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DEVELOPMENT AND PERFORMACE ANALYSIS OF A MODIFIEF CASSAVA FUFU/YAM POUNDING MACHINE

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ABSTRACT

Pounded yam/cassava fufu is a special Nigerian delicacy enjoyed by communities in western and other parts of Nigeria. It is traditionally obtained from manually pounding yam with a mortar and pestle. It is usually a very phenomenal and time-taking task, hence the need for a simpler modified machine, modified from the existing fufu pounding machine that is not as versatile to be able to both grind cassava fufu and yam. The major modifications involved widening the versatility of the existing cassava fufu, improving the safety considerations by installing a safety guard. Materials used included; stainless steel, mild steel, angle iron, metal sheet, belt, galvanized steel, shaft, pulley, metal gauze, bolts and nuts, and bearing at an affordable cost of #60,180.00 affordable for rural populace. At the final analysis, the machine has the performance efficiency of 78% compared to the traditional existing manually piston and mortar machine of 44% at the same effort input capacity to grind an estimated 10kg of boiled yam at an equally 7and 40 minutes respectively.

KEYWORDS: Cassava/Fufu, Pounding Machine, Performance, Analysis.

1.0 INTRODUCTION

Cassava fufu meal is traditionally prepared by pounding boiled, peeled and chopped cassava tubers with a wooden pestle in a wooden mortar until a fine texture and plastic structure is obtained Figure 1. It is pounded alone or could be mixed with cooked plantain, cocoyam or yam. It's a nutritious meal popular among households of West Africa. Likewise, the West African community living in Nigeria/diaspora relies on the processed cassava flour (Neat Fufu and Tropical Fufu), so also, as popularly traditionally fermented waste paste food product from cassava, [1] Bela et. al, 2021, [2] Chijioke *et. al, 2021*, [3] Mirjail, 2023, [4] Collins et. al, 2003). This means that there is a good, healthy benefit of the traditional fermented food in Nigeria as demand for cassava fufu. The main disadvantage of cassava fufu is its traditional way of processing and preparation as also discussed and is physically energy sapping and time-consuming [5] Osueke, 2010)

The use of yam for pounding appears to be the most popular use of the food crop in Nigeria and the process of making the food is also laborious [6] (Osasumwen Ogiemudia, 2016). Pounded yam being similarly and traditionally prepared by pounding peeled, boiled and chopped yam tubers with a wooden pestle in a wooden mortar until a fine texture and plastic structure is obtained, the modified machine is used to grind same boiled cassava into fine, dough-like, pasty texture with basically a combination of auger and die.

Consequently, the machine is a kitchen appliance used to pound cooked starchy vegetables particularly cassava, plantains, or yams. It could also be used to achieve fine dough-like, pasty texture of fufu/yam. The traditional hand-pounding methods using pestle and mortar described above generally requires several hour as identified by [7] O. kachi and N. S akomas, 2006 for a reasonable result.

Figure 1

The first cassava fufu pounding machine was developed in 2004 by Ghanaian electrical-equipment dealer Fadegnom Charles for local consumption according to [8] Kwadeo, et al, 2013 as well stated b a scholar [9] Julius Caesar Puoza, 2016), shortly after with little modification and thereafter was re-modified for a mass-marketable design by a team led by [10] Kwadeo, et al, 2013 and subsequently again modified by [11] Kuuchi, 2024, but with some deficiencies of fufu texture. The machine had significant adoption in both homes and small businesses in Accra by 2014.

In 2017, a Togolese entrepreneur named Logou Minsob successfully invented a replica model Foufoumix used for efficient mixing of the cassava fufu into a well-set texture and consistency, [12] Parent, (2017). All the exited cassava fufu pounding machines had a number of limitations such as: the available technology are not so versatile. They are mainly designed to grind cassava fufu only, The Safety considerations were too low and the output in the available technologies wasn't as even as plastic as the traditional pounding.

Cassava fufu meal is a very popular food in West-Africa, especially in Nigeria, Ghana, Cameroon to mention just a few. It is mainly served with soup and could be eaten at any particular time of the day. But according to [13] Chiamba, 2010, it is however served as lunch or supper in modern times. The drudgery involved in turning boiled cassava to cassava fufu and boiled yam to pounded yam initially is an enormous that it makes the pounders perspire profusely during pounding and some of this perspiration inadvertently gets into the food being pounded thereby contaminating it. Although, the existing cassava fufu pounding machine has good utility such as processing large volumes of boiled cassava into cassava fufu in much shorter time frames, but has several limitations which includes; no secondary utility (can only be used to pound cassava), the product of the machine is not plastically pounded as cassava fufu should be because it is manually and the safety consideration is poor. Therefore, this work addressed these critical issues through the designed modified, constructed and performed evaluated cassava fufu/Yam pounding machine. It could both pound cassava fufu and yam with a fine plastic and a pasty texture output with adequate safety guards and with an appropriate hygiene. Therefore, in this study, by the optimization of the design, there is a need to produce the cassava fufu pounding machine that is more efficient, versatile, hygienic and most importantly with safer operation method.

2.0 MATERIALS

Material selection in developing the machine was an important aspects that demanded the understanding of the functional requirements of individual device production. Similarly, there are ever-increasing varieties of materials presently available and the development of new materials with their properties and applications. As stated by [14] Budynas and Nisbett (2008), the difficulty in materials selection for production is as a result of the varieties of materials in the engineering field coupled with the complex relationships between the selected parameters and functionality. If the selection process is done haphazardly, the risk of overlooking a possible attractive alternate material may occur. To avoid this, below were the selected and analyzed materials used.

1. Galvanized steel
2. Mild steel material
3. Stainless steel
4. Angle iron
5. Shaft

2.1 Component Parts of the machine

Cover: its function is to prevent contaminants from entering the hopper during use and in storage is made of Formica wood, Length = 44 mm, Breadth = 39 mm

Hopper: Hopper is a funnel-shaped device that stores the food for pounding. The hopper is made of mild steel, Length = 42 mm, Breadth = 37 mm

Shaft: shaft is the component of circular cross-section that rotates and transmits power from a driving device such as a motor or engine through a machine. The shaft is made of mild steel, Length = 72 mm

Pounding compartment and Auger

The pounding compartment contains the auger. It is where the pounding takes place. The pounding compartment is made of stainless steel, Length = 27 mm

An auger is a device for moving material by means of a rotating helical spring. The auger is made of mild steel, Length x breadth = 27 mm x 45 mm

Discharge outlet: A discharge outlet is an opening through which the pound material is ejected. The discharge outlet is made of stainless steel, Diameter = 3 mm

Bearing: Is a device that consists of two rings separated by freely rotating metal balls used to reduce friction between two surfaces with a specification P205

Pulley: Is the wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and the cable or belt. The pulley is made up of mild steel.

Motor and Power Source: The core of the cassava fufu/Yam pounding machine is an electric motor or sometimes a gasoline engine that provides the necessary power to drive the machine components. The pounding mechanism comprises one or more pestles or pounders, often made of heavy metal or wood that move up and down to crush and mash the starchy root crops. The pounders are connected to the motor through a system of belts, pulleys, or gears. The user now loads the peeled and cut cassava, yam provided by loading into the hopper or feeding tray to ensure user safety around the pounding area, and to prevent accident from moving parts.

But, using this machine, a helical auger is mounted on the shaft supported by a bearings so that the shaft rotates in the stationary cylindrical pounding compartment. The machine serves as a time-saving and hygienic alternative to that of the manual grinding. With a motor of 5.5 hp, the cassava fufu pounding machine could process up to 120 Kg mass of cassava fufu in one (1) hour with the following modified parts; the pounding compartment, a shaft on which is welded the auger, the hopper, the discharge outlet, the bearing and the main frame.

Cover: its function is to prevent contaminants from entering the hopper during use and in storage is made of Formica wood, Length = 44 mm, Breadth = 39 mm

Hopper: Hopper is a funnel-shaped device that stores the food for pounding. The hopper is made of mild steel, Length = 42 mm, Breadth = 37 mm

Shaft: A shaft is a component of circular cross-section that rotates and transmits power from a driving device, such as a motor or engine, through a machine. The shaft is made of mild steel, Length = 72 mm

Pounding compartment and Auger: The pounding compartment contains the auger. It is where the pounding takes place. The pounding compartment is made of stainless steel, Length = 27 mm. the auger is the device for moving material by means of a rotating helical spring. The auger is made of mild steel, Length x breadth = 27 mm x 45 mm

Discharge outlet: A discharge outlet is an opening through which the pound material is ejected. The discharge outlet is made of stainless steel, Diameter = 3 mm

Bearing: Is a device that consists of two rings separated by freely rotating metal balls used to reduce friction between two surfaces with a specification P205

Pulley: Is the wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and the cable or belt. The pulley is made up of mild steel.

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2.2 Design Analysis of the Materials.

The design analysis was carried out to determine the parameters necessary for the selected appropriate grade and size of materials for the fabrication of the various components used.

Shaft Design: The shaft of the cassava fufu pounding machine that is rotating the auger and pulley was subjected to twisting moment only. The element that exerts force on the shaft is the driven pulley and auger. From the Machine,

Weight of Pulley, $W_p = M_p g$ ....Equation (1)

Where,

M_p = Mass of driven pulley = 1.5 kg

g = Acceleration due to gravity = 9.81 m/s

$W_p = 1.5 \times 9.81 = 14.715$

Weight of Auger, $W_a = \rho v g$....... Equation (2)

Where,

ρ = Density of material

= For Stainless, 7930kg/m^3

= For Mild steel, 7860kg/m^3

v = Volume of material

r = 0.045 m

Volume of Auger = $\pi r^2 h$

$= 3.142 \times (0.045)^2 \times 0.275 = 1.749 \times 10^{-3}\ m^3$

Point Loading of Shaft Due to Auger = $7930 \times 1.749 \times 10^{-3} \times 9.81 = 136.12N$

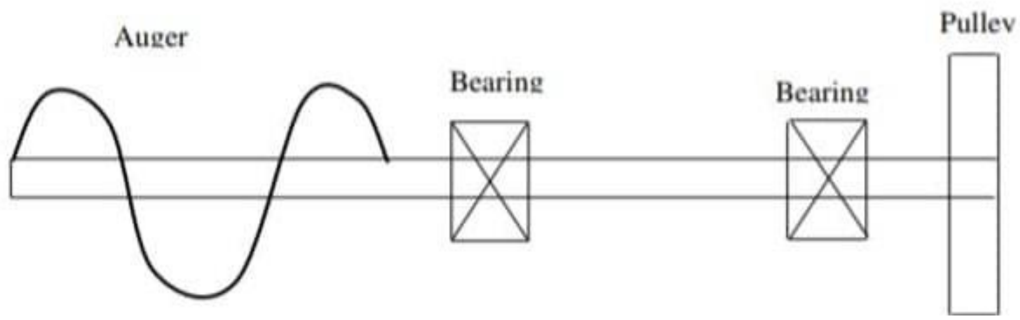

Figure 1: Shaft Bending Moment Determination

Reactions at the bearings due to vertical loading: Below is the free body diagram of vertical forces acting on the shaft:

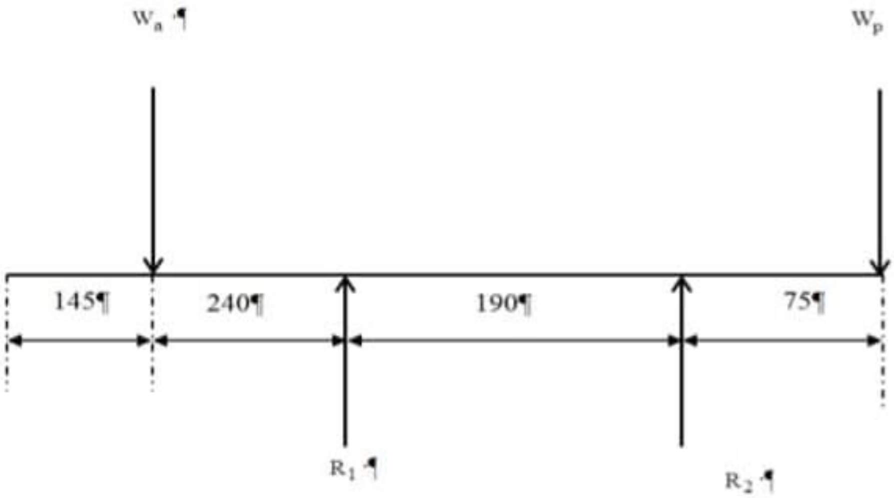

Figure. 2: Reactions of Force

To obtain the reactions at each bearing, we take moment about the two bearing points independently.

Taking moment about point R_1

W_a x 0.24 = $0.19R_2$ + $0.265W_p$

-136.12 x 0.24 = $0.19R_2$ - 14.715 x 0.265

R_2 = - 151.4175N

Taking moment about point R_2

W_a x 0.43 x $0.19R_1$ = $0.075W_p$

-136.12 x 0.43 + $0.19R_2$ = 14.715 x 0.075

R_1 = 302.25N

The maximum bending moment is obtained from the resultant bending moment

Total bending moment = (136.12 x 0.24) + (14.715 x 0.265) = 36.5683Nm

Therefore, the equivalent twist moment from the torque = 36.5683Nm for a shaft subjected to twisting moment only, the diameter of the shaft was obtained by using the torsion equation given in Equation below. (3):

$T = {}^{\pi}/_{16} \times d^3 \times \tau_{max}$ Equation 3)

Where, T = Twisting moment (Nm)

τ_{max} = Maximum shear stress (N/m^2) = 42 MPa

d = Diameter of shaft (m)

$36568.3 = {}^{\pi}/_{16} \times 42 \times d^3$

d = 16.43mm

Selection of transmission drives: The power transmission drives used for the machine are belt and pulley.

Design for pulley or sheave: The rotor pulley diameter was selected using the equation for the speed ratio shown in Eq. (4):

$D_r = \frac{Dm\ Nm}{Nr}$……………………... Equation (4)

Where,

N_m = Rotational speed of electric motor = 1400 RPM

D_m = Diameter of motor's pulley = 130 mm

N_r = Rotational speed of driven rotor (RPM)

The speed of the rotor was chosen as 1213 RPM.

2.2.2 Belt Design: Selection of belt type: Based on the power transmitted, 5.5kW and according to the Indian standards IS: 2491-1974, belt type B was selected from the Table 1.

Table 1: Dimension of Standard V-Belts

Types of belt	Power range[kW]	Minimum pitch diameter of driver pulley (D) [mm]	Top width (b) [mm]	Thickness (t) [mm]
A	0.7-3.5	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

To calculate the length of the belt used;

$L = \pi/2\ (D_1 + D_2) + 2c + \frac{D1 + D2}{4C}$; Khurmi and Gupta, 2005 …………....Equation (5)

Where,

L = Length of belt (mm)

D_1 = Smaller sheave diameter = D_m (130mm)

D2 = Larger sheave diameter = D_r (150mm)

c = Center distance between pulleys = (440mm)

$L = \pi/2\ (130 + 150) + 2 \times 440 + \frac{130 + 150}{4 \times 440}$ = 1320.04mm

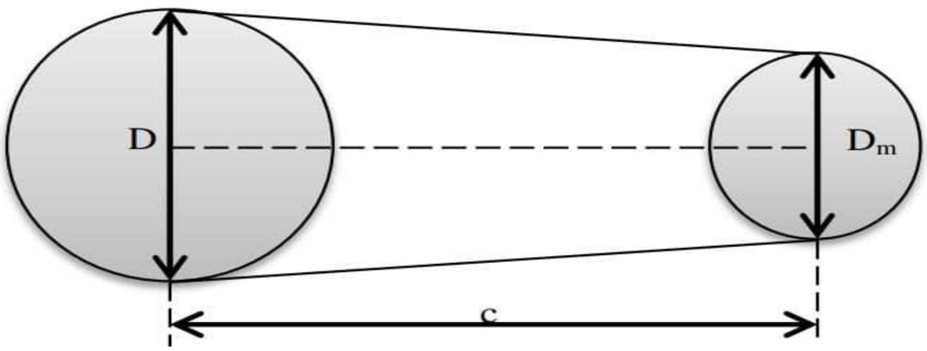

Figure 3 : Open Belt Drive

These parameters are represented in Fig. 3.2.

Torque: The torque is a function of power and speed of the shaft:

$T_q = \frac{60 \times P}{2\pi N}$...........................Equation (6)

Where:

T_q - Torque (Nm)

$T_q = \frac{60 \times 5500}{2\pi \times 1400} = 37.51$ Nm

Screw Length: Screw length calculation is a function of the equations of a helix, wound on a tapered shaft

$S = 3.42\ (r + ml)\ \theta_2$..........................Equation (7)

Where

S - Screw length (m)

r - Radius of shaft (m)

l - Length of shaft (m)

m - Tangent of tapping angle (rad)

θ_2 - Helix angle (rad)

Volumetric Capacity: The volumetric capacity of a screw is a function of the screw speed, diameter and distance between flights of the screw

$Q_v = \pi d_s H_p N$ ....Equation (8)

Where:

Q_v - Conveying volume (m^3/s)

d_s - Diameter of screw (m)

H_p - Pitch (m)

N - Screw speed (r/min)

Volumetric Flow Rate: The volumetric flow rate is a function of pressure drop and viscosity

$Q = K_d \frac{P_d}{\mu_d}$ …………………..Equation (9)

Where:

Q - Volumetric flow rate (m^3/s)

ρ_d - Total pressure drop (N/m^2)

μ_d - Dough viscosity at the die

K_d - Die constant (fraction)

Die Constant: Die constant for a die of circular cross-section:

$K_d = \frac{\tau R4}{8L_D}$ ………………………Equation (10)

Where:

τ - Shear stress (N/m^2)

R - Nozzle radius (m)

L_D - Land length of die (m)

2.2.3 Bearing: A 207 pillow bearing according to ASAE standard [15] (H. S. Hall, 1980) was chosen. The operating characteristics of a rolling-element bearing depend greatly on its diameter and clearance. The internal diameter of the bearing is 35 mm while its external diameter is 80 mm.

From the design calculation, the shaft diameter was calculated to be 25.5 mm (bigger than the Bearing diameter). A 40 mm shaft was obtained from the market and used during fabrication. Part of the shaft was machined to fit the bearings diameter. The screw length and volumetric capacity was calculated to be 0.275 m and 0.020 m^3/s, respectively. The machine power requirement was calculated as 5.4 kW of which 5.5 kW (7.5Hp) was used for the construction of the machine. The choices of the size of the shaft and power requirement was to withstand the resistance of cassava and for stability of the machine. The die plate hole for the plates was drilled using the calculated land length of the die opening of 6 mm.

3.0 METHOD

Below is the AutoCAD representation of the Cassava Fufu/Yam pounding machine showing the sectional views Figure 5, while the product collection of the pallet (fufu) produced plate 1 at the discharge outlet of the complete machine as shown in Figure 6.

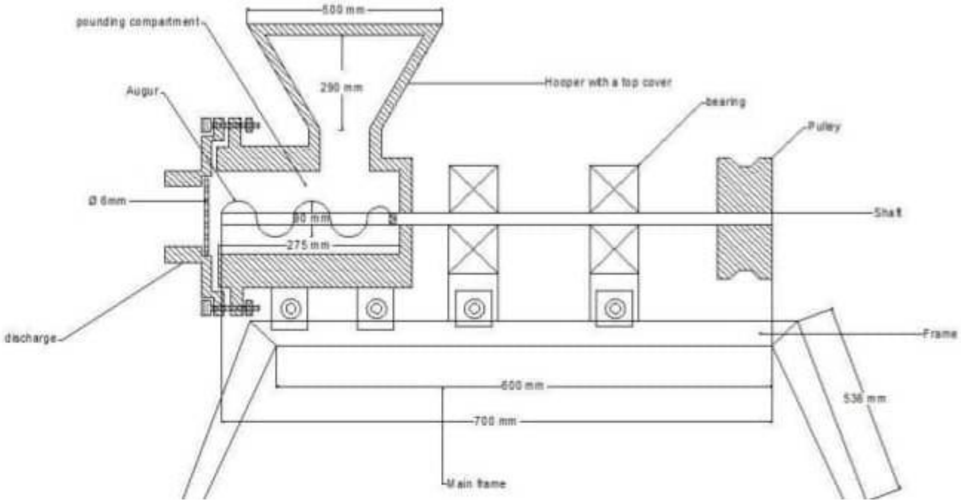

Figure 5

3.1 Construction Details

The machineries and machining processes used in the fabrication processes were as follows:

3.2 Drilling Machine: This machinery was used for most drilling jobs. The work was stationery while the spindle carrying the drill chuck and bit moves the work were held with a vice during drilling.

3.3 Milling Machine: This machine was used for the cutting of the keyway on the pounder shaft.

3.4 Lathe machine: This was used for an extensive array of precision works such as boring, turning and facing of the assembly parts.

3.5 Hand Grinding\Cutting Disc Machine: This was hand held that came in two sizes. The disc came in the sizes 9”, 7” and 4” diameters. The 7” disc was used for cutting and grinding.

3.6 Welding Machine: It was used in conjunction with electrode and tong for joining two or more metals together. It was used with both stainless and mild steel electrode when welding stainless and mild steel. Welding was tacking during setting and stitching, used to hold thin metals, 1mm metal sheets together firmly which was used for thick metal plates, 3mm. The stainless and mild steel electrode of gauge 10 (2.5mm diameter) was used. Welding glasses (dark) was used when working.

3.7 Bending Machine: It was used for bending sheet metals up to 5mm thick at different desired angles. It was used for bending the stainless and mild steel plates.

3.8 Table Shear: It was big and heavy, used for cutting plate less than the 3mm and 4mm sheet, and it gave a straight cut edge unlike the hand cutting disc.

3.9 Pedestal Grinding Machine: It was used for sharpening the tools, work piece drill bits.

Table 2: Bill of Engineering Measurement and Evaluation (B.E.M.E) Showing the Cost of Materials Used

S/N	Material	Cost (₦)
1	Mild steel	6700
2	Stainless steel	5300
3	Angle iron	7500
4	Metal sheet	4850
5	Electrode	4830
6	Belt	550
7	Galvanized steel	6300
8	Shaft	4500
9	Pounding compartment	5000
10	Metal gauze	1200
11	Pulley	1500
12	Bolts and Nuts	2450
13	Paint	1500
14	Body filler	2000
15	Bearing	6000
Material cost (MC)	**Total**	**60,180**

3.10 Costs Implications

3.11 Direct Labour Cost (DLC)

The DLC for production was assumed to be 30 percent of the material cost.

DLC = $\frac{30}{100}$ x 60,180 = ₦18, 054

3.12 Overhead Cost (OHC)

This cost includes cost incurred during production such as transportation, lubrication as well as other consumables. It was taken as 15 percent of the material cost,

OHC = $\frac{15}{100}$ x 60,180 = ₦9, 027

3.13 Total Production Cost (TPC)

TPC= MC + DLC + OHC =

= ₦60, 180 + ₦18, 054 + ₦9, 027 = **₦87, 261**

3.14 Principle of operation of the machine

After complete modification and construction, the machine was powered by a 5.5 hp prime mover. Boiled cassava tubers/yam tubers were introduced into the hopper, passed through the throat into the auger via the inlet gate of the pounding chamber. The auger broke the boil lumps into mash and conveyed it to the die and built up pressure for extrusion. Pressure resulting from rotating auger forced the mash through the perforations in the die, compressed and formed it into pellets. The pellets were allowed to break off by force of gravity.

Figure 6: Modified Cassava Fufu/Yam Pounding Machine

Plate 1

4.1 Performance Evaluation

After the assembly, the machine was first test-runned without loading it and thereafter loaded with boiled yam slices and then tested. The grinding operation was satisfactorily achieved. This was done by powering the prime mover that transmitted the turning force unto the cassava fufu/pounding machine by a 5.5 hp prime mover and finally to the auger through the pulley and tabulated results recorded are shown below

Table 3: Rate of Pounded Yam Discharge.

Quantity of Boiled Yam (Kg)	Time Taken Using the Modified Machine (Min/Sec) A	Time Taken Using Piston and Mortar (Min/Sec) B	Efficiencies (%) A	Efficiencies (%) B
10	7	40	70	40
8	6	45	75	56
6	4	30	67	50
2	2	15	100	30
Average Efficiency			**78**	**48**

4.0 RESULTS AND DISCUSSION

The cassava fufu/yam pounding machine is shown in Figure 6, while the pounded Fufu/yam product in pate 1

Based on the evaluation analysis, the result obtained an average efficiency of 78% greater compared to the traditional method of pounding using the piston and mortar with an efficiency of 48%.

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study proved the possibility of modifying the existing cassava fufu/pounding machine for pounding yam effectively using available materials. The following are therefore concluded

The machine has versatile advantages as to grind/pound cassava fufu and yam effectively and efficiently with relatively very little efforts.

5.2 Recommendations

Works could be needed on the material selection so that the boiled cassava fufu and yam product could be of contamination impurities free.

1. In the case that appropriate materials for components that are not readily available, for example stainless steel for the auger, coatings can be applied using various means like electrolysis so as to prevent the contamination of the product.
2. Use of dampers at the base and joints with frame to absorb and reduce vibrations and noise.

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