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Development of a Portable Hammer Mill for Processing Agricultural Products in Rural Communities

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Abstract In this study, an attempt was made in designing and fabricating a portable milling machine from locally sourced raw materials which can be utilized by low income rural dwellers not connected to the electricity grid to achieve size reduction of grains such as maize, sorghum and other agricultural materials. The machine seeks to improve on some the shortfalls observed in previous designs of existing hammer mills currently in use. The size reduction was achieved with the aid of freely rotating hammers attached to a shaft. The prime mover employed for the machine was petrol engine. Detachable screens with various screen sizes were provided to achieve various particle sizes of milled samples. From the result of the preliminary investigation performed on the machine, it was seen that the machine performed satisfactorily with a maximum efficiency of 92 % and optimum throughput of 18.2 kg/hr.

Keywords: hammer, mill, portable, agricultural, rural

I. Introduction

Cereals are plants which are cultivate for their edible seeds known as grains [1] They are important stables in many household in Africa providing more dietary energy than any other types of crop [2]. Cereal products are usually eaten after processing which involves grinding either though iteration or hammering. The role of grinding before consumption of cereals is very important and it is necessary to be able to achieve it in a very efficient manner most especially in rural communities in developing nation without access to grid energy supply. Hammer mill is a machine which is design for processing and reducing the grain size of cereals such as maize sorghum, wheat, millet even though it may also be employed for the processing of non-cereal materials such as cassava and yam tuber [3].

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The hammer mill is an equipment which consist of a shaft rotating at high speed incorporated with free swinging beaters which achieve the size reduction of cereal grains or other hard materials to a predetermined sizes via holes in made in a screen. Size reduction of dry grains introduced into the hammer mill is achieved through a combination of impact of the hammer blows on the grains, impact of the grains on the wall of the hammer mill and impart of grains on one another within the hammer mill. The materials remain within the grinding section of the mill until they are able to pass through the perforations on the screen covering the discharge section of the mill [4].

Hammer mills cannot be operated manually and will require a prime mover in the form of an electric motor, petrol or diesel powered engine. The performance of a hammer mill may be measure from the rate of energy consumption and the size distribution and fineness of the milled product [5]. Also, some other factors that affect the performance of the hammer mill include particle size of grain, moisture content, the rate of feeding grain into the mill and the initial particle size [5, 6].

Size reduction of agricultural product, an essential step in the further processing and utilization of agricultural products is challenging in rural areas of Nigeria due to lack of access to suitable and efficient hammer mills, prohibitive cost of available ones which are usually on industrial scale as well as lack of access to electricity infrastructure to power these mills. Therefore, this endeavor seeks to develop a suitable hammer mill to aid in the processing of agricultural products most especially in rural communities in Nigeria. This will help in the enhancement of agricultural processing capabilities in rural areas, ultimately empowering farmers, reducing post-harvest losses as well as fostering economic development. The development of an appropriate hammer mill holds promise for improving the quality, efficiency and accessibility of agricultural processing thereby promoting food security, and enhancing sustainable development in rural communities.

Many farmers in rural Nigeria are usually unable to afford the purchased of hammer mills imported into the country. Therefore it is very imperative to develop mils that are both efficient and affordable for local farmers. Many technologies for milling agricultural product has been developed in Nigeria, however, there are many challenges associated with the use of the existing locally fabricated hammer mills including the enlargement of the screen holes for sieving milled products as a result of wear and corrosion due to friction on the holes thereby resulting in the passage of larger sized particles than expected. Also, gradual accumulation of moisture occurs thereby making the materials wet thereby becoming plastic and absorbing a substantial part of the impact energy of the beaters without breaking the particles into smaller sizes [7, 8]

Adekomaya and Samuel [9] fabricated a hammer mill consisting of a free swinging hammers attached to a rotating head powered by a petrol engine. Even though the machine was able to mill grains with an efficiency of 94%, uniform size distribution could not be achieved with the production of a combination of coarse, medium and fine particles necessitating the reintroduction of the output into the machine to achieve uniform grain distribution.

Hadi et al. [4] improved the design and construction of an existing hammer mill by improving the hammer mill chamber, shaft and beaters and directly incorporating a gasoline powered engine to the hammer mill shaft with a means of varying the speed of the shaft. They were able to improve on the efficiency of the existing machine from 54% to an average of 92.47%, however, some losses were observed as a result of fine powdery products sticking to the internal walls of the hammering chamber leading to clogging of the screen thereby preventing the easy exit of mill products through the screen.

II. Materials and Methods

A. Material selection

Several factors were considered in the selection of materials for constructing the hammer mill including material hardness, wear resistance, strength, toughness, corrosion resistance, density, weight, thermal conductivity, and manufacturability. To ensure durability and optimal performance, materials such as mild steel, angle iron, flat bar, bolts, and nuts were utilized in construction.

B. Design consideration

The following factors were considered in the design of the hammer mill

i. Ease of fabrication
ii. Ease of operation of the hammer mill
iii. Ease of inspection, maintenance and repair
iv. Availability of replacement parts
v. Safety during operation
vi. Cost
vii. Utilization of locally available materials

C. Description of components

Components of the fabricated hammer mill are described below

i. Frame: The frame of the hammer mill stands as its foundational structure, crafted with meticulous attention to durability and stability. The designed machine frame is as shown in Figure 1. Constructed from heavy-duty material (mild steel), the frame provides the necessary support for all other components of the mill.

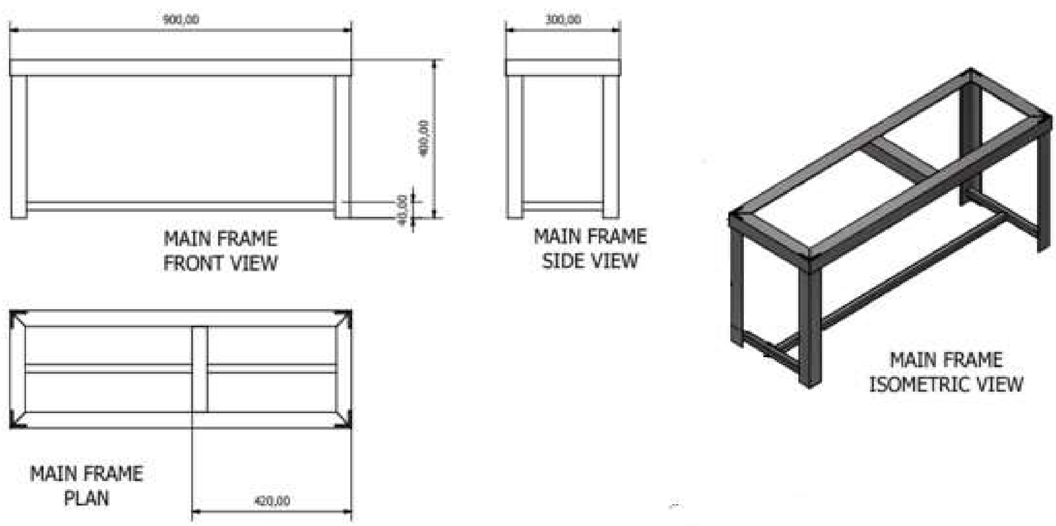


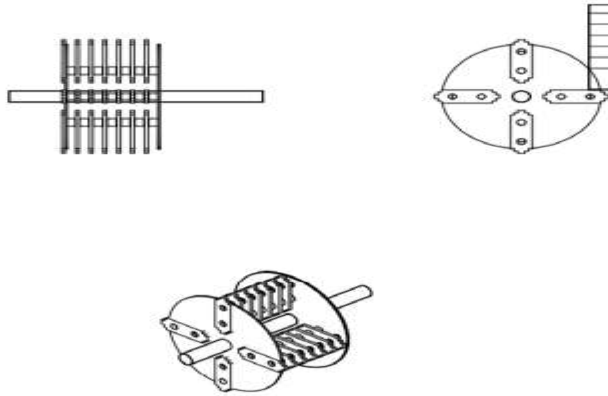
Figure 1: Frame of Hammer Mill

ii. Prime Mover (Petrol Engine): At the core of the hammer mill lies its prime mover, typically a robust petrol engine chosen for its capability to deliver the required torque and rotational speed. The engine specifications meticulously selected to match the operational needs of the mill, taking into account variables such as material density, feed rate, and desired particle size. The engine's power output is carefully calibrated to optimum speed to ensure it generates ample energy to propel. Beyond power generation, considerations like engine efficiency, reliability, and maintenance demands were prioritized during the prime mover selection process.

Ultimately, the petrol engine serves as the driving force behind the hammer mill, supplying the essential energy to refine raw materials into finely processed particles.

iii. Feeding Trough: The feeding trough of the hammer mill serves as the entry point for raw agricultural materials into the milling chamber. It was carefully designed the trough to facilitate a smooth and controlled material feed, ensuring optimal milling performance. Also, the design implemented a feature of sloped troughs to facilitate self-cleaning and prevent material build-up or blockages. The feeding trough is positioned strategically to ensure efficient material transfer into the milling chamber, minimizing waste and maximizing throughput.

iv. Rotor with Free-Swinging Hammers: The rotor of the hammer mill is a central component responsible for pulverizing raw agricultural materials into finely ground particles. The rotor was designed to withstand the high-speed rotation and impact forces generated during operation, using materials such as hardened steel for optimal durability and performance. At the core of the rotor shaft are a series of hammers, strategically positioned and independently mounted to facilitate free-swinging motion. Each hammer is carefully welded to deliver maximum impact force while minimizing wear and tear on the rotor and associated components. Additionally, the hammers are arranged in a uniform pattern around the rotor shaft to ensure consistent milling performance and particle size distribution. The designed hammer is as shown in Figure 2 below.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Hammer disc	3mm Mild steel plater
2	28	Hammer	5mm mild steel
3	4	Main shaft	25 diameter mm mild steel
4	4	Hammer shaft	12mm diameter mild steel
5	28	Hammer spacer	14mm mild steel sleeve 1.5mm thick

Figure 2: Rotor with Free Swinging Hammer

v. Grinding Chamber: The grinding chamber of the hammer mill is the space where the actual milling process takes place, housing the rotor and associated components. It was designed facilitate efficient particle size reduction while minimizing energy consumption and heat generation as shown in Figure 3 below. The chamber's dimensions, geometry, and airflow dynamics are carefully optimized to ensure optimal milling performance and particle size distribution. The walls of the grinding chamber are lined with interchangeable screens and sieves, which regulate the size of the milled particles.

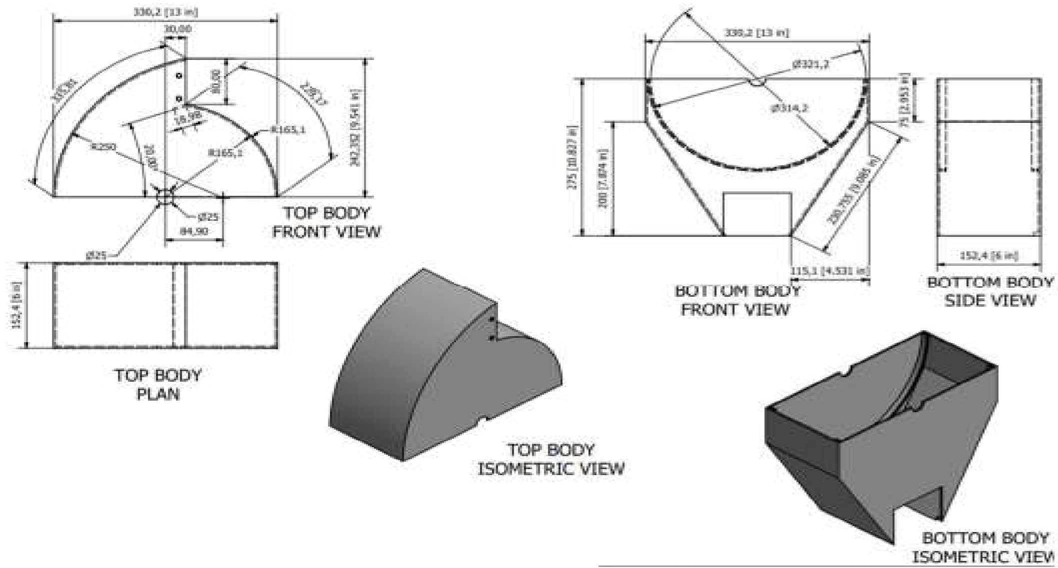


Figure 3: Grinding Chamber of the Hammer Mill

vi. Screen/Sieve: The screens/sieves installed in the grinding chamber of the hammer mill play a critical role in controlling the particle size of the milled material. The screen configurations will be based on desired particle size distribution and material characteristics, allowing for precise control over the milling process. Perforated plate configuration was employed the fabricated hammer mill. This was designed such that it is easily replaceable thereby allowing operators to customize milling performance and maintain optimal particle size distribution. Some features introduce in the design include quick release mechanisms and tool-less stream changes to streamline maintenance and minimize downtimes.

D. Design of the Hammer Mill

i. Determination of shaft speed

The prime mover utilized in this study is a petrol engine with an output speed of 3600 rpm. Speed of the petrol engine was transmitted to the shaft of the milling machine via pulley arrangement and the speed of the shaft is determined using equation 1 below.

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \quad (1)$$

Where D_1 and D_2 represents the diameter of the pulley on the prime mover and shaft respectively and

N_1 and N_2 represent the speeds of the prime mover and shaft respectively

ii. Determination of hammer weight

The weight of the hammer is determined using equation 2 below

$$W_h = m_h \times g \quad (2)$$

Where $m_h =$ mass of the hammer (kg) and $g =$ acceleration due to gravity (m/s^2)

iii. Determination of centrifugal force

The centrifugal force exerted at the tip of each hammer is calculated using equation 3

$$F_c = \frac{mv}{r} \quad (3)$$

$$v = \omega r \tag{4}$$

The angular velocity of the hammer is given by equation 5 as

$$\omega = \frac{2\pi r N}{60} \tag{5}$$

Where N = number of revolutions

iv. Determination of hammer shaft diameter

The hammer shaft diameter was determined as

M_b = maximum bending moment$(N.m)$
$= \frac{wl^2}{8}$ [4] (7)
l = length of the shaft (m)
W = force per unit length (N/m)

The allowable stress is given by equation 8 as

$$\sigma_s = \frac{M_b \cdot y_{max}}{I} \tag{8}$$

$$\frac{I}{y_{max}} = z = \sigma_s = \frac{M_b}{Z} \tag{9}$$

Where σ_s = allowable stress
I = moment of inertia (m^4)
z = section modulus
y = maximum distance from neutral axis to outer section (m)

For a solid round bar, the moment of inertia and section modulus were determined by equations 10 and 11 respectively

$$I = \frac{\pi d^4}{64} \tag{10}$$

$$Z = \frac{\pi d^2}{32} \tag{11}$$

According to Hannah and Stephens (2004) [10], the shaft diameter for a solid shaft experiencing little or no axial load is determined using equation 12 as

$$d^3 = \frac{16}{\pi \sigma_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{12}$$

Where d = shaft diameter
M_t = torsional moment(N.m)
K_b = shock and fatigue factor for bending moment

K_t = shock and fatigue factor for torsional moment

Since the load is suddenly applied with heavy shock, the values of K_b and K_t are assumed to be 2.0 [9]

E. Performance Evaluation of the Hammer Mill

Palm kernel shell (PKS) was used in the performance evaluation of the equipment. The milling efficiencies and milling capacities at different weight of un-milled samples (0.5 kg, 1.0 kg, 2.0 kg) were determined. Each experiment was carried out in triplicates.

i. Determination of Milling Efficiency

The milling efficiency is the capacity of the machine to reduce the axial dimensions of feedstock into the required particle sizes. Typically expressed as percentage, it represents the extent to which the milling machine can achieve size reduction relative to initial size of the material fed into the machine. A higher milling efficiency percentage is indicative of a greater capability of the machine to effectively reduce the size of the material. It is determined using the mathematical expression given in equation 13 below

$$E_m = \frac{W_r}{W_t} \times 100 \tag{13}$$

Where E_m = milling efficiency, %

W_r = weight of milled kernel passing through the sieve
W_t = total weight if feedstock inroduced into

the machine

The loss during milling operation is also computed using equation 14 below as

$$\text{losses}(\%) = \frac{\text{mass before milling} - \text{mass after milling}}{\text{mass before milling}} \quad (14)$$

ii. Determination of milling capacity

The milling capacity indicates the throughput or the rate of production of the machine. It represents the amount of feedstock that can be fed into the mill and processed into desired product within a specific time frame. The milling capacity is determined using equation 15 below.

$$C_m = \frac{W_m}{T_o} \quad (15)$$

Where C_m = milling capacity, kg/hr
W_m = weight of milled sample, kg
T_o = total time taken for milling operation

III. Results and Discussion

The fabricated hammer mill is shown in Figure 4 below

Figure 4: Fabricated Hammer mill

Table 1 shows the result of the performance evaluation carried out on the milling machine using PKS

The milling efficiencies, milling capacities and losses were computed using the average values for each of the initial masses introduced into the milling machine and presented in Table 2. From Table 2, the highest milling efficiency of 92% was obtained when a mass of 0.5 kg was introduced into the machine. However as the mass of PKS introduced into the milling machine is increased from 0.5 kg to 2.0 kg, the milling efficiency was determined to decrease to 77.5%. Losses were also seen to increase as the mass of PKS introduced into the milling machine increased which was said to be as a result of the powdery sticky materials to the internal walls of the milling chamber and clogging of the screen as submitted by [4]

From Table 2, it is also seen that the milling capacity increased from 15.5 kg/hr when the mass of PKS introduced into the machine was 0.5 kg to an optimum value of 18.2 kg/hr when the mass introduced was 1.0 kg. A decrease in the milling capacity was subsequently observed when the mass of PKS introduced into the milling machine was increased to 2.0kg with further increase in the losses recorded.

IV. Conclusion

The hammer mill designed and fabricated in this study was aimed at reducing the grain size for agricultural materials most which is a major step in further processing of agricultural materials, most especially in rural Nigeria. The performance evaluation of the produced machine showed that the efficiency is optimum at 92% with minimum loss when the mass of PKS introduced into it was 0.5 kg. 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 following objectives can be said to be achieved; designing the hammer mill, fabricating the hammer mill, performance evaluation, hence, improving milling operation. of agricultural products for both human, birds and animals feed, alleviating the physical sufferings associated with the conventional grinding machine and improving the economic condition of rural populace.

Table 1: Performance Analysis Result of Hammer Mill Using PKS

Run	Initial mass of PKS before milling (kg)	Final mass of PKS after milling (kg)	Total operational time (Hr)
1		0.44	0.0298
2	0.5	0.47	0.0293
3		0.47	0.0297
Average		**0.46**	**0.0296**
4		0.76	0.0408
5	1.0	0.79	0.0459
6		0.84	0.0461
Average		**0.80**	**0.044**
7		1.54	0.0920
8	2.0	1.56	0.0924
9		1.55	0.0923
Average		**1.55**	**0.0922**

Table 2: Milling Efficiency, Milling capacity and Losses of hammer Mill at different Mass Input

Mass introduced into the milling machine (kg)	Milling efficiency (%)	Losses (%)	Milling capacity (kg/hr)
0.5	**92**	**8**	**15.5**
1.0	**80**	**20**	**18.2**
2.0	**77.5**	**22.5**	**16.8**

References

[1] Das S. Amaranthus: a promising crop of future. Singapore: Springer, 2016. Singapore. https://doi.org/10.1007/978-981-10-1469-7.

[2] Erenstein, O., Poole, N., Donovan, J. (2022). Role of staple cereals in human nutrition: separating the wheat from the chaff in the infodemics age. Trends Food Sci Technol. Vol. 119, 2022, pp. 508–513.

[3] Nasir, A. Development and testing of a hammer mill. AUJ.T. vol. 8 No 3, 2005, pp. 124-130.

[4] Hadi, M. I., Bawa, M. A., Dandakouta, H., Ahmed, M., Kamtu, P. M. Improvement on the design, construction and testing of hammer mill. American Journal of Engineering Research. Vol. 6 No. 3, 2017, pp. 139-146

[5] Mugabi, R., Byaruhanga, Y.B., Eskridge, K.M., Weller, C. L. Performance evaluation of hammer mill during grinding of maize grains. AgricEngInt: CIGR Journal Open Access. Vol. 21 No. 2, 2019, pp. 170-179.

[6] Dey, S. K., Dey, S., Das, A. Comminution features in an impact hammer mill. Powder Technology, 235 2013, pp. 914–920

[7] Dance, A. The importance of primary crushing in mill feed size optimization. Proceedings International Autogenous and Semi-Autogenous Grinding Technology 2011, eds. D.J Barrat. M.J Allan and A.I Muller.

[8] Eyo, O. Macroeconomic environment and agricultural growth in Nigeria. World Journal of Agricultural Sciences vol. 4 No. 6, 2008, pp. 781-786.

[9] Adekomaya, S. O. and Samuel, O. D. Design and development of a petrol-powered hammer mill for rural Nigerian farmers. Journal of Energy Technologies and Policy. Vol. 4 No 4, 2014, pp. 65-74

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