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Elimination of Multiple Milling of Bambara Grains with Dual Cross-Beater Machine

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ABSTRACT

This study involves elimination of multiple milling of bambara grains with dual cross-beater crushing machine which increases the amount and quality of bambara flour produced each time while also improving milling efficiency, saving both time and energy. This dual cross beater crushing system is made up of the milling shaft driven by an electric motor, the hopper, and the milling chamber that holds the cross beaters. The performance evaluation result shows that the developed machine mills 40kg of beans at an average speed of 816 rpm, output capacity of 39.57kg/hr, milling efficiency of 98.7% at 270 seconds. The machine's performance evaluation also shows that it saves time compared to the existing technology adopted in bambara beans processing, which mills 40 kg of bambara beans at 570 seconds on average. Both quantitative and qualitative work can be completed quickly and with less energy thanks to the new machine. Because of its high productivity and versatility in grinding different varieties of bambara beans, the use of double/dual cross-beater hammer milling machines in bambara flour processing industry is thus encouraged. Consequently, bambara bean farming attracts young people and ensures food security.

Keyword: Bambara bean; dual cross-beater; flour; food security; machine; milling

INTRODUCTION

One of the extremely nutrient-dense crops that are farmed throughout Africa is bambara beans [1]. Growing interest in bambara beans and the mechanization of equipment for their processing to enable commercialization of the products across the sub-Saharan region coincides with the growing urgency for whole and sustainable food products. The demand for bambara beans in the local African market can be attributed to their distinct and pleasant flavor. Because of their high nutritional content and ability to withstand drought during cultivation, bambara beans have great potential for achieving food security and reducing poverty in Nigeria and throughout

Africa [2, 3]. Among the leguminous plants grown for food in sub-Saharan Africa, bambara beans rank as the third most common type of seeds. [4,5,6,7]. When cooked, the newly harvested pods are eaten as food; they can also be decorticated and eaten as a vegetable snack. Similar to groundnuts, dry seeds are roasted and consumed as a snack [4,8,9]. The best use for bambara beans is to process them into flour. It becomes more versatile for a variety of diet and beverage productions when the beans are processed into flour [10,11]. Consequently, this industry has witnessed a constant need for a mechanized bambara bean flour milling machine. This requirement is necessary to get rid of the tediousness related to the industry's predominant traditional processing method. [11,12,13], but because Bambara beans have unique characteristics, processing them is thought to call for specialized tools and technical know-how. Its underutilization among other leguminous plants and the setback in the mechanization of its processing equipment are clearly related to this [14.15,16].

Therefore, the development of a bambara bean processing machine is a crucial instrument that needs immediate attention in the food processing sector. The most crucial step in the production of bambara beans flour is milling because, before they can be utilized for any significant purpose, dry bambara nuts must be ground into extremely fine particles in order to weaken the bond between their seed coat and cotyledon. Other legumes have also been mechanized in their milling process, particularly with the development of the most recent hammer mill model [14] for grinding wheat and maize. According to [1,2], the production of bambara beans flour has been hindered by the inefficient matching of other grain flour milling machinery. The current state of the inefficient automated milling system for bambara flour production identifies the fundamental reason for the crop's ongoing underutilization and the subsistence level of its farming in the sub-Saharan region. Because of its negative "hard-to-cook" trait, bambara beans are referred to as hard nuts because their milling processes were found to be ineffective when matched with other machinery [15,16,17].

The phenolic compound content of the bambara nut and the lack of an inherent crack in the seed coat are responsible for the nut's high binding strength between the cotyledon and seed coat [1]. Therefore, a milling system that can handle this quirk is required to enable the efficient milling of bambara beans into flour. Thus, the creation of a dual cross beater mill, utilizing this technology which eliminates multiple milling, will suitably position bambara groundnut to mitigate future food and nutritional issues in the country and across continents, as per [17,18,19]. The advice of [2] is followed in the design and assessment of a dual cross-beater bambara beans mill. The paper "Parametric improvement of a hammer mill for bambara flour production" states that the milling efficiency increases with the number of beaters. Because multiple milling is phased off with this dual cross-beater milling machine, the development of this machine for crushing bambara beans is therefore a cure-all for the low production and underutilization of bambara beans.

2. METHODOLOGY

2.1 Design concepts generation

The following ideas and factors were taken into account when designing and developing the dual cross-beater milling machine for bambara bean flour production:

i. The physicochemical and structural characteristics of the most popular variety of cream bambara beans were taken into consideration when designing this machine.

ii. The discharge unit was chosen with a standard 400-mesh screen opening of 37μm because the maximum size of starch granules from cream bambara beans is 35μm, whereas the normal size of crushed seed coat of this grain is above 40μm, [20].

iii. The machine was built using conventional materials that could be found locally, and its parts were assembled so that the process materials flow is gravity driven, which enhances hygiene and guarantees low production and maintenance costs.

iv. The development of the machine's milling unit used a double cross-beater mill to separate the flour from the beans that needed to be ground through a bottom screen at the same time.

v. When fabricating its milling units, a maximum of 75% of the fill volume was taken into consideration.

Selection of Pulleys and Belts

Two cast iron pulleys of diameters 200 mm and 100 mm respectively were used for the centrifuge power transmission. These diameters were obtained using equation 1 [21].

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (1)$$

Where:

N_1 = Speed of the driving pulley in r.p.m
N_2 = speed of the driven pulley in r.p.m

d_1 = diameter of the driving pulley = 200 mm

The length of the belt was determined as 932 mm for the crushing chamber given in equation (2), [21].

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \quad (2)$$

2.2 Maximum allowable pressure Design of the system:

A hammer known as a cross-beater was created to crush grain, and its beaters were spaced 150 mm apart [1]. The measured dimensions of the beater blade are 130 mm in length, 15 mm in thickness, and 1440 rpm in speed. The beaters have a total of eight blades, and their cross-sectional area is represented by the number 6400, which stands for both the beaters' diameter and the electric motor pulley's diameter [1]. Utilizing (3), [19] expressed the centrifugal force on the cross beater.

$$F_{cb} = N_{cb} m_{cb} r_{cb} \omega_{cb} \quad (3)$$

F_{cb} = Centrifugal force of the cross beaters, N_{cb} represents Number of cross- beater, m_{cb} = Mass of each Cross-beater, r_{cb} = Radius of cross-beater, ω_{cb} = Angular velocity.

Assuming inelastic impact between the cross-beaters and materials being crushed, the velocity of the material is given by [1]:

$$V_m = \left(\frac{2F_h r_h}{M_m N_m}\right)^{\frac{1}{2}} \quad (4)$$

$V_m =$ Velocity of material being crushed, $M_m =$ Mass of material being crushed, $N_m =$ Number of material impacted, $F_h =$ centrifugal force of hammer, $r_h =$ radius of hammer.

The minimum width of cross-beaters to withstand the centrifugal force at impact is given by (5), [1].

$$W_{cb} = d_{cb} + \frac{F_{cb}}{t_{cb}\delta_{cb}} \quad (5)$$

$W_{cb} =$ Width of cross beater, $t_{cb} =$ Thickness of cross-beaters, $d_{cb} =$ Diameter of cross-beater, $\delta_{cb} =$ working stress on cross-beater

The weight of cross beater can be expressed using equation (6),

$$W_{cb} = M_{cb}g \quad (6)$$

$W_{cb} =$ Weight of cross-beater, $M_{cb} =$ Mass of the cross-beater, g = Acceleration due to gravity.

But speed of the cross beater blade is generated from equation (7), [21].

$$N_2 = \frac{D_1 N_1}{D_2} \quad (7)$$

$N_2 = 816$ rpm

But the power p, transmitted by the cross-beaters blade is given by equation (8), [22, 23].

$$P = \frac{2\pi N_2 T}{60} = \text{T}.\omega \quad (8)$$

$$\omega = \frac{2\pi N_2}{60} \quad (9)$$

$\omega = 85.45$ *rad/sec*

Where,

P = power transmitted by the cross-beaters blades

ω = angular velocity of blades

Linear velocity V, is represented by equation (10), [21].

$$V = \omega r_2 \quad (10)$$

V = 12.8175 m|s

Torque T, is represented in equation (11), [18].

$$T = \text{force} \times \text{radius} \quad (11)$$

Assuming the force to be overcome is 50 N.

T = 7.5 N-m

Therefore power, P was determined as;

P = 640.875 watts

Equation (1) was used to determine the speed that was chosen for the grinding unit's design, which came out to be 3702.86 rpm because the electric motor's rated speed is 1440 rpm and a 200 mm pulley is fixed to the motor shaft. The pulley that was fixed to the crushing shaft had a diameter of 100 mm. The selection of a 38° groove angle (2β) cast iron pulley was based on its affordability, accessibility, and efficiency. The velocity ratio (V.R) was generated using equation 12 by [19].

$$V.R = \frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (12)$$

And was determined as $V.R$ = 3702.86 rpm

Where;

V.R = velocity ratio, N_1 = Rated speed of the electric motor = 1440 rpm N_2 = Speed of the crushing shaft pulley = 180 rpm D_1 = Diameter of the pulley fixed on the electric motor shaft = 200 mm, D_2 = Diameter of the pulley on the milling unit = 100 mm.

The centre distances (C) between the pulleys of the electric motor and the crushing unit pulley was determined as 290 mm from equation 13 by [19].

$$C = \frac{D_2+D_1}{2} + D_1 \quad (13)$$

The shaft was designed on the basis of rigidity and stiffness because vibration of the shaft would be hazardous.

$$d = [\frac{16}{\pi\tau}\sqrt{(k_b m_b)^2 + (k_t m_t)^2}]^{1/3} \quad (14)$$

Where;

τ = Allowable shear stress for steel shaft with provision for keyway = 42 N/mm^2.

σ_b = Maximum bending Stress for steel shafts. M_t = Maximum Twisting Moment on the shafts, N-m. K_b = Combined shock and fatigue factor for bending (=1.0). K_t = Combined shock and fatigue factor for twisting (=1.5).

The maximum twisting moment on the crushing unit was determined as M_t = 4587.1N using equation (15)

$$M_t = (T1 - T2)\frac{D_2}{2} \quad (15)$$

Where 134.19 N was determined as the tension on the tight side of each drive belt from equation (16) while the respective tension on the slack sides of the grinding shaft

Where,

T_1 = tension on the tight side of belt,

T_2 = Tension on the slack side of belt. This can be determined using the equation

$$2.3log\ \frac{T_1}{T_2} = \mu\theta\ cosec\ \beta \quad (16)$$

Where,

$$T_1 = T_{max} - T_c \quad (17)$$

$$T_{max} = \sigma a \quad (18)$$

$$T_c = mv^2 \quad (19)$$

Where,

v = Linear velocity of the belt (m/s) = $\frac{\pi D_1 N_1}{60\ X\ 1000}$ (20)

Where a, m, 2β, μ and σ are cross-sectional area of the belt, mass per unit length of belt material, groove angle of pulley, coefficient of friction between the belt and pulley, and the maximum safe stress respectively . The angle of lap, θ of belt on small pulley of each drive were computed from equation (16) as 2.72 rad for the grinding 13.57 m/s was determined as the speed of each drive belt form equation (21), [18].

$$\theta = 180 - [2sin^{-1}(\frac{D_2 - D_1}{4C})]\ \frac{\pi}{180} rad \quad (21)$$

2.3 Selection of Prime Mover (Electric Motor)

The total power needed to operate this machine is the sum of the power needed to power its components and the power needed to reduce the friction in the drives.

Equation 22 was used to calculate the power (p) needed to run the centrifuge, and the result was 11.185 kw (5 hp) [18,19].

$$p = \frac{(T_1 - T_2)v}{1000}, kw \quad (22)$$

The 15 HP I.C. engine prime mover transfers energy to the crushing chamber by means of a B 85-Belt connecting a 200 mm pulley to a 100 mm pulley at a shaft with a 60 mm diameter.

It was established what the crushing shaft's bending moment was;

The weight of the crushing shaft pulley is 9.81N, the weight of the bambara seed is 294.3 N, the weight of the shaft is 134.19 N, and the tension at the tight side and slack side of the crushing drive are 10.89 N and 10.67 N, respectively. T (2882.53 N) is the tension on the bearing as a result of bearing seating (1530.41N).

Torque due to rotation of the double cross-beater respectively

$W_P + T_1 + T_2 + T_b = 1685.29\ N$

$W_{bg} + W_S + T$, was determined as 3245.5 N

The reactions of bearing RB and RD were determined by taking the moments about D and B respectively as $\Sigma MD = 0$; $RB = 4403.495\ N$, ,$\Sigma MB = 0$; $RD = 527.305$ N.

Thus, the bending moments on this shaft are calculated as follows; = 0 Nmm,

$MB = 219089$ N/mm

$MC = -52730.5$ N/mm, $MD = 0$ Nmm

Thus, the maximum bending moment on the crushing chamber shaft is 219089 Nmm. The maximum twisting moment on the shaft is 4315.5 Nmm from. Since the feeding of the bambara seed into the machine is gradual and steady, $Kb = 1.5$, $Kt = 1.0$ [18]. The shaft diameter, d was determined using equation (14) as 60 mm. The shear force and bending moment diagram is given in figure 1.

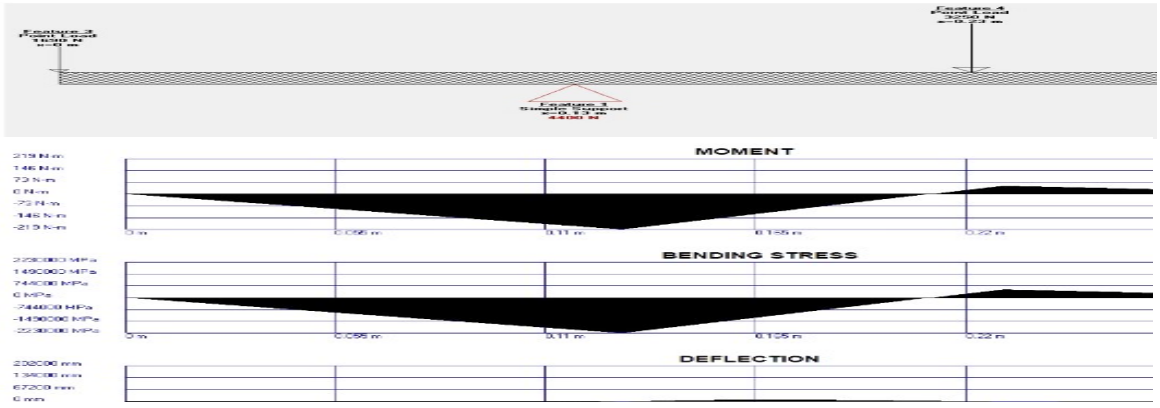


Figure 1: The shear force and bending moment diagram of the crushing shaft

The reactions of bearing RB and RD were determined by taking the moments about D and B respectively. $\Sigma MD = 0$; = 1272.85 N, $\Sigma MB = 0$; = 114.85 N. Thus, the bending moment of this shaft was calculated as $MA = 0\ Nmm$, $MB = 129831$ N/mm, $MC = -93601.25$ N/mm, $MD = 0$N/mm. Since the feeding of the Bambara beans into the machine is gradual and steady, $Kb = 1.5$, $Kt = 1.0$ [18].

2.4 Machine description

The hopper, milling chamber, cross-beaters, mesh, discharge chute and shaft make up the dual cross-beater hammer mill. The hopper depicted in Figure 2 is an inverted pyramidal funnel made of 4 mm stainless steel sheet metal, with corresponding top and base dimensions of 0.00375 and 0.0915. The cross-beaters depicted in Figure 3 are made of a 60 mm diameter stainless steel shaft on which a 40 mm diameter stainless steel rod, mounted at the end of the shaft, was welded with a 0.03 m pitch to a 0.12 m length in Figure 4, to transfer bambara seed from the hopper to the crusher.

The crusher is composed of a bottom sieve with an aperture of 0.0026 mm and two cross-beater blades for grinding beans. It is housed inside a 5 mm thick stainless steel plate casing. Figures 5 to 8 show additional significant machine parameters, as well as sectional views. These include the hub, big and small pulleys, energy-transmission belt, and prime mover (15 horsepower). The main supporting structure of this machine is formed by the assembly of these parts on the frame depicted in figure 9, which is then joined by welding to form a support for the other machine components. The frame's cross-sectional measurements of 620 x 1000 x 1130 mm were specified, and it was constructed using mild steel angle bars measuring 6 mm.

The fineness of the ground bambara flour is regulated as desired by adjusting the gap between the hammers using an adjustable locknut screw on the driving shaft.

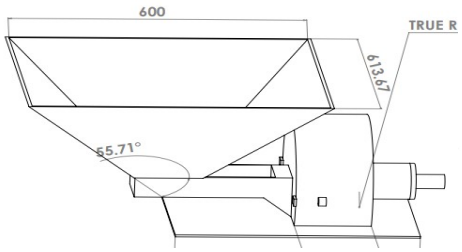


Figure 2: Machine hopper

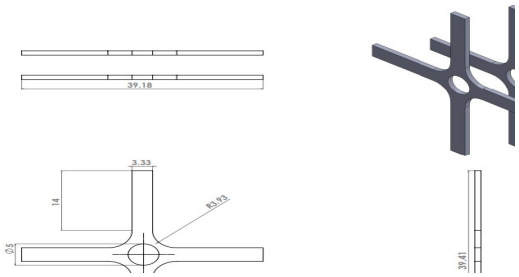


Figure 3: Double cross-beaters

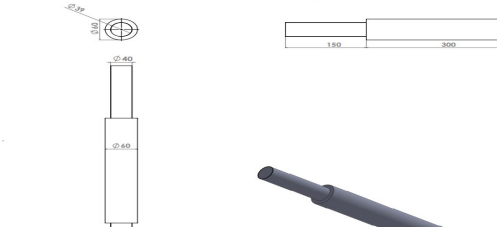


Figure 4: Milling shaft

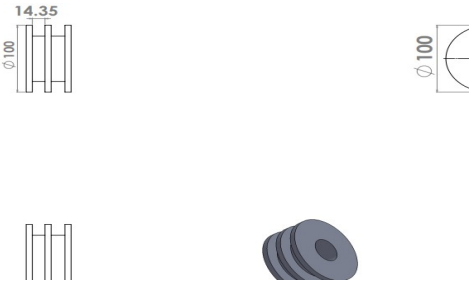


Figure 5: Small pulley of the machine

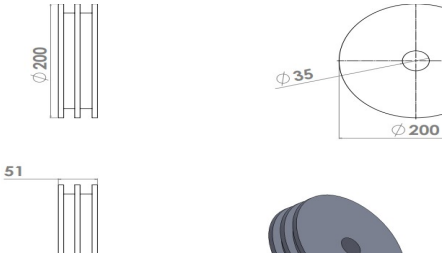


Figure 6: Big pulley of the machine

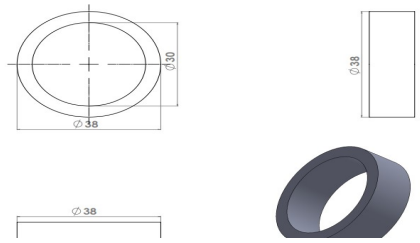


Figure 7: small hub of the machine

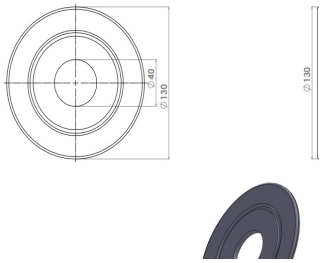


Figure 8: large hub of the machine

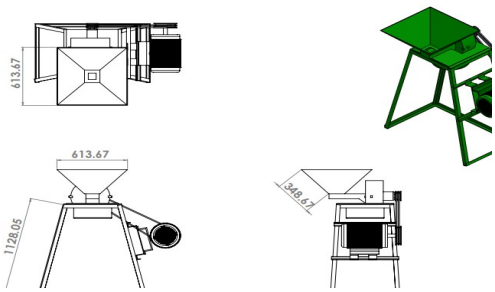
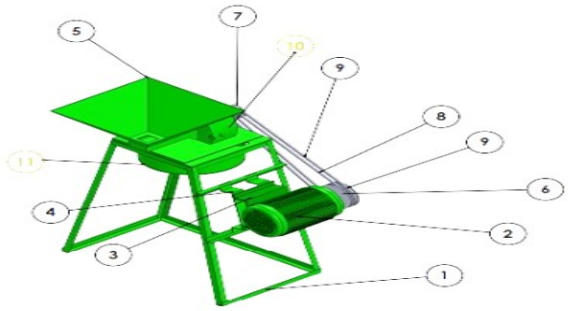


Figure 9: Orthographic view of the machine



ITEM NO.	PART NUMBER	DESC
1	Base	
2	Electric Motor	
3	motor base	
4	motor stand	
5	Hopper	
6	Big Pulley	
7	Small Pulley	
8	Belt2	
9	Belt1	
	Milling	

Figure 10: the dual cross-beater milling machine

3. RESULTS

The performance analysis of the feed rate, time, output, and efficiency of the current milling technology used to produce bambara flour is displayed in Table 1. The tables indicate that processing time, output capacity, and milling efficiency all increase as feed rate rises from 10 kg to 40 kg. Therefore, crushing 40 kg of bambara beans at an output capacity of 39.57 kg/hr and an average efficiency of 96.9% takes an average of 565 seconds. Table 2 shows the outcomes of the performance analysis conducted on the feed rate, time, output, and efficiency of the dual cross-beater hammer mill that was developed for the production of bambara flour.

It indicates that the developed machine saves time as it takes an average of 270 seconds to mill 40 kg of bambara beans unlike the existing technology.

Table 1: Performance analysis of feed rate (kg) time (s) and efficiency of the Auger milling machine.

Feed Rate (kg)	Time (s)	Output (kg/hr)	Capacity	Efficiency (%)
10	140	9.75		95.5
20	283	19.95		96.25
30	424	29.58		96.6
40	565	39.57		96.9

Table 2: Performance Analysis of feed rate (kg) and time (s) on the developed dual cross-beater hammer milling machine.

Feed Rate (kg)	Time (s)	Output (kg/hr)	Capacity	Efficiency (%)
10	76	9.75		97.5
20	145	19.65		98.25
30	218	29.58		98.6
40	270	39.57		98.9

The performance analysis of time (s) against feed rate between the developed double cross-beater hammer milling machine and the existing technology is displayed in Figure 11. According to the graph, more work will be completed faster, with less energy used, and with better efficiency with the new machine. The graph also shows that the higher the feed rate, the more time spent time spend using existing technology. Also re-milling of grain is witnessed with existing technology but phased off with double cross-beater machine.

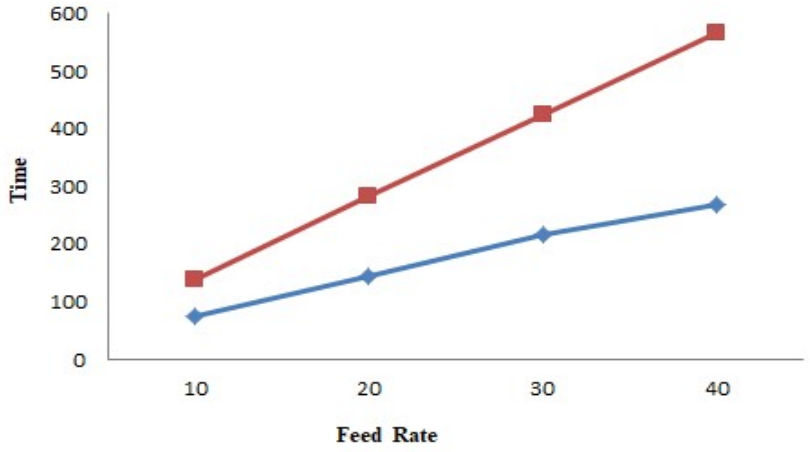


Figure 11: Line graph of time(s) against feed rate M_O (kg) of Auger milling machine (red line) and the developed dual cross-beater hammer milling machine (blue line)

4. CONCLUSION

This study involves elimination of multiple milling of bambara grains with dual cross-beater crushing machine. This dual cross-beater crushing machine is made up of the milling shaft driven by an electric motor, the hopper, and the milling chamber that holds the cross-beaters. The double cross-beater comprising of two cross-beaters of

eight hammers set up in a star shape is responsible for the effective crushing of bambara beans inside the milling chamber.

The performance evaluation result shows that the developed machine mills 40 kg of beans at an average speed of 816 rpm, output capacity of 39.57 kg/hr, milling efficiency of 98.7% at 270 seconds. This technology increases the amount and quality of bambara flour produced each time while also improving milling efficiency, saving both time and energy. This study, which focuses on creating a dual cross-beater hammered machine for producing bambara beans flour, is an innovation that has shown promise by reducing processing time for bambara bean flour production by roughly 300 seconds at 98.7% efficiency when compared with the other bambara bean flour production technologies currently in use, this feat would not have been feasible. Re-milling is phased out with this new machine because it only takes single milling operation to achieve the desired 40 micron flour texture in accordance with end users prescription. The local and worldwide community will be interested in this machine's detailed design for ease of development. This new device will improve the commercialization of bambara flour and position the bean to reduce poverty and unemployment.

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