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Development of a High-Efficiency Yam Pounding Machine: Revolutionizing Traditional Food Processing in West Africa

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Abstract: Pounded yam is a staple starchy food enjoyed by many West African countries. Traditionally, the yam is mashed using a pestle in a mortar, a process that requires significant physical effort and is typically performed by housewives who often lack the necessary strength for this laborious task. Additionally, this traditional method generates excessive sweat and noise, making it unsanitary. This study aims to design and fabricate a yam pounding machine that hygienically processes pounded yam, eliminates the strenuous manual labour, and reduces processing time. During the machine's design and construction, several factors were considered, including the electric motor's power, machine capacity, effectiveness, material availability, and maintenance. The machine was constructed using stainless steel, mild steel, pulleys, belts, bearings, and shafts. Specifically, a type A37 V-belt was used, the bowl's depth is 160 mm, and the beater's dimensions are 73 x 30 x 3 mm. Testing with two different types of yams demonstrated that the yam pounding machine produced hygienic and well-processed pounded yam in less time. The machine completely eliminated the laborious manual pounding process, achieving an efficiency of 88.171%, which is commendable for a locally fabricated machine.

Keywords: *Yam, Pounding Machine, Design, Fabrication, Performance Evaluation*

INTRODUCTION

Technology innovation of today has led to the development of new methods for home and industrial large-scale food processing. This assigns the duty of creating improved processing models to pertinent engineering parties (Jack *et al.,* 2022). Food crops' post-harvest processing is a crucial step in ensuring a country's food security (Oyejide *et al.,* 2018; Olabanji, 2020). Another crop that's grown all over Nigeria is yam, which is a seasonal crop that rots easily and is consumed by almost all Nigerians, especially the Yoruba tribe. One of the most important and labor-intensive steps in growing yams is harvesting them (Ola *et al.,* 2021).

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Yam is eaten in a variety of processed forms, such as boiled, mashed, fried, roasted, baked, or meshed into stick paste or dough. It is also eaten as chips. The leftovers from the peeling are given to cattle or processed even more into yam flour. Since there is no waste, yams are extremely important economically (Oladipo *et al.,* 2020). When yam is crushed or struck in a mortar, it forms bonds with other yams and is a common meal among the locals, although pounding yam by hand is a very labor-intensive process. To process freshly harvested yam and other tuber crops before they rotten, mechanization is crucial in tuber crop post-harvest unit activities (Palani *et al.,* 2022). The process of pounding yams requires physical labor from one or more individuals, based on the amount in the mortar (Ogiemudia *et al.,* 2016; Madu *et al.,* 2019). In an attempt to reduce the labor involved, the Herbert mixer, Kenwood mixer, and Hammer mill were manufactured in the early part of 1975. The Herbert and Kenwood mixers shared nearly the same operating principle and were known for their insufficient pounding because of their stirrer or mixer's flapping (moving up and down) in response to the electric rotating shaft. These intended yam pounders were unsuccessful because of certain limitations in their operational functions. Along with the inadequate pounding of both pounders, the Herbert mixer was discovered to overheat, necessitating periodic stops to allow the machine to cool.

One of the main factors motivating technological growth from the beginning has been the necessity to replace human energy with machine power (Richta, 2018). One such method of replacing human labor in the crushing process of yams is the invention of a yam-pounding machine. One of the earliest recipes ever discovered is yam. It is a tuber crop that is a member of the carbohydrate class and has long been a staple of African cuisine. The species in the genus Dioscorea (family Dioscoreaceae) is known by its common name, yam. Although it is not a member of the Dioscoreaceae family, the sweet potato (Ipomea batatas) has historically been called yam in some regions of Canada and the United States (en.wikipedia.com/yam). The Wolof word "nyam" is ultimately the source of both the Portuguese and Spanish names for yam, meaning "to sample" or "taste". Other African languages may likewise interpret it as "to eat" e.g. yam yam and nyama in Hausa (Mignouna *et al.,* 2003). A few species in the genus are also known by their common name, yams. They are perennial herbaceous vines that are grown throughout Africa, Asia, Latin America, and Oceania for the starchy tubers they produce. They are prepared similarly to how sweet potatoes and potatoes are (Brand–Miller *et al.,* 2003). In Nigeria, yam is known by numerous names in the languages of the many ethnic groups and dialects. In Yoruba, yam is translated as "Isu," or "Iyan" when ready to be eaten as the main course for supper (Amosun, 2020). The vegetable yam is incredibly adaptable, yielding a variety of derivative products after cooking, roasting, grilling, boiling, smoking, pounding, and grating it into a dish for dessert (Neumann *et al.,* 2023). Yam, also called "Iji" in their language, is a major crop among the Igbo people of Nigeria. Iri-ji or Iwa-ji festivals are held in southern Nigeria to honor yam, whereas new yam festivals are held in the country's southwest (Ukpokolo *et al.,* 2018).

Kingsley and Olodu, (2022) designed and constructed a wood-based modified yam pounder machine as a result of the high cost of creating yam pounder machines from stainless steel and other metals, which creates significant problems in terms of efficiency and cost. Some pounding machine consists of a pounding unit, boiling unit, transmission unit and a frame (Onipede and Oyedokun, 2022). Analysis carried out by Abulude *et al.,* (2018) shown that the mashed yam gotten from the pounding machine was more satisfactory than that gotten by pounding with mortar and pestle. The technique used to prepare food ultimately impacts how well-liked it is by the populace. For instance, our European peers find it difficult to embrace our local cuisine since they believe the cooking process to be harsh and unclean. Second, the idea of a full-time housewife has totally been superseded by women's emancipation and employment in the workforce, necessitating the development of a mechanized and contemporary approach to food preparation—hence the current investigation and research. The creation of a yam pounding machine is the goal of this project, that performs the hygienic processing of pounded yam.

MATERIALS AND METHODS

2.1 Design Analysis

The mechanism of the machine was designed as follow:

2.1.1 Pulley and Belt Analysis

With the use of belts, pulleys transfer power from one shaft to another. Appropriate choice of pulley diameter is significant because the driving and driven pulley diameters are inversely correlated with the velocity ratio. The pulleys need to be precisely lined up with one another for the belt to move in a path normal to their faces. For the design of the pulley and belt, the speed of the driving and driven unit, center distance must be known (Khurmi and Gupta, 2006).

$N_1D_1 = N_2D_2$ (1)

where;

N_1 = Speed of motor = 1450 rpm

D_1 = Diameter of driver = 50 mm

D_2 = Diameter of driven = 250 mm

N_2 = Speed of shaft

$D_1N_1 = N_2D_2$

$N_2 = \frac{D1N1}{D2} = \frac{50 \times 1450}{250}$

N_2 = 290 rpm

Hence, the speed of the main shaft pulley N_2 = 290 rpm. This implies a speed reduction 5:1

The pulleys' center distance, C, is gotten from;

$C = \max\left(\frac{3D1}{2} + \frac{D2}{2}\right)$ (2)

$= \max\left(\frac{3X50}{2} + \frac{250}{2}\right)$

= 200mm

The groove angle of the pulley

$\text{Sin}\beta = \frac{R-r}{C}$ (3)

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

$R = \frac{250}{2}$ = 125mm = 0.125m

$r = \frac{50}{2}$ = 25mm = 0.025mm

$\beta = \sin^{-1}\left(\frac{0.125 - 0.025}{0.2}\right)$

$\beta = 30^0$

Length of belt

$L = \pi\frac{(D1+D2)}{2} + 2C + \frac{(D1+ D2)^2}{4C}$ (4)

$= \pi\frac{(50+250)}{2} + 2(200) + \frac{(50+ 250)^2}{4(200)}$ = 983.74mm

Then, a normal belt is selected since the closest match, a type A43 belt, is 1026 mm

Angle of wrap

$\alpha_1 = 180 - 2\beta$ (5)

$= 180 - 2(30) = 120^0$

$\alpha_2 = 180 + 2\beta$ (6)

$= 180 + 2(30) = 240^0$

Tension on tight side of belt T_1;

$T_1 = btS_s$ (7)

b = 12mm

t = 8mm

S_s = 3.0 Mpa

$T_1 = 0.012 \times 0.008 \times 3 \text{ x } 10^6$ = 288N

Tension on the slack side T_2;

$2.3 \log\left(\frac{T1}{T2}\right) = \mu\theta\text{cosec}\beta$ (8)

θ is taken as the smallest of α

$\mu = 0.25$

$2.3\ \log\left(\frac{288}{T2}\right) = 0.25x120\times \frac{\pi}{180}\mathrm{Cosec}30^0$

$T_2 = 182.7N$

Power transmitted through belt:

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

$= (288 - 182.7)\ \frac{\pi\times1450\times50}{60}$

$= 535.829W$

2.1.2. Bearing Analysis

A pillow block bearing was used because of itself contained, greased, sealed and ready for installation on the equipment. The diameter of the bearing is 1 inch. The specific static load rating C_o (Arvid, 1945).

$$C_o = \frac{1}{5}\ K_o \times i \times z\cos\alpha D_w^2 \tag{10}$$

where,

C_o = Specific static load rating

K_o = Bearing factor

D_w = Ball diameter

α = Nominal angle 25^0

i = Number of rows of ball in anyone bearing = 1 (Khurmi and Gupta, 2005)

D_w = Diameter of the ball

Z = Number of balls per row = 6

$K_o = \frac{RA}{D} = \frac{633.21}{25.4} = 24.9$

R_A = Bearing load = 633.21 (from shaft analysis)

$$D_w = \sqrt{\frac{Co\ X\ 5}{Ko \times i \times z\cos\propto}} \tag{11}$$

$= \sqrt{\frac{1000 \times 5}{24.9 \times 1 \times 6 \times\cos 25}}$

$= 6.08mm$

Then the maximum bearing load Q_{max}:

$$Q_{max} = K_o \times D_w^2\ \text{(Arvid, 1945)} \tag{12}$$

$Q_{max} = 24.9 \times (6.08)^2$

$= 920.5N$

$= 0.9KN$

2.1.3. Shaft Analysis

The primary goal of shaft design is to choose the appropriate shaft diameter so that the shaft can transmit power under a variety of operating and loading conditions with sufficient strength and rigidity.

$$M_t = \frac{63000\times hp}{rpm} \tag{13}$$

$$M_b = T_1 - T_2 \tag{14}$$

M_t = torsional moment

M_b = bending moment

T_1 = tight side of belt

T_2 = loose side of belt

$M_t = \frac{63000\times 1hp}{290}$

N_2 = 290 rpm (the pulley that hold the shaft)

$M_t = 217.4$

$M_b = 105.3$

According to ASME code equation

$$d^3 = \frac{16}{\pi Ss}\sqrt{(KbMb)^2 + (KtMt)^2} \tag{15}$$

K_b = Bending moment subjected to combined shock and fatigue factor

K_t = Torsional moment subjected to combined shock and fatigue factor

$K_b = 1.5$

$K_t = 1.0$

$S_s = 8000$

$d^3 = \frac{16}{\pi Ss}\sqrt{(KbMb)^2 + (KtMt)^2}$

$d^3 = \frac{16}{\pi(8000)}\sqrt{(1.5 \times 105.3)^2 + (1.0 \times 217.4)^2}$

d = 12.17mm

2.1.4. Blade analysis

Length, L = 140mm

Width, W = 60mm

Thickness, T = 8mm

$V = L \times W \times T$ (16)

$= 0.14 \times 0.06 \text{ x } 0.008$

$= 0.0000672\text{m}^3$

density of stainless steel, $\rho = 7500\text{kg/m}^3$

mass = density x volume (17)

$= 7500 \times 0.0000672$

= 0.504kg

Weight, $W_b = mg$

$= 0.504 \times 9.8$

= 4.9N

The weight of the beater is 4.9N

Area of the beater in contact with the yam:

$A = \frac{1}{2}(a + b)h$ (18)

$= \frac{1}{2}(0.03 + 0.026)(0.08)$

$= 0.0024 \text{ m}^2$

Beater's volume occupied:

$V = At = 0.0024 \times 0.005 = 0.000012\text{m}^3$

Effect of yam on the beater:

For this analysis, a yam slice with the measurements L = 40 mm, B = 40 mm, and H = 40 mm is used.

Volume of yam piece = $(40/1000)^3 = 0.0000046 \text{ m}^3$

Density of boiled yam: 1950kg/ m^3

Mass of the piece of yam:

$\rho \times v = 1950 \times 0.000064 = 0.1248\text{kg}$

A maximum of two (2) yam pieces may be present on the beater, therefore

Mass of 2 pieces of yam = 2 × 0.1248 = 0.2496kg

Weight of 2 pieces of yam = 0.2496 × 9.81 = 2.449N

The beater's total weight with the yam on it is:

Total weight = weight of the beater + weight of two pieces of yam

Total weight = 0.942 + 2.449 = 3.391N

Calculating the force and crushing pressure on the beater's surface

$P = \frac{F}{A}; F = P_y \times A$ (19)

$P_y = \rho_b gh$ (20)

Where P_y = Crushing pressure, h = height (yam)

The device is intended to pound a typical yam tuber. In one experiment, a tuber was divided into 22 pieces, each measuring 40 mm cube.

$P_y = 1950 \times 9.81 \times 0.051 = 975.6\text{N/m}^2$

$F = 975.6 \times 0.0024 = 23414.4\text{N}$

To smash 22 pieces of yam using the right side of the beater; $F = 2.34144 \times 22 = 51.5\text{N}$

Effect of Turning and Power Needed:

Torque Computation: $F = T \times D$ (21)

Where T = Torque, F = Force, D = Distance from center of pivot

Torque from the beater's weight, including the weight of the yam

T = 2.34 × (0.04 + 0.0125) = 0.1779755Nm
Torque generated by a force applied to the beater's surface
T = 40.4008 × (0.04 + 0.0125) = 2.121Nm
Torque of RHS of beater = 0.177975 +b2.121 = 2.299 Nm
Total Torque of beater = 2 × 2.299 = 4.598Nm
Power needed:

It is provided as: $\text{Power(P)} = \frac{2\pi NT}{60}$ (22)

Where N =speed of revolution and T = Torque

Using a speed reduction factor of 1:3; $N = \frac{Motor\ speed}{3} = \frac{1440}{3} = 480\text{rpm}$.

$P = \frac{2 \times \pi \times 480 \times 4.598}{60} = 231.121$ Watts

Consequently, taking into account the safety factor of 1.5 and the design's minimal power need; = 231.121 × 1.5 = 346.681. Thus, an electric motor of 1 horsepower with a speed of 1440 rpm, phase 3 and voltage of 440V was selected based on the calculations above.

2.2 Material Selection

The following factors are taken into account when choosing the material and component used here: the material's cost analysis; its durability; its availability; and its properties, including its mechanical, chemical, and thermal characteristics as well as its physical attributes. Also, the materials used were locally sourced. The materials were purchased in line with the design specifications.

Table-1 Materials Utilized

S/N	Item description	Quantity utilized	Chosen material
1	Shaft	1	Stainless steel
2	Bearing	1	Mild steel
3	Electric motor (1hp)	1	Purchased
4	Yam beater	1	Stainless steel
5	Pounding bowl	1	Stainless steel
6	Welding electrode	20,20	Stainless steel and mild steel
7	Angle bar	1 full length	Mild steel

RESULTS AND DISCUSSION

3.1 Cost Analysis

While designing the machine, cost in procuring the machine played an important role. A well-designed machine may fail economically if cost is not taken into consideration.

Table-2 Measurement and Evaluation of the Bill of Engineering

S/N	Component	Material	Quantity	Unit Cost (N)	Total Cost (N)
1	Electric motor (1hp)	Purchased	1	45,000	45,000
2	Belt drive	Rubber	1	2,500	2,500
3	Bearing	Mild steel	1	1,500	1,500
4	Shaft material	Stainless steel	1	6,500	6,500
5	Welding electrode	Purchased	20,20	3,700	3,700
6	Angle bar	Mild steel	1 full length	4,000	4,000
7	Labour	-	-	20,000	20,000
Total					**83,200**

3.2 Performance Evaluation

After assembling all the working part (electric motor, pulley, belt, shaft and blade) that make up the yam pounding machine. The machine was put to the test by mashing water yam and white yam, two types of cooked yam. The time for pounding the two yams were taken and recorded.

Table-3 Pounding different yam specimens

S/N	Yam Specimen	Pounding Time (Minutes)	Texture of Yam
1	White yam	8:20	Starchy
2	Water yam	6:15	Semi-Starchy

After pounding, both yams were weighed which gave us 2.9kg for the white yam and 2.4kg for the water yam. The pounding efficiency can be determined by dividing the mass of the pounded yam by the initial mass of the yam multiplied by 100. Since we have two yam specimens, we use the formula for both yam specimens and find the average efficiency.

$$\text{Pounding efficiency} = \frac{mass\ of\ the\ pounded\ yam}{Initial\ mass\ of\ the\ yam} \times 100\% \qquad (23)$$

For white yam,

$$\text{Pounding efficiency} = \frac{2.9}{3.2} \times 100 = 90.625\%$$

For water yam,

$$\text{Pounding efficiency} = \frac{2.4}{2.8} \times 100 = 85.714\%$$

$$\text{Pounding efficiency of the machine} = \frac{90.625 + 85.714}{2} = 88.171\%$$

The pounding efficiency of the machine after calculation was gotten as 88.171% which is fair for a locally fabricated yam pounding machine. The isometric and sectional view of the yam pounding machine is shown in Fig. 1 and Fig. 2.

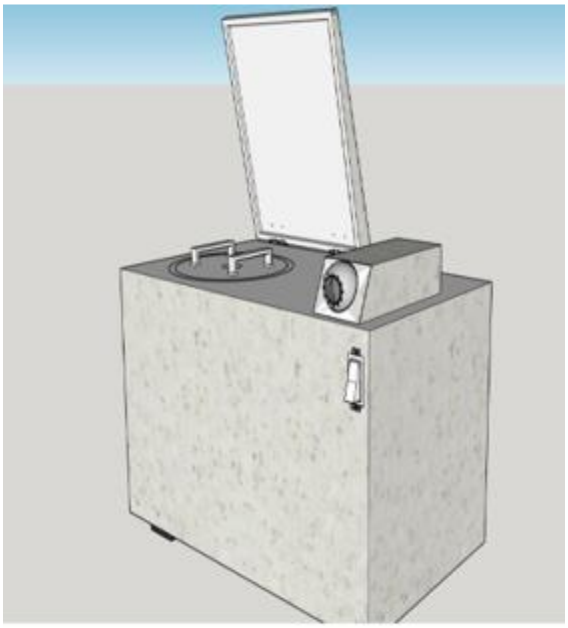

Fig. 1 Isometric view of the yam pounding machine

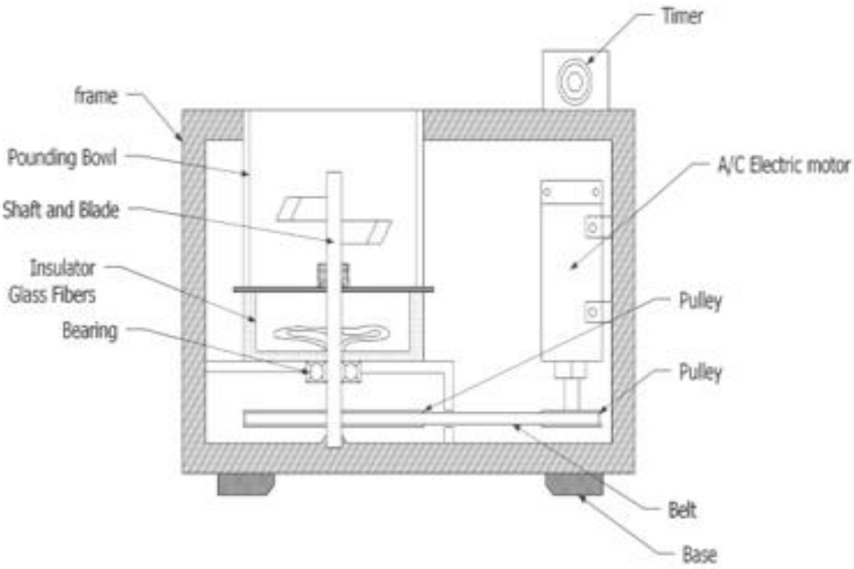

Fig. 2 Sectional view of the yam pounding machine

CONCLUSION

The yam pounding machine fabricated with an efficiency of 88.171% was able to carry out a hygienic yam pounding process there by eliminating food contamination. Furthermore, we were able to completely eliminate the tedious and laborious process involved in pounding yam. Compared to the indigenous method, we were able to minimize the time taken in processing the cooked and pounded yam. With the minimized time we were able to produce pounded yam with a nice texture. Producing this machine on a large will provide an opportunity for making pounded yam in large quantities with reduced time of processing and also reducing the cost of labor for restaurants and canteens.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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