when the Hammers hit the grain particles across the inner walls of the grinding or crushing chamber. The final size of the ground sorghum is a product of the aperture size which ranges from 87μm to 2 mm. This particular design has its major focus on the analytical design of an improved compact hammer mill that employs a single-acting operation to pulverize, move and push out pulverized bulk material particles against gravity through a cyclone. This machine consists of some vital components like the loading hopper and tray, low and high-pressure throats, shaft, spacing discs, hammers, axial fan, gate, cyclone, electric motor, bearings and pulley. This fabricated hammer mill is compact, and cost-effective to produce, operate and maintain. Its commercial production and use will be a reprieve to rural farmers as well as promote local content technology in Nigeria. The economic evaluation of the machine revealed that the material worth of US$85.20 was used for its construction. Testing and performance evaluation carried out on the machine showed that the machine had a 98.4% crushing and grinding efficiency.

1. INTRODUCTION

"Sorghum, is a cereal grain plant of the grass family (Poaceae) and its edible starchy seeds. The plant likely originated in Africa, where it is a major food crop, and has numerous varieties, including grain sorghums, used for food; grass sorghums, grown for hay and fodder; and broomcorn, used in making brooms and brushes. In India sorghum is known as jowar, *cholam*, or *jonna*, in West Africa as Guinea corn, and in China as kaoliang. Sorghum is especially valued in hot and arid regions for its resistance to drought and heat" [1].

"Sorghum is of a lower feed quality than corn (maize). It is high in carbohydrates, with 10 percent protein and 3.4 percent fat, and contains calcium and small amounts of iron, vitamin B$_1$, and niacin. For human consumption, the gluten-free grain is usually ground into a meal that is made into porridge, flatbreads, and cakes. The characteristic strong flavour can be reduced by processing" [2].

Fig. 1. The various forms of Sorghum

"The grains are edible and nutritious. It can be eaten raw when young and milky but has to be boiled when older. One species, Sorghum bicolor, native to Africa with many cultivated forms, is an important crop worldwide, used for food (in the form of grain or sorghum syrup), animal fodder, the production of alcoholic beverages, and biofuels. Sorghum's cultivation has been linked by archaeological research back to ancient Sudan around 6,000 to 7,000 BP" [2].

"All sorghums contain phenolic acids, and most contain flavonoids. Sorghum grains are one of the highest food sources of the flavonoid proanthocyanidin. Total phenol content (in both phenolic acids and flavonoids) correlates with antioxidant activity. Antioxidant activity is high in sorghums having dark pericarp and pigmented testa. The antioxidant activity of sorghum may explain the reduced incidence of certain cancers in populations consuming sorghum" [1].

"Popped sorghum is popular as a snack in India. The popped sorghum is similar to popcorn, but the puffs are smaller. Like popcorn, popping sorghum is done by microwave, in a pot, or other similar ways. It may also be used as a flavoring for clarified butter (ghee)" [3].

"In China, sorghum flour is used in combination with wheat flour to make noodles and bread. Most varieties are drought- and heat-tolerant, nitrogen-efficient, and are especially important in arid and semi-arid regions, where the grain is one of the staples for poor and rural people. These varieties form important

components of forage in many tropical regions. S. bicolor is an important food crop in Africa, Central America, and South Asia, and is the fifth most important cereal crop grown in the world" [4].

"Global demand for sorghum increased dramatically between 2013 and 2015, when China began purchasing US sorghum crops to use as livestock feed as a substitute for domestically grown corn. China purchased around $1 billion worth of American sorghum per year until April 2018, when China imposed retaliatory duties on American sorghum as part of the trade war between the two countries" [4].

"Indeed, the milling of dried grain materials into finer bulk material particles is a long practice which has undergone various methods and advancements over time. These traditional methods include earth stones, forced beating using human effort, mechanical devices by attrition and blenders" [5,6]. "Each of these methods have their various advantages and set back. Increased demand for various materials arising from a growing human population around the world has necessitated technological exploration and improved productivity. This has led to the massive request of new machineries and optimization of existing ones" [4].

"This hammer mill, otherwise called the Sorghum Miller, is designed for processing, grinding, and sieving all kinds of cereal grains, such as Sorghum, maize, wheat, millet, corn, wheat. Whilst it can also process it can also process non-cereal materials such as dry cassava tuber and yam tuber, we would advise that the usage stick to the grinding of cereals. There is a great complexity in the processing of cereals as well which is a major factor in ensuring that the Hammer mill machine be fine-tuned to specific operations and usage. The principal procedure is milling; that is, the grinding of the grain so that it can be cooked and rendered into an attractive foodstuff. In ancient time, the cereal grains were crushed between two stones and made into crude cake but the advent of modern automated systems employing steel material such as hammer mill have revolutionized the processing of cereals and their availability as human foods and other purposes. The machine is of hammer mill type. In this case, there is hammer-like projection mounted on a shaft. The hammer revolves at high speed and grinds the materials fed into pieces by beating. Moreover, the machine can mill only the dry materials. The machine is incorporated with a detachable sieving mechanism to ensure fineness of cereal grain ground. The industrial screen - the main components responsible for sieving - is made of wire cloth with aperture sizes ranging from 870 µm to 2 mm" [7].

"The machine cannot be operated manually. The electrical operation is effected by the use of one horsepower electric motor with speed of 1,400 rev/mm. The machine can handle 5 kg of cereal grains in a single operation lasting 15 min. The entire construction is brought about by locally sourced material thereby making the cost not prohibitive" [8,9]. "The machine elements are easily accessible and detachable to facilitate assembling and maintenance process. Due to the cost of importing the Hammer mill machine, there was a necessity to fabricate a machine from locally sourced material for the ease of maintenance, a machine that is easy to maintain, less expensive yet highly efficient machine and we have been able to fabricate such machine" [10].

It is true that the hammer mill is a product of improved methods for bulk material grain processing into smaller and finer particles. The machine operates by pulverizing, grinding, and sieving the grains through a solid mesh or forced draft. The components of a typical hammer mill include a shaft with free-swinging metal weights, a loading hopper, a milling chamber, bearings, and a motor. The motor is connected to one end of the shaft via a pulley and belt, which drives the shaft and hammers at high speed to effectively mill the grains. In Nigeria, as in many other developing countries, modern hammer mills are often imported from developed nations, making them expensive to acquire and maintain. However, Nigeria has vast arable lands, particularly in rural areas where subsistence and commercial farmers reside. The farmers cultivate agricultural produce that requires mechanical processing, such as milling, to convert them from their raw state into semi or fully-finished products like flours made from sorghum, rice, cassava, yam, soybean, and more. The hammer mill is a suitable mechanical system for farmers.

While imported hammer mills may be costly for farmers in Nigeria, there is a need for locally available or improvised methods that are affordable and efficient. Conventional and many locally made hammer mills have been utilized in farming communities in the country, but they often have setbacks and recurring issues. These

setbacks have prompted the design and development of improved and optimized local models of the machine. Efforts to design and optimize local hammer mills in Nigeria aim to address the challenges faced by farmers, including affordability, ease of use, and reliability. These localized models take into consideration the specific needs of the farmers and the agricultural produce they work with, providing more accessible solutions for grain milling. The design improvements can vary, focusing on aspects such as materials selection, manufacturing techniques, operational efficiency, maintenance requirements, and overall performance. Developing and promoting locally optimized hammer mill designs, the goal is to empower farmers in Nigeria and similar contexts to access efficient grains milling technology that meets their specific needs and contributes to improved productivity and livelihoods within the agricultural sector [11].

The underlisted are setbacks of many of the existing locally fabricated hammer mills that have been reported by various researchers and they are [12];

"Wear and corrosion as a major cause of friction at the sieve screen holes' thus leading to enlargement or burst which often allows passage of larger than desired particles to pass through. There is tendency of a build-up of moisture which makes the materials wet and become elastic and therefore absorb most of the impact energy of the hammer without breaking down to smaller particles. In a bid to proffer solution to the setbacks identified, the authors designed a petrol-powered hammer mill with a dimensionally controlled open gate endless sieve to solve the problem of sieve bust and clogging" [13]. "After several hours of milling operation, the sieve holes are clogged with a consequential reduction in its efficiency and operating capacity. A fan was also introduced at some point to induce forced convection and dry out moisture from the product. These researchers also introduced a mechanical separator, which rotates at the same speed as the shaft to ensure that all solid particles above certain sizes are blown back into the hammer mill chamber until they are ground or broken by impact into fine particles" [11].

2. METHODOLOGY

The design process for the improved and optimized hammer mills in Nigeria involved an analytical and adaptive approach. The initial step

was to conduct an observatory study of all existing hammer mills, examining their design and operation. Additionally, relevant research works on hammer mill designs were reviewed to gather insights and identify areas for improvement. By adopting an analytical and adaptive method, the design team was able to leverage existing knowledge while incorporating new ideas and solutions that are innovative to optimize the performance and functionality of the hammer mill [11]. This process allowed for the development and functionality of the hammer mill. This process allowed for the development of a locally suitable and affordable design that specifically addressed the needs and challenges faced by farmers in Nigeria. Overall the analytical and adaptive design approach ensured that the improved hammer mill took into consideration the practical realities and constraints of the local context, utilizing available materials and refining alternatives where necessary. The goal was to create a cost-effective and efficient solution that could enhance grain milling processes for Nigerian farmers [12].

Some critical areas that was focused on for improvement and materials utilized are as follows;

- Stainless steel was employed as an improvement in this hammer mill design to counter the inefficiencies of Mild steel for food processing machines and avoid the high corrosion tendencies in Mild steel which was used by many of the previous research work. Corrosion of metals which is synonymous with mild steel is a harmful to food and human health.
- Compactness and simplicity of the new hammer mill was achieved by ensuring that all operational components exist as a single operating unit. The primary objective of this was to ensure that the machine area became less bulky and the machine more cost-efficient and durable to transport.
- Hopper was constructed in such a way that the grains aren't fed directly into the hammers. It was ensured that they pass through a horizontal flat tray on which the grains are pushed through a tunnel distance before falling through an opening via a long throat to the milling chamber. This aim of this was to avoid any form of fly back or rebound of grain particles and powders from the milling chamber.
- Throat: This was fabricated and positioned such that bulk materials are directed into

the milling chamber where it takes direct hit and crush by the impact of the hammers.

- Shaft: Been an important part of the machine, the shaft diameter was critically selected to ensure it can resist twisting and bending moments, and the shaft length has enough space to carry the embedded components of discs, hammers, spacers, connecting rods and axial fan.
- Crushing chamber; This houses the working part of the machine such as shaft and the entire embedded components. It has an ellipse profile and passes through a hole at the opposite end from the loading end through which powder material was pushed out against gravity via an exit cut-out.
- Electric motor: this was the prime driver of the machine. It was selected to have the capacity to drive the shaft and all its embedded components whilst having the capacity to create a push force from the fan required to move the pulverized grain powder up the exit throat against gravity. A 10hp motor was used for effective operation of the machine.
- Bearings: these were selected according to the type of machine, machine mechanical properties, the design load and shaft diameter
- Structural frame: The frame fabricated in such a way that it is close to the ground so as to reduce vibration and reduce the centre of gravity for good stability.
- Pulley and belts: a single pulley was used implying that a single belt would be used to connect the electric motor from one end of the shaft via a driver pulley on the motor to the driven pulley on the shaft.

2.1 Aim of the Project

The aim of this project is for the development of an efficient hammer mill suitable for Sorghum grinding out of locally sourced materials and at a reduced production and maintenance cost. This will play a vital role in the cereal production company especially in application to food making for infants and babies.

2.2 Objectives of the Research

The objectives of this research is to: -

1. develop an efficient Food processing Hammer Mill, and

2. carry out performance evaluation of the machine developed in order to determine its functional requirements.

2.3 Justification

The problems associated with the existing process of grinding sorghum are enumerated thus:-

1. The old method of sorghum grinding is extremely time-consuming, cumbersome with little output and labour intensive.
2. Cost of buying imported machine is high.

Therefore, the project is to provide an alternative means to the problems highlighted above while still placing emphasis on efficiency of the machine.

3. RESEARCH METHODOLOGY

Extensive review of literatures on the different types of cereals, methods of grinding and existing machines was also carried out. Literatures on cereal grinding machines were read and used. Some experimental grinding processes were done and literature on construction and fabrication techniques was also consulted to get a good development which is cheap, made from local materials and with good aesthetics.

The Conceptual design: The emphasis of the conceptual design was based on the principle of design by analysis. The methodology aimed to reduce the identified lapses in the convectional hammer mill by introducing special features. The focus of improvement was on the enclosed crushing chamber of the hammer mill. The physical and mechanical properties of the material to be crushed were studied as because its understanding was crucial for designing various components of the rotor. Engineering properties and other important parameters were also considered in the design process. Alternative materials were used to overcome the said limitations as the goal was to develop a cost-effective and efficient hammer mill tailored to meet the needs of the Nigerian farmers.

The assembly of the machine was also researched, and the materials selection software (GRANTA) was adequately used. Evaluation and testing of the project work was carried out under a controlled environment of the institute's workshop so that the behaviour of the machine

was properly ascertained and its behaviour under other conditions can be predicted.

Vast knowledge of various CAD software (ProEngineer, AutoCAD and Autodesk Inventor) was adequately used in the Modeling and Simulation of this machine and the force analysis was carried out to know its performance under different loading conditions.

3.1 Significance of the Project

The manual method of sorghum grinding is very slow and burdensome which apparently led to the wastage of resources, low output and time consumption. This work aims at increased productivity, optimal performance of the machine and affordability by the Small and Medium scale industries in the country.

3.2 Design Considerations

The design was carried out on the basis of the safety of the operator. Some other major hazards which may arise in the course of crushing were properly put into consideration. One major concern that was addressed was the deflection of the hammers during operation. To prevent such issues such as rotor or hammer jamming, swinging hammers were used instead of stiff ones. This design choice allowed for flexibility in the hammer's movements. If a hammer encounters a material, it cannot break upon first impact, the swinging motion helps to avoid the rotor or hammer from getting stuck or jammed. Overall, operator safety was a key consideration throughout the design process, and measures were implemented to mitigate hazards

3.1.1 Basic design

Determination of Shaft Speed: To calculate the shaft speed, the following design parameters are used.

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \tag{1}$$

Where

N$_1$ = revolution of the smaller pulley, rpm
N$_2$ = revolution of the larger pulley rpm
D$_1$ = diameter of smaller pulley, mm
D$_2$ = diameter of larger pulley, mm

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value (913.5 rpm) is reduced by 4% [14].

Determination of Nominal Length of the Belt:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \left(\frac{D_1 - D_2}{4C}\right)^2 \tag{2}$$

Where,

L = Length of the belt, mm
C = Centre distance between larger pulley and the smaller one, mm

Centre distance minimum, C$_{min}$ was calculated using:

$$C_{min} = 0.55(D_1 + D_2) + T \tag{3}$$

And Centre distance maximum:

$$C_{max} = 2(D_1 + D_2) \tag{4}$$

T = Nominal belt thickness
D$_1$ = Larger pulley diameter
D$_2$ = Smaller pulley diameter

Determination of Belt Contact Angle: The belt contact angle is derived by equation

$$\sin^{-1}\beta = \frac{(R-r)}{C} \tag{5}$$

Where,

R = radius of the larger pulley, mm
r = radius of the smaller pulley, mm

Determination of the Belt Tension:

$$T_2 = \frac{(T_1 - MV_2)}{exp\left[\frac{\mu\alpha}{\sin\frac{1}{2}\theta}\right]} \tag{6}$$

$$T_2 = SA \tag{7}$$

Where

S = the maximum permissible belt stress, MN/m^2
A = Area of belt

Determination of the Torque & Power Transmitted for the Shaft:

$$POWER = (T_1 - T_2)V \tag{8}$$

$$T_r = (T_1 - T_2)V \tag{9}$$

Where,

T_r = Resultant Torque
T_1 & T_2 = Tension in the belt, N
R = Radius of bigger pulley, mm

Determination of Hammer Weight:

$$W_h = M_n g \qquad (10)$$

Material = Mild Steel
Density = 7.85 g/cm3

$$Density = \frac{Mass}{Volume} \ (kg/m^3) \qquad (11)$$

Determination Maximum Power Transmissible (Kw):

The maximum power, which the belt can transmit, is given by:

$$P = \frac{0.45}{V^{0.09}} \left[\frac{19.62}{D_o} + 0.765 + 10^{-4}V^2 \right] V$$

Where D_o = equivalent pitch diameter (mm). If F_b is the small diameter factor to account for the arc of contact, then $D_o = d.F_b$ where d = diameter of the driver pulley (mm).

Determination of Hammer Shaft Diameter

$$\sigma_s \ (allowable) = \frac{M_b Y_{max}}{I}$$
$$\frac{I}{Y_{max}} = Z = \sigma_s = \frac{M_b}{Z} \qquad (12)$$

Where

Y_{max} = Distance from neutral axis to outer fibers
I = Moment of inertia
Z = Section modulus
For solid round bar

Hopper Design: Hopper design is based on a common criterion, which is required for it to function. This criterion is called the *"Angle of Repose"*. Angle of repose is defined as the angle of friction of rest. The hopper designed is a gravity discharge one, and the recommended angle of repose for gravity discharge ranges between 15^0 and 25^0

The volume was estimated from equation;

$$V = \frac{h}{3}\left(A + a + \sqrt{Aa}\right)$$

Where:

h = perpendicular height (mm);
A = Area of the upper opening (mm^2);
a = area of the lower opening (mm^2).

Note that the slant height, l is derived from the relation, $h = l\cos\phi$ where ϕ is defined as the angle of repose.

Table 1. Design specifications (Authors' Estimate; 2018)

Components	Assumed Parameters	Design Parameters
Hopper	h=280 mm, A= 129,600 mm^2, a=12,100 mm^2	V=16.92x10^6 mm
Speed Ratio	N_1 = 2600 rpm; N_2 = 2267 rpm; d = 102 mm	D = 117 mm
Maximum power	F_b = 1.0; d = 0.102 m	P = 4.85 kW
Prime Mover	From Shaft, Pulley and capacity design	2,600 rpm, 4.85 kW
Width of pulley	t = 11 mm	W $\cong$ 14 mm
Belt Number (*N*)	F_d = 0.98; F_c = 0.8; F_a= 1.2; P = 4.85 kW	N = 2.124
Tension, T_1 and T_2	W_1 = 14 mm; β = 175^0; θ = 34^0; W_2= 4.99 mm; h = 22.26 mm; V = 5.93 ms^{-1}	A = 7.16x10^{-5}m^2; T_1 = 145.2 N; α_1 =175^0; α_2 = 185^0; CI_1 = 66.89; CI_2=84.02; T_2 = 4.85 N
Diameter, *d*, of shaft	Mb = 68.27 Nm; Mt = 11.41 Nm; Kb= 1.5; Kt = 1.0; S_s = 55x10^6 N/m^2	d = 35 mm

4. MATERIALS SELECTION PROCEDURE

The considerations contained in this work are aimed at meeting the desired standard as expected for a Sorghum grinding machine. This were the Materials selection procedure that was carried out before each material was considered appropriate for usage and a final selection was made. Different parameters were used for the selection of materials for various parts of machine and this was based on the following factors (Table 2): -

- Strength of the material and rigidity of the machine,
- Economic feasibility,
- Durability,
- Availability of the material to ensure its locally sourced,
- Cost of material and hence production cost with consumer in view,
- Ease of fabrication

5. MACHINE DESCRIPTION

The machine is being driven by a prime mover with a rated power output of 4.85 kW and a speed of 2600 RPM. The prime mover is connected to the shaft driving the hammers by a Pulley - belt drive system. The machine comprises of four major parts, the hopper, the crushing chamber, machine frame and the prime mover. The Sorghum is fed into the hopper, with the feed control locked. The feed control is then released gradually to allow flow of Sorghum into the crushing chamber. There in the crushing chamber, the Sorghum has been beaten by set of hammer mills to reduce the sizes of the feed Sorghum. The reduced Sorghum flows out of the crushing chamber through the delivery chute connected to the bottom of the crushing chamber.

5.1 Electric Motor

The Electric motor was selected based on the speed and required power output for the smooth and efficient operation of the machine. The specifications of the diesel engine as available on its tag are Table 3.

Table 2. Materials selection procedure

S/N	Machine Component	Criteria for Selection	Most Suitable Materials	Materials Selected	Reason for Selection
1.	Shaft	Strength, machinability, surface finish, weight, cost, availability.	Mild steel, cast iron	Mild steel	High strength and light weight
2.	Pulley	Weight, good wearing property, availability	Mild steel, cast iron	Mild steel	Availability and weight
3.	Belt Guard	Strength, machinability, surface finish, weight	Mild steel, carbon steel	Mild steel	Surface finish, light weight
4.	Grinding Unit	Weight, good wearing property, availability	Mild Steel, Galvanised Steel, stainless steel	Stainless Steel	Cost, Usage and availability
5.	Bearing	Self-aligning bearing	Standard part	Pillow block bearing	Self-aligning
6.	Hopper	Weight, good wearing property, availability	Mild Steel, Galvanised Steel and stainless.	Stainless Steel	Cost, Usage and availability
7.	Frame (grinding Unit stand and diesel engine stand)	Strength, Ability to withstand impact load/stress, availability	Mild Steel, Galvanised Steel	Mild Steel	Strength, Ability to withstand impact load/ stress and availability

Table 3. Electric motor specifications

Description	Data
Power	5.75 Kw
Speed	2800rpm

Fig. 2. Picture of the coupled hammer mill machine

Fig. 3. Picture of the Uncoupled Hammer Mill Machine to show the grinding chamber (hammer mills and compartment)

6. PERFORMANCE EVALUATION

Sorghum was used to determine the performance evaluation of the fabricated machine. A testing apparatus used were the digital stopwatch and weighing balance. 5 kg of sorghum was used as the sample, and this was fed into the crushing chamber of the machine through the hopper of the machine. The time taken to crush the sample i.e., the sample to fully discharge was noted, and the weight of the crushed sample taken. The process was repeated for samples of weight 10 kg, 15 kg, 20 kg and 30 kg with the results obtained as follows;

Table 4. Performance evaluation of machine

Trials/Test	Weight input (kg)	Time Taken (min)	Weight output (kg)
1	5	6	4.7
2	10	10.5	9.5
3	15	16.7	14.85
4	20	23.3	20
5	25	29.2	24.5
Average	**75**	**85.7**	**73.55**

The performance criteria tested for, were;

   a. Grinding capacity (GC), and
   b. Grinding efficiency (GE).

Crushing Capacity (CC): The grinding capacity is the rate at which the machine grinds in kilogram per hour and this was calculated as;

$$GC = \frac{M}{t}$$

Where;

   GC = Grinding Capacity (kg/hr)
   M = Average mass of Sorghum loaded into the hopper (kg)
   T = Average time taken to complete the grinding (hr.)

Considering the results obtained from the optimum performance of the machine, the capacity of the fabricated machine (GC) is obtained as follows;

$$GC = \frac{M}{t}$$
$$GC = \frac{73.55}{0.714}$$
$$GC = 103.01 kg/hr \approx \mathbf{103 kg/hr}$$

This means this machine has the capacity of processing 103kg/hr of Sorghum which makes it a good machine for usage.

Crushing Efficiency (CE): This is defined as the ratio of crushed sorghum to the mass of sorghum loaded to the machine and is calculated as;

$$CE = \frac{average\ mass\ of\ crushed\ sorghum}{average\ mass\ of\ loaded\ sorghum} \; x\ 100\%$$

Where

$$CE = Crushimg\ Efficiency$$
$$average\ mass\ of\ crushed\ sorghum = 73.55kg$$
$$average\ mass\ of\ loaded\ sorghum = 75kg$$
$$CE = \frac{73.55}{75} x\ 100\%$$

$$\mathbf{CE = 98.10 kg}$$

7. CONCLUSION

The sorghum hammer mill designed and fabricated in this work was aimed at reducing the grain size of sorghum to finer sizes for cereal production. The performance evaluation of the produced machine showed it works at an efficiency of 98.10 % , thereby making the fabricated hammer mill efficient. The materials selected for the development of the machine are locally available which is one of the advantages of the fabricated machine thereby making the machine easy assessable and affordable.

The nutritional hazards associated with the use of conventional hammer mills is eliminated in this newly fabricated hammer mill. Thus, there is no health hazard experienced by the operation of the new machine. Furthermore, the new hammer mill would reduce working losses, reduce production downtime, give nutritional advantages, enhances greater consumer choice and it reflects a more effective response to changing market requirements and increases better working capability of the Machine.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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