Development of indigenous yam pounding machine for home use

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Development of indigenous yam pounding machine for home use

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Abstract. Pounded yam is a local delicacy rated as special food in Nigeria. It is always prepared using a local means – mortar and pestle. Due to development in technological advancement, the mechanical preparation of pounded yam at home using simple machine is imperative. Several efforts made on home-made devices for this purpose need more research and technology. This paper discussed an indigenous yam pounding machine developed by the Department of Agricultural and Bio-Environmental Engineering, Federal College of Agriculture Akure, Nigeria. It operated with principle of horizontal rotational milling of the yam by beater attached to the pounding chamber. The beater of mass 0.157 kg supplied force of 155 N at 1500 rpm, required for optimum pounding of the fed cooked yam. The maximum load of yam per batch of pounding is 11.9 kg. The machine has power rating of 1 hp while its capacity is 1.07 tons/hr. The testing of the machine revealed it as best operated at 1500 rpm to achieve pounding efficiency of 97%. This makes the machine a good home appliance for safe and effective pounded yam making.

1. Introduction
Yam (species *Dioscorea*) are starchy staples in the form of big tubers generated by annual and perennial plants cultivated in Africa, the Americas, the Caribbean, South Pacific and Asia. FAOSTAT [1] disclosed that 68.1 million tons of yams were produced globally in 2014, led by Nigeria with 66% of the total globally. Nigeria farmed yams on 5.4 million hectares, equivalent to 70% of the 7.8 million hectares of world territory dedicated to yam farming. Yams ' annual world average output in 2014 was 8.8 tons per hectare, with Ethiopia having 29.7 tons per hectare of the most productive farms[1] .

Uwaegbute et al.,[2] indicated that raw yam has only moderate nutrient density with appreciable content (10 percent or more of Daily Value, DV) restricted to potassium, vitamin B6, manganese, thiamine, nutritional fiber and vitamin C, and supplies 118 calories per 100 grams. Yam usually has a reduced glycemic index, about 54% of sugar per serving of 150 grams compared to potato foods [3]. In general, roots and tubers have a reduced protein content and quality than other food staples,

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with yam and potato having a fresh weight content of about 2 % protein content. According to [4,5]Several researches, such as Tropical Medicine Central Resource provided yam and cassava with a much higher percentage of protein consumption in Africa, varying from 6% in East and South Africa to around 16% in wet West Africa. However, it is imperative to note that yam is not a good source of essential amino acids as a comparatively low-protein food. As such, specialists stressed the need for more protein-rich foods to complement a yam-dominant diet to promote good development in kids.
Yam is a significant nutritional factor for the individuals of Nigeria and West Africa. For more than 150 million individuals in West Africa, it adds more than 200 calories per individual per day and is an significant source of revenue. Yam is an appealing crop with restricted resources in bad farms. It is wealthy in starch, and in many respects it can be ready. Yam is accessible throughout the year, unlike other unreliable seasonal plants. In some sub-Saharan African nations, these features make yam a preferred food and a culturally significant food safety crop [6].

Yam was processed into a variety of finished products including fried yam chips, pounded yam, yam porridge, etc. Pounded yam, a local delicacy in Nigeria, has wider domestic consumption and is classified as unique food, particularly in the country's southern portion. After cooking, the processing of yam to pounded form was performed manually through the use of mortar and pestle from centuries. This processing is energy-intensive and labor-intensive. Technology development offered an option with the creation of processing machines, which resulted in the pounded yam being easily, efficiently and neatly prepared. The aim of this job is to develop a domestic-use indigenous yam pounding machine.

2. Materials and Methods

The indigenous yam pounding machine was designed and fabricated using appropriate materials in the Department of Agricultural and Bio-Environmental Engineering Technology, Federal College of Agriculture Akure. As a food processing machine, stainless steel was used for its construction with good fabrication technology that aid its aesthetics.

2.1 Machine description

The yam pounding machine, as shown in figure 1, figure 2 and plate 1, comprises the protective cover, pounding chamber, beater, frame and power transmission system. The protective cover screens the pounding machine from the environment to avoid contamination and accident during pounding process. The pounding chamber does the pounding with the help of the beater while the power transmission devices supply power needed for pounding. All the components of the machine were mounted on the frame which serves as support for the machine.

2.2 Operational mechanism of the machine

The operational mechanism adopted for the design of the pounding system utilizes the horizontal rotational milling of the yam to gelatinous form. The pounding takes place in the pounding chamber. The vertically installed beater is powered by the electric motor which transmits rotational motion to the beater through the motion transmission devices attached, as shown in figure 2. As cooked yam is fed into the pounding chamber in batches, the high speed rotational beater mills the yam against the wall of the chamber. The forward action of the rotational beater against the yam and the repelling reaction created by the rigid wall of the chamber led to pounding of the yam. The milling continues until the solid yam transform completely into gelatinous form without lumps. After complete pounding, the pounded yam is removed from the pounding chamber ready for consumption.

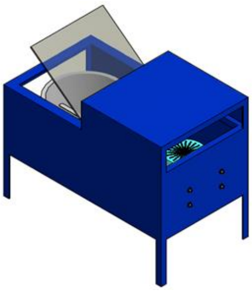

Figure 1. Isometric drawing of the machine

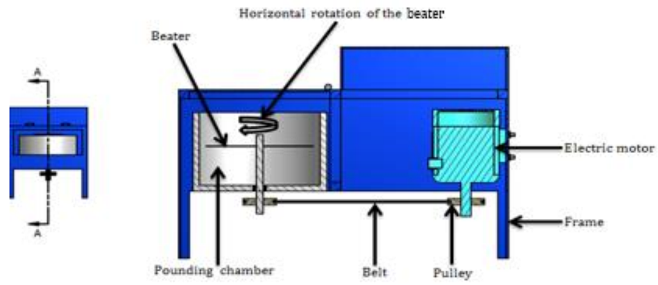

Figure 2. Operational mechanism of the machine

2.3 Design of the pounding chamber

The design of the pounding chamber, as shown in Figure 3, centered on the determination of the pounding chamber's volume, which explained the holding capacity of the chamber, and determination of its weight. Considering the conventional mortar diameter range ($90\,mm \leq \theta_c \leq 110\,mm$) by [7](2014), the volume (V_c) of the chamber can be estimated mathematically using the expression;

$$V_c = \frac{\pi {\theta_c}^2}{4} h_c \quad (1)$$

$$V_c = 0.0055\,m^3$$

The weight (W_c) of the chamber, according to Khurmi and Gupta [8] (2005), is given by;

$$W_c = \frac{\pi({\theta_o}^2 - {\theta_c}^2)}{4} h_c \rho_c g \quad (2)$$

Where (ρ_c) is density of the chamber ($7850\ kg/m^3$), (g) is acceleration due to gravity and (θ_o) is the outer diameter of the chamber (mm). Using allowable clearance of 5mm, $W_c = 8.9\ N$.
The weight of the pounding chamber is 8.9 N.

2.4 Design of the beater

The beater, as shown in Figure 4, does the pounding of the cooked yam into pounded form with the aid of its flat plates which operate under high revolutional speed and mill the yam against the wall of the chamber until the yam turns pounded.
The volume (V_b) and weight (M_b) of the beater, according to Khurmi and Gupta [8], were determined using the expressions:

$$V_b = 2(l_b \times w_b \times t_b) \quad (3)$$

$$M_b = \rho_b V_b \quad (4)$$

Where; l_b = length of beater (80 mm); w_b = width of beater (10 mm); t_b = thickness of beater (10 mm); and ρ_b = density of the beater (7850 kg/m^3 – density of stainless steel). Thus,
$V_b = 0.00002\,m^3$ and $M_b = 0.157\ kg$.
The volume and mass of the beater are 0.00002 mm^3 and 0.157 kg respectively.

The Pounding force

The force (F_p) supplied by the beater to pound the cooked yam and transform it into pounded form was determined using a formula derived from Khurmi and Gupta [8](2005).

$$F_p = \frac{\pi^2 {N_b}^2 r_b M_b}{900} \quad (5)$$

Where; M_b = unit mass of the beater (kg); r_b = rotational radius of the beater (m) and N_b = rotational speed of the beater (rpm). Using designed values of $0.04\ m\ and\ 1500\ rpm$ for $r_b\ and\ N_b$ respectively, $F_p = 155\ N$, hence the pounding force of the machine is $155\ N$.

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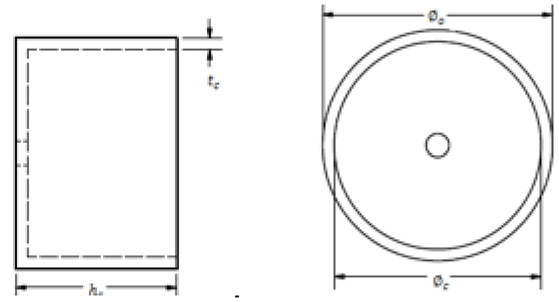

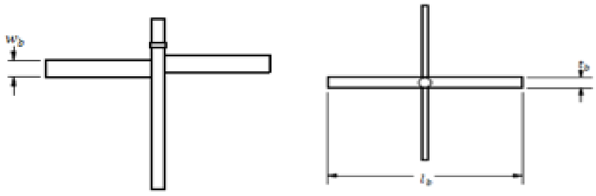

Figure 3. Schematic diagram of the pounding chamber **Figure 4.** Beater

2.5 Power rating of the machine

The power rating of the machine (P_T) is a function of the total power needed to drive the machine expressed as;

$$P_T = P_b + P_p \quad (6)$$

Where; P_b = power required to drive the beater shaft (kW); P_p = power required to drive the beater shaft's pulley (kW). According to Khurmi and Gupta [8,9], the power required to drive the blades was be expressed as;

$$P_b = \frac{2\pi N_b r_b}{60} W_b$$

Where; W_b = weight of the beater, 1.5 N, hence $P_b = 9.4\ W$.

The power required to drive the shaft's pulley is given as;

$$P_p = \frac{\pi N_b \emptyset_2}{60} W_2$$

The pulley has diameter 150 mm and weighs 0.98 N, hence;

$$P_p = 3.85\ W$$

Equation (6) gives;

$$P_T = P_b + P_p = 13.25$$

$$P_T = 0.01325\ kW$$

$$P_T \equiv 0.018\ hp$$

With respect to the value gotten, 1 hp electric motor was used to power the machine in order to give room for the unknown weight of yam to be pounded. This weight was estimated thus;

$$W_y = \frac{60 P_c}{2\pi r_b N_b}$$

Where; W_y = maximum weight of yam per pounding batch; P_c = power required to pound the fed cooked yam.

$$P_c = P_r - P_T = 1 - 0.018 = 0.982$$

$$P_c = 0.982\ hp$$

$P_c = 732.572\ w$, hence;

$$W_y = 116.6\ N$$

$$W_y \equiv 11.9\ kg$$

The design maximum load of yam the machine can pound per batch is 11.9 kg.

2.6 Design of beater shaft

The shaft of the beater was designed using appropriate expression according to [8], to obtain the diameter of the shaft.

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$$d_s{}^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (7)$$

Where; S_s = shaft ($55\ MNm^{-2}$); K_b = combined shock and fatigue factor applied to bending moment (1.5); K_t = combined shock and fatigue factor applied to torsional moment (1.0); M_b = resultant bending moment (Nm); M_t = resultant torsional moment (Nm).

$$M_t = \frac{60P}{2\pi N} \qquad (8)$$

Where; N = speed of the shaft in rpm (1500 rpm) and P = power transmitted to the shaft (746W). Hence $M_t = 4.75\ Nm$.

The schematic diagram of the shaft and the various loads carried by the shaft is as shown in Figure 5, where; L_1 = beater first arm load (N); L_2 = beater second arm load (N); L_C = combined load of shaft pulley and net tension of the belt (N); R = reaction at the bearing (N). All these loads were determined and obtained as 0.77 N, 0.77 N, 119.77 N and 121.31 N for $L_1,\ L_2,\ L_C\ and\ R$ respectively. These values were used to determine the shearing forces $(S.F)$ and bending moments $(B.M)$ experienced by the shaft. The results obtained, as shown on Table 1, and Figure 5, displayed the maximum bending moment $(B.M_{max})$ experienced by the shaft as15.98 Nm.

Therefore;

$$M_b = B.M_{max} = 15.98\ Nm$$

Hence, using equation (7), gives;

$$d_s{}^3 = \frac{16}{\pi \times 55 \times 10^6}\sqrt{(1.5 \times 1.44)^2 + (1 \times 4.75\,)^2}$$

$$d_s = 7.85\ mm$$

From the value gotten, the diameter of the beater shaft can be conveniently taken as 10 mm.

Table 1. Values of shearing force and bending moment experienced by the beater's shaft

	Vertical Loading	
Point	$S.F\ (N)$	$B.M\ (Nm)$
a	119.77	0
b	-1.54	1.44
c	0.77	1.39
d	0.77	0

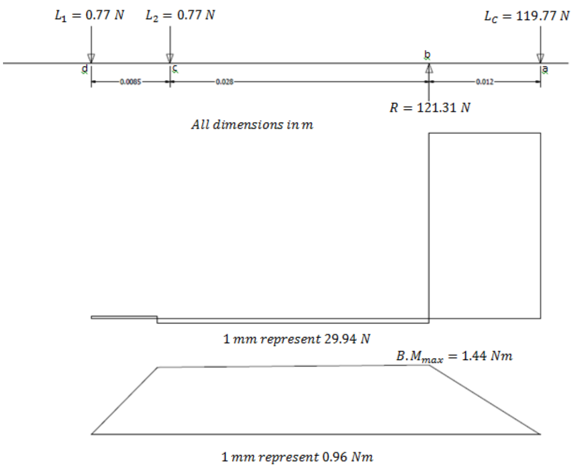

Figure 5. Shearing force and bending moment diagram of the shaft

2.7 Machine capacity

The capacity of the machine(M_C), in terms of the quantity of yam that can be pounded in the pounding chamber, is the amount of yam that can be milled by the beater into gelatinous form at optimum allowable time. The capacity of the machine, using feed rate, can be expressed as;

$$M_C = \frac{3600Q}{T} \ kg/hr \quad (9)$$

Where $Q =$ optimum quantity of yam fed into the machine (kg) (11.9 kg); $T =$ time taken for the yam to be pounded completely (40 s). Hence, $M_C = 1.07 \text{ tons/hr}$.
The capacity of the machine is 1.07 tons/hr.

2.8 Pounding efficiency of the machine

According to Oluwole and Adio [9](2012), the pounding efficiency of the machine was determined with respect to the percentage of lumps noted in the pounded yam. This was determined using the expression;

$$E_p = \left(1 - \frac{M_l}{M_t}\right) \times 100\% \quad (10)$$

Where; $E_p =$ pounding efficiency of the machine; $M_l =$ mass of lumps noticed in the pounded yam; $M_t =$ total mass of yam pounded per batch. Loading the machine to maximum capacity of 11.9 Kg, 0.35 Kg of lumps was noticed in the pounded yam. Thus;

$$E_p = \left(1 - \frac{0.35}{11.9}\right) \times 100\%$$

$$E_p = 97 \ \%$$

2.9 Cost of production

The total cost of production of the machine was forty thousand naira (₦40,000), equivalent to $110.41 (at 363.30 rating). Considering the capacity and pounding efficiency of the machine, it can be concluded that the machine is cost effective and thus affordable

2.10 Machine testing

The pounding machine was tested using rotational speeds of 1000 rpm, 1250 rpm, and 1500 rpm with respect to 9.9 kg yam loading (Ld $_1$), 10.9 kg yam loading (Ld $_2$), and 11.9 kg yam loading (Ld $_3$). The results obtained are explained below.

3. Results

The developed pounding machine shown in Plate 1 was tested using rotational speeds of 1000 rpm, 1250 rpm, and 1500 rpm with respect to 9.9 kg yam loading (Ld $_1$), 10.9 kg yam loading (Ld $_2$), and 11.9 kg yam loading (Ld $_3$). The results obtained is given in pictorial form in Plate 2 and figure 6 depicts the machine efficiency. Peak efficiency of about 98.5% was obtained at yam loading of 8.5 kg and decreases gradually as yam loading increase upto a 9.0 kg yam loading afterwards experiences sharp decrease, However, texture preference was at 9,5 kg yam loading by seasoned panellist who performed organoleptic and sensory evaluation of the products.

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Plate 1. The fabricated machine **Plate 2.** Result of yam pounded by the machine.

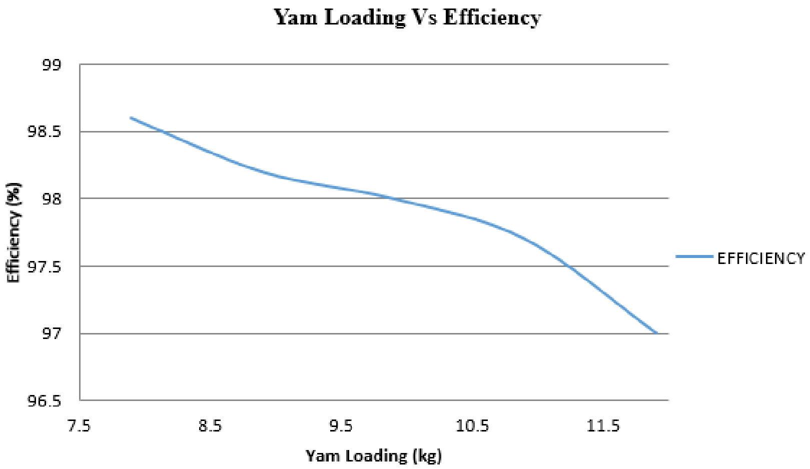

Figure 6. The effect of yam loading on pounding efficiency at 1500 rpm

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