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Design, Fabrication and Testing of Yam Pounding Machine

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Abstract: *Pounded yam is a delicacy that commands respect and often ranked topmost in a typical Nigerian menu list. In a bid to reduce time and energy consumption associated with traditional mortar and pestle method of yam pounding, a yam pounder was designed and developed based on factor of safety, hygiene, cost and availability of materials in the market. The performance tests on the machine were replicated five times using cooked yam masses of 2, 2.5, 3, 3.5 and 4 kilograms respectively based on the following performance parameters; Pounding efficiency (E_p), Percentage lump of yam remaining after pounding (L_p) and the pounding Capacity (C_p) kg/hr. The findings of the tests showed that the yam pounder had average pounding efficiency of 98.04% whereas the maximum and minimum pounding capacity (output) were observed to be 120kg/hr and 96.0kg/hr at pounding time, T_p of 1 minute and 2.5 minutes respectively. The pounding output had linear relationship with the mass of well pounded yam, M_{wp},(kg) as the pounding capacity, C_p (kg/hr) decreases with proportional increase in the mass of well pounded yam M_{wp},(kg). The performance of the machine was satisfactory; households and restaurant operators will find more comfort in using it for pounding yam.*

Keywords: *Yam; pounded yam; pounding machine; cook**;** fabrication.*

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I. Introduction

Yam, a tropical crop in the genus *Dioscorea*, is one of the principal root and tuber crops of the tropics. It has as many as 600 species out of which six are economically important staple species. These staple species include: *Dioscorea rotundata* (white yam), *Dioscorea alata* (yellow yam), *Dioscorea bulbifera* (aerial yam), *Dioscorea esculant* (Chinese yam) and *Dioscorea dumetorum* (trifoliate yam). Out of these species, *Dioscorea rotundata* (white yam) and *Dioscorea alata* (water yam) are the most common species in Nigeria [1].

Yams are widely grown and consumed as subsistence staples in many parts of Africa, Latin America, the Pacific Islands and Asia [2, 3, 4]. According to the Food Information Network, 2008 the world production of yam was estimated at 28.1 million tonnes in 1993. Out of this production, 96% came from West Africa and the main producers being Nigeria with 71% of world production; Côte d'Ivoire 8.1%; Benin 4.3% and Ghana 3.5% [1]. In the humid tropical countries of West Africa, yams are one of the most highly regarded food products and are closely integrated into the social, cultural, economic and religious aspects of life. Traditional ceremonies still accompany yam production, indicating the high status given to the plant [5].

Pounded yam is a common meal in Nigeria; it is consumed domestically and mostly in many important occasions. It is a delicacy that commands respect and preference and often ranked topmost in a typical Nigerian menu list. Pounded yam is consumed with individual choice of soup such as ogbono, ewedu and spinach with egusi soup. Pounded Yam is thus an authentic African food and the presentation of it with ogbono or egusi soup to visitors in Igbo and Yoruba lands in Nigeria for example, is considered a great act of love and respect. Its medicinal use as a heart stimulant is attributed to its chemical composition, which consists of alkaloids of saponin and sapogenin [6].

However, despite the importance attached to pounded yam specifically, majority of Nigeria homes still depend on traditional mortar and pestle method of pounding yam in which hygiene is not guaranteed and pounding efficiency are very low [7]. Most times, the huge stress, time and energy consumption associated with this method of pounding discourage majority of the people from preparing pounded yam but rather, choose to consume it either cooked as yam slices and porridge, roasted as lumps, fried as chips and yam cake or cooked or even go for alternative methods of processing yam before consumption [8].

Few years ago, development of yam pounding machines have been in progress in Nigeria. Some of the existing designed yam pounders failed due to some limitations in their operational functions. The major and common challenges facing the existing pounding machines as reported by many researchers among them are [9, 2, 10, 11, 1, 12] generally centred on the following observations that the pounding efficiency of the machines have been very low. Furthermore, some of the developed pounding machines were observed to operate with electric motor.

The machines had no adjustable electric motor base for proper tensioning and some were not adequately ventilated resulting to overheating of the electric motor.

Presently the developed pounding machines operate with electric motor that uses only electric current. This power supply is not suitable in Nigeria and as such people do not find it easily to use it when needed for pounding yam. Worst still, 96% of the rural area in Nigeria where yam cultivation is carried out does not have electricity.

In a bid to overcome the identified twin problems of yam pounding machines and electric power supply in Nigeria, a cost effective yam pounder that uses petrol (I.C) engine and gas cooker for dual purposes of cooking and pounding yam respectively becomes necessary. The general objectives of this project are to design, fabricate and test yam pounding machine that uses petrol engine and gas cooker as power sources.

II. Materials And Methods

2.1 Choice of Materials

The factor of safety was considered during the selection of materials for machine fabrication. This was done with respect to cost implication and the availability of raw material that were locally sourced from the market. However, the materials used in the fabrication of the yam pounding machine were also chosen based on the following considerations:

(i) To prevent the pounded yam from contamination, a stainless steel pot was used.

(ii) The rotating blade is made up of stainless steel materials to make it easier for cleaning and free from corrosion.

(iii) The blade was not permanently fitted to the rotating vertical power transmission gear, so that they can be easily detached for cleaning after pounding.

(iv) The stainless steel pot was also made detachable for easy cleaning after pounding.

(v) The stainless steel pot for pounding was positioned on a well stable seat to minimize vibration, whenever the machine is used for pounding.

(vi) The yam pounding machine has gear lever for engaging and disengaging during operation.

(vii) The machine has also tyres at both stands for durability.

(viii) The petrol engine was used to power the machine due to unsteady power supply in Nigeria.

(ix) The machine was painted to prevent rusting.

2.2 Design calculations

i. Belt and pulley drive mechanism

The pounding machine requires two pulleys for operation: one pulley will be attached to the petrol engine (driver) and the second pulley will be attached to the shaft (driven) carrying the yam pounding compartment and beaters. The intended ratio of the speed driven pulley to that of the driver is 2:3. The relationship below is used to determine the transmitted speed:

$$N_1D_1 = N_2D_2 \qquad (1)$$

Where N_1 = rpm of the petrol engine = 1400 rpm

D_1 = Diameter of petrol engine (driver) pulley = 50 mm

N_2 = rpm of the driven pulley

D_2 = Diameter of driven pulley = 76 mm

$$N_2 = \frac{N_1 D_1}{D_2} \qquad (2)$$

$$N_2 = \frac{1400 \ x\ 50}{76} = 921 \ rpm$$

ii. Power requirement to drive the machine

Recall that:

$$P = (T_1 - T_2)\ V \qquad (3)$$

Where P = Power required to drive the machine kw

T_1 = Tension in the tight side of the belt, N

T_2 = Tension in the slack side of the belt, N

V = Velocity of the belt, m/s

Since the power of the petrol engine is 6 hp and 1hp = 0.746 kw.

Therefore 6hp = 6 x 0.746 = 4.476kw = P

$$V = \frac{\pi D_1 N_1}{60} \qquad (4)$$

$$V = \frac{\pi \, x \, 0.05 \, x \, 1400}{60} = 3.665 \; m/s$$

Substituting in the initial equation (3), we get

$$T_1 - T_2 = 1219.65 \; N \qquad (5)$$

iii. Pulley Centre Distance

According to a useful rule given by [13], when the diameter of smaller pulley is less than one-third that of the larger pulley, the distance between the centres of the two pulleys must not be less than the difference of the two pulley diameters. In this case:

$D_1 - D_2 = 0$ (6)

Where C = pulley centre distance

D_1= diameter of petrol engine pulley = 50 mm

D_2 = diameter of rotor pulley = 76 mm

Centre to centre distance of the machine and motor pulleys = 270 mm was selected

iv. Length of Belt Required for Power Transmission.

According to [14];

$$l_b = \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} + 2c \qquad (7)$$

Where L_b = Length of the belt, mm

D_1 = Diameter of the petrol engine pulley = 50 mm

D_2 = Diameter of the driven pulley = 76 mm

C = Centre to centre distance of the machine and motor pulleys = 270 mm

$$l_b = \frac{\pi}{2}(50 + 76) + \frac{(76 - 50)^2}{4x270} + 2x\,270 = 739mm$$

v. Angle of contact between pulleys and the belt.

The contact angle α_1 and α_2 for small and large pulley respectively may be calculated as follows:

For the driver,

$$\alpha_1 = 180 + 2\theta \qquad (8)$$

Where α_1 = Angle of contact for small pulley

θ = Angle of wrap

But $\theta = sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) = 180 + 2\left(sin^{-1}\left(\frac{D_2 + D_1}{2C}\right)\right)$ (9)

Therefore $\theta = sin^{-1}\left(\frac{76-50}{2 \, x \, 270}\right) = 2.77^0$

Then substituting the value of θ in equation (8)

$\alpha_1 = 180 + 2 \text{ x } 2.77 = 185.52^0 = 1.03$ rad

For the driven

$$\alpha_2 = 180 - 2\theta \qquad 10$$

Where α_2 = Angle of contact for small pulley

θ = Angle of wrap

$\alpha_2 = 180 - 2 \text{ x } 2.77 = 174.48^0 = 0.97$rad

vi. Volume of pounding pot with beaters (V_{pb})

$$V_{pb} = \frac{2\pi dh}{4} \qquad (11)$$

Where H= Height of pounding pot, mm

d = diameter of the pounding pot, mm

$$V_{pb} = \frac{2\pi \, x 250 \, x \, 140}{4} = 54.978 \; m^3$$

vii. Volume of the beaters (V_b)

$$V_b = 2\left(\frac{\pi \, x \, 10^2 x40}{4}\right) = 6.28 \text{ m}^3$$

Actual volume of pounding pot, V_{ap}

$$V_{ap} = V_{pb} - V_B = 54.98 - 6.28 = 48.70m^3$$

viii. Belt tension

The tension on the belt was determined using the following relation [15]:

$$2.3log\frac{T_1}{T_2} = \mu\theta \quad (12)$$

Where T= Tension on the belt, N

T_1 = Tension on the tight sight, N

T_2 = Tension on the slack side, N

θ = Angle of wrap

From equation (9) we know that

$$\theta = sin^{-1}\left(\frac{38-25}{270}\right) = 2.77^0$$

When two pulleys of different diameters are connected by an uncrossed belt, the angle of contact of the small pulley should be considered for determining tensions T_1 and T_2 of the tight and slack sides of the belt respectively [15]. Also for rubberized v-belts, μ =0.30; therefore,

$$2.3log\frac{T_1}{T_2} = \mu\theta = 0.30 \, x \, 2.77 = 0.83$$

$$\frac{T_1}{T_2} = 2.28,$$

$$T_1 = 2.28T_2 \quad (13)$$

Substituting the value of T_1 in equation (5), we get

$$2.28T_2 - T_2 = 1219.65 \quad (14)$$

$$T_2 = 952.85 \, N$$

$$T_1 = 2172.50 \, N$$

ix. Centrifugal tension in the belt

The tension on both sides of the belt could be obtained from the following expressions:

$$\frac{T_1 - T_C}{T_2 - T_C} = e^{\mu\theta} \quad (15)$$

Where Tc = Centrifugal tension which tends to cause the belt to leave the pulley and reduces the power that may be transmitted.

Also Tc is given by:

$$T_c = MV^2 \quad (16)$$

Where M = Mass of the belt, kg/m^3

V= Velocity of the belt, m/s

According to [15], the rubberized class B type of v-belt material that was selected has the following specifications density, σ_{belt} = 1000kg/m^3; shear stress maximum, σ_{max} 2Mpa, and belt dimensions, b = 25 mm and t = 15 mm. The belts' pitch length l = 2075.1 mm. therefore the mass of the belt,

M = b x t x l x σ_{belt} = 0.78kg

However, the maximum tension, T of a belt = σ x b x t = 2 x 106 x 0.025 x 0.015 = 750N

For greater power transmission, the belt speed,

$$V_{max} = \sqrt{\frac{T}{3M}} \quad (17)$$

$$V_{max} = \sqrt{\frac{750}{3 \, x \, 0.78}} = 18 \text{ m/s}$$

Substituting the value of V_{max} in equation (16), it becomes

$$T_c = MV^2 = 0.78 \, x \, 18^2 = 252.72 \, N$$

x. Torque found in the driven pulley

$T = (T_1 - T_2)\,R$ (18)

Where T = Torque supplied to the driven pulley, Nm

T_1 = Tension in the tight side of the pulley = 2172.50 N

T_2 = Tension in the slack side of the pulley = 952.85 N

R = Radius of the driven pulley = 38 mm

$$T = (2172.50 - 952.85)x\ 38 = 46.35\ Nm$$

xi. Equivalent twisting moment

$$Te = \sqrt{(M_b)^2 + T^2} \qquad (19)$$

Where Te = Equivalent twisting moment, Nm

M_b = maximum bending moment on both vertical and horizontal loading = 24.36 Nm

T = Torque supplied to the driven pulley = 46.35 Nm

$$Te = \sqrt{24.36^2 + 46.35^2} = 52.36\ Nm$$

xii. Diameter of the shaft

$$d_s = \sqrt[3]{\frac{16Te}{f_s\pi}} \qquad (20)$$

Where d_s = Diameter of the shaft, mm

Te = Equivalent twisting moment = 52.36 Nm

f_s = Allowable shear stress of shaft = 55 Mpa for mild-steel chosen

$$d_s = \sqrt[3]{\frac{16\ x\ 52.36}{55\ x\ 10^6\ x\ \pi}} = 16.92\ \text{mm}$$

To allow for variation in twisting moment and the effect of other straining actions, the calculated diameter of line shafting is often multiplied by a factor of 4 for reliability [15].

$$d_s = 17\ \text{x}\ 4 = 68\ \text{mm}$$

xiii. Second polar moment of the area of the shaft

The second polar movement of the area of the shaft is given by

$$\text{J} = \frac{\pi d_s^4}{32} \qquad (21)$$

J = second polar movement of the area of the shaft, mm^4

Ds = diameter of the shaft = 68 mm

$$\text{J} = \frac{\pi d_s^4}{32} = \frac{\pi\,\text{x}\,68^4}{32} = 2.099\,\text{x}\,10^6\text{mm}^4$$

xiv. Torsional shear stress on the shaft

Torsional shear stress on the shaft is given by

$$S_s = \frac{T}{\pi d_s^3} \qquad (22)$$

$$S_s = \frac{46.35}{\pi\ \text{x}\ 64^3} = 46.92\ \text{N/mm}^2$$

Where S_s = Torsional shear stress, N/m^2

T = Torsional moment, Nm

ds = Diameter of the driven shaft = 68 mm

$$S_s = \frac{46.35}{\pi\ \text{x}\ 64^3} = 46.92\ \text{N/mm}^2$$

xv. Torsional rigidity

The amount of twist permissible is given by

$$\theta = \frac{2TL}{Gd_s} \qquad (23)$$

Where L = Length of shaft = 99 mm
θ = Angle of twist in radians = 2.77^0
T = Torsional moment on shaft = 46.35 Nm
G = Modulus of rigidity, N/mm^2
ds = Shaft diameter = 68 mm

Now $G = \frac{2TL}{\theta d_s}$ (24)

$$G = \frac{2 x 46.35 x 99}{2.77 x 68} = 48.72 x 10^3 \frac{\partial y}{\partial x} N/_{mm^2}$$

xvi. Total load on the shaft (maximum load to be supported by the shaft)

$T_L = T_1 + T_2$ (25)

$T_L = 2172.50 + 952.85 = 3125.35\ N$

xvii. Strain energy in the shaft

The strain in the shaft due to torsion is
$E_s = ½\ T\theta$ (26)
Where E_s = Strain energy in joules
T = Torsion on the shaft,= 46.35 Nm
θ = Radian deformation (angle of twist)

$E_s = ½ \times 46.35 \times 2.77 = 64.19\ J$

xviii. Angular speed of the driven shaft

$W_2 = \frac{2\pi N_2}{60}$ (27)

Where W_2 = Angular speed of the driven shaft, rad/s
N_2 = rpm of the driven pulley

$W_2 = \frac{2\pi x 921}{60} = 0.54 rad/s$

xix. Velocity of the belt

The relationship is given by

$V = \frac{\pi D_1 N_1}{60}$ (28)

Where V = Velocity of the belt, m/s
D_1 = Diameter of the driver pulley, mm = 50mm
N_1 = rpm of the petrol engine = 1400 rpm.

$$V = \frac{\pi x 50 x 1400}{60} = 3.665\ m/s$$

2.3 Functions of the Components parts of the Machine

The machine was fabricated according to standard designed specification of each component used in the machine as presented in Figure1. The reasons for selecting a particular material for each component are also shown in Table 1 while machine component parts are explained below. Furthermore, the fabrication process and developed yam pounding machine are also shown in plates 1 and 2.

1. **Frame:** The frame is a piece of angle iron welded together to carry the entire sifter. It was fabricated to carry the entire weight of the machine. The frame of the machine is made up of angle bar and hollow rectangular bar made from mild-steel. The frame holds the two compartments together and at the same time housed the petrol engine that generates the required power for operating the yam pounder.
2. **Engine Frame**: The engine frame is a seating created for the internal combustion engine and machine component meant to resist excessive vibration.
3. **Pulley:** This houses the belt in the V – groove created and transmits power from the driving pulley to the driven pulley.

4. **Pounding Bowl/Stainless Pot:** This unit pounds the cooked pieces of yam through the rotation of the impellers.
5. **The Rotating Shaft:** The rotating shaft transmits power from the internal combustion engine to the impeller through the knuckle joints.
6. **Gas burner:** This is a machine component attached to the frame of the machine. It is used for cooking the yam with a stainless pot.
7. **Petrol Engine:** This is the prime mover of the entire pounding impellers.
8. **Gear lever:** This is used for engaging and disengaging the machine. It also performs the speed reduction function; so that the engine will not need to be switched off before loading or unloading the pounding unit.
9. **Yam Boiling Compartment:** The aim of adding yam boiler to this machine is to maximize the available cooking space, power source and to prevent the use of firewood or separate kerosene stove for cooking the yam. The yam cooking section is made up of electric coil and a stainless boiler-pot that was placed directly on the coil. The heat transfer method is by conduction.
10. **Yam Pounding Compartment:** The pounding compartment is made up of a pounding beater in a stainless pot with cover. The petrol engine transmits power from the internal combustion engine to the pounding compartment through the V-belt.

Table 1: Specifications of the component parts of the yam pounder

S/N	Machine component	Specifications	Reasons for material selected
1.	Frame	1146mm x 366mm x 317 mm mild-steel Angle Iron	It is cheap and readily available. Good tensile properties. Suitable to avoid buckling.
2.	Engine Frame	197mm x 366mm mild-steel	It is cheap and readily available, suitable to avoid buckling.
3.	Pulley	φ20mm, φ24mm and φ20mm mild-steel for petrol engine, rotor and gear handle respectively	Possess reliable strength and also easy to be fixed into the shaft.
4.	Pounding Bowl/Stainless Pot	φ250mm x 140mm stainless steel	To avoid contamination of the pounded yam.
5.	Rotating Shaft	φ68mm x 150mm mild-steel shaft	High strength and rigidity, suitable to avoid buckling.
6.	Electric hot plate		Cheaper and good conductor of electricity.
7.	Bearing	φ20mm pillow block Bearing	Possess high strength and rigidity.
8.	Gear lever	φ16mmx180mm mild-steel round pipe	High strength and rigidity, suitable to avoid buckling, readily available.
9.	Petrol engine	6 Hp, 1400 rpm	Most suitable, readily available, durable and cheaper.
10.	Yam cooking and Pounding Compartment	850mm x 383mm mild-steel	Easy to cut and weld, suitable to avoid buckling.

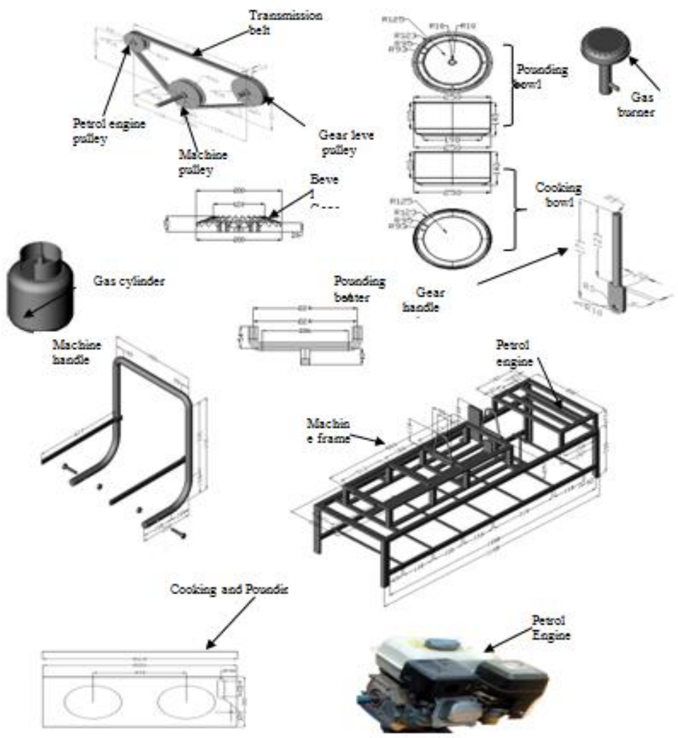
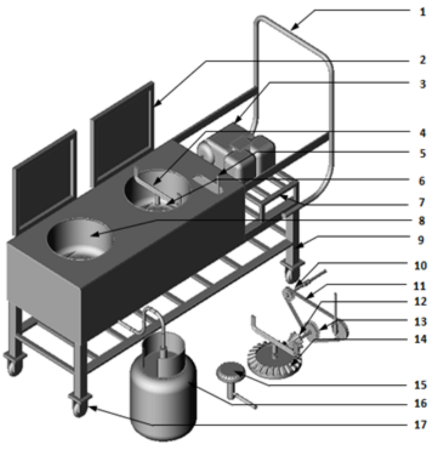


Figure 1 Component Parts of Yam Pounder

Plate 1. Fabrication process of yam pounding machine

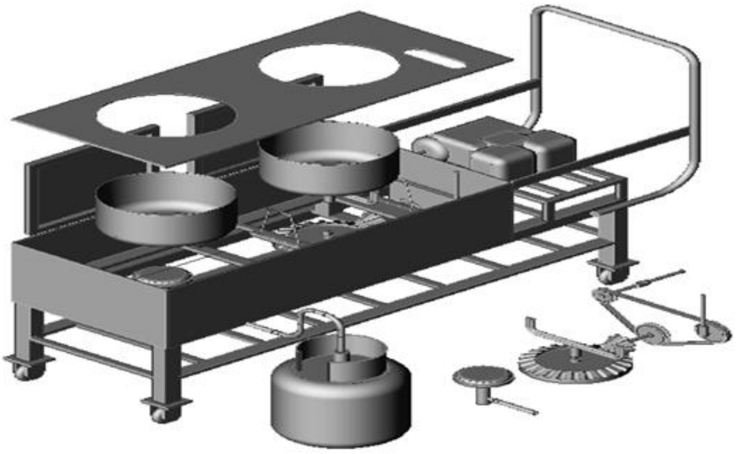
Plate 2a. Developed Yam Pounding Machine with Cooking and Pounding Chambers Open

The isometric and exploded views of the pounding machine are shown in Figures 2 and 3 below.



S/N	DESCRIPTION	QTY	MAT	REM
1	MACHINE HANDLE	1	M.S	FAB
2	COVER	2	M.S	FAB
3	ELECTRIC MOTOR	1	M.S	PUR
4	POUNDING BLADE	1	M.S	FAB
5	GEAR HANDLE	1	M.S	FAB
6	POUNDING CHAMBER	1	M.S	FAB
7	ELECTRIC MOTOR SUPPORT	1	M.S	FAB
8	COOKING CHAMBER	1	M.S	FAB
9	FRAME	1	M.S	FAB
10	BEARING	5	M.S	PUR
11	BELT	1	RUB	PUR
12	BEVEL GEAR	1	M.S	PUR
13	PULLEY	3	M.S	PUR
14	SPUR GEAR	1	M.S	PUR
15	GAS BURNER HEAD	1	M.S	PUR
16	GAS CYLINDER	1	M.S	PUR
17	ROLLER	4	RUB	PUR
18	BOLT & NUT	20	M.S	PUR

Figure 2. Isometric view of the Yam Pounding Machine



Figures 3: Exploded view of the Yam Pounding Machine

2.4 Principle of Operation of yam pounding Machine

The operation of the machine follows a process of peeling, washing and slicing into small sizes of 5 mm length and 2mm thickness before feeding inside the cooking pot of the machine. Then plugging the electric hot plate under the cooking pot to an electric current switched on to cook the yam. The yam pieces is cooked for 20-30 minutes after which they are transferred into the stainless pounding pot after further slicing the cooked yam tubers into smaller pieces of 2.5 mm retaining same 2mm thickness. Then ¼ litre of water is added to the sliced cooked yam tubers with the pot tightly covered with the petrol engine switched on. With the aid of the gear lever to engage and disengage the engine, the cooked yam pieces will be pounded by the rotational action of horizontal gear transmitting power to vertical gear that rotates the two beaters fixed on the top of vertical gear and inside the stainless pounding bowl.

3. Machine Performance Test

Free Run Test of the Yam Pounding Machine after Fabrication

In order to test the machine for efficient running speed, the size of pulley on the petrol engine (driver) was varied. The effect of varying speed on the machine performance is presented in Table 2. With same pulley sizes of 75 mm diameter on both ends, it was observed that the entire machine frame vibrated with excessive noise. As the pulley size on the petrol engine was reduced from 75 mm to 65 mm, the rotor speed reduced from 1400 to 997 rpm; there was reduced vibration on the entire frame of the machine and no excessive noise noticed. As the diameter of pulley on petrol engine was further reduced to 60 mm, there was a corresponding reduction in the rotor speed to 904 rpm.

However, the efficient machine speed was observed when the petrol engine pulley diameter size was reduced to 50 mm. This gave a corresponding rotor speed of 700 rpm. At this moment, the machine ran smoothly and there was no vibration. Further reduction in petrol engine pulley diameter to 45 mm resulted to very sharp reduction on the speed of the machine to 557 rpm which may probably not be able to pound cooked yam well. Therefore, the recommended efficient running speed of the machine was 700 rpm with a petrol engine pulley diameter of 50 mm.

Table 2. Effect of Varying Speeds on the Machine Performance

Diameter of pulley on petrol engine, d_1 (mm)	Diameter of pulley on rotor shaft, d_2 (mm)	petrol engine speed, n rpm	rotor speed, N rpm
75	75	1400	1400
65	75	1400	997
60	75	1400	904
50	75	1400	700
45	75	1400	557

Testing of the Machine with cooked pieces of yam

The yam tubers were peeled, sliced into small sizes of 5 mm length and 2mm thickness, washed and weighed. The sliced yam pieces were neatly arranged into the stainless pot with ½ litre of water added into it. The yam pieces were cooked for 20-30 minutes and then transferred into the stainless pounding pot after further slicing them into smaller pieces of 2.5 mm retaining same 2mm thickness. Also, ¼ litre of water was added to the cooked yam with the pot cover tightly. The petrol engine was put on and the gear lever engaged till the pounding of the yam was completed, after which the gear was disengaged. The time taken was recorded with the help of stop watch. The performance tests on the machine were replicated five times using cooked yam masses of 2, 2.5, 3, 3.5 and 4 kilograms and the results were recorded as shown in Table 2.

The performance test of the machine was evaluated using the following parameters: the Pounding efficiency (Ep), Percentage lump of yam remaining after pounding (Lp) and the pounding Capacity (C_p) kg/hr. Mathematical expressions were derived for estimating the performance of the yam pounder as stated in equations 29, 30, 31 and 32 below:

(i) Yam pounding efficiency(E_p):

$$E_p = \frac{M_{wp}}{M_{wp}+M_L} \times 100 \qquad (29)$$

(ii) Percentage of Lump (Lp):

$$L_p = \frac{M_L}{M_{wp}+M_L} \times 100 \qquad (30)$$

(iii) Machine pounding Capacity (C_p):

$$C_p = \frac{M_{wp}}{T_p}\left(\frac{kg}{hr}\right) \qquad (31)$$

Where M_C = Mass of cooked yam fed into the pounder, (kg)
M_L = Mass of lumps of yam remaining after pounding, (kg)
T_P = Total time taken for pounding operation (hr).
M_{wp} = Mass of pounded yam without lump, (kg) and also $M_{wp} = M_C - M_L$, (kg) (32)

III. Results and Discussion

The results of the test analysis carried on the pounding machine are presented in Table.3.

Yam pounding efficiency (E_p)

From Table 3, the optimum pounding efficiency of the machine was observed to be 98.80% at the feed rate of 2.5 kg of cooked yam and pounding time of 1.7 minutes respectively. The pounding efficiency of the machine ranges from 97.66% to 98.80% with mean value of 98.04%. [12] reported threshing efficiency of 93% at feed rate of 1.8kg/min using electric motor as power for the pounding machine These higher value of 98.80% can be attributed to high horse power of the prime mover driving the beaters in the pounding chamber. The same Table also shows the effects of time of pounding on pounding efficiency at different feed rates. The time for pounding ranges from 1.0minute, 1.7minutes, 2.0minutes, 2..3minutes and 2.5 minutes for pounding cooked yam masses of 2.0kg, 2.5kg, 3.0kg, 3.5kg and 4.0kg respectively. This shows that the time taken to pound the yam increases with increase in mass of cooked yam pounded.

Table 3. Results of Testing the Yam Pounder with Different Quantities of Yam Masses

S/N	M_c (kg)	M_{wp} (kg)	M_L (kg)	Cooking Time T_c (min)	Pounding Time T_p (min)	E_p (%)	L_p (%)	C_p (kg/hr)
1	2.0	1.96	0.04	25.0	1.0	98.06	0.94	120.0
2	2.5	2.47	0.03	35.0	1.7	98.80	1.20.	88.2
3	3.0	2.94	0.06	36.0	2.0	97.95	2.05	90.0
4	3.5	3.42	0.08	39.0	2.3	97.71	2.29	105.0
5	4.0	3.91	0.09	40.0	2.5	97.66	2.34	96.0
Average	3.0	2.94	0.06	35.0	1.9	98.04	1.77	99.84

Percentage of Lump (Lp):

The results of the percentage lump of yam remaining after pounding at various feed rate are shown in Table 3. A highest percentage lump of yam remaining after pounding was 0.09% which occurred at a pounding time of 2.5 minutes. The highest feed rate of 4 kg of cooked yam and machine capacity of 99.84 kg/hr were also obtained at 0.09% lump loss of yam. The lowest percentage lump of 0.03% was obtained at feed rate of 2.5 kg of cooked yam which occurred at the lowest machine capacity of 88kg/hr. This shows that the feed rate (cooked yam), machine capacity and pounding time had linear relationship with percentage lump of yam remaining after pounding.

Pounding Capacity (C_p)

Table 3 shows the result of pounding capacity of the machine in relation to masses of well pounded yam at any given pounding time. The pounding capacity of the machine ranged from 96.0kg/hr to 120 kg/hr at the pounding time of 2.5 and 1 min(s) for cooked yam mass of 4kg and 2 kg. From the result obtained in Table 3, the average pounding capacity was 99.84 kg/hr at average pounding time of 1.9 minutes which shows that the capacity of the machine can only serve a small home of three to four member families at a particular period of

time. The pounding output of the machine had linear relationship with the mass of well pounded yam, M_{wp},(kg) as the pounding capacity, C_p (kg/hr) decreases with proportional increase in the mass of well pounded yam M_{wp},(kg). Also, the pounding capacity decreases with increase in yam pounding time, T_p (hr).
The pounding time and mass of pounded yam without lump mash followed increasing trend; as the mass of cooked yam for pounding increases, so also the pounding time T_p (mins) increased.

IV. Conclusion

The developed yam pounding machine is economical and efficient for pounding cooked yam. The maximum pounding efficiency at the best combination was 98.80% at throughput capacity of 88.20 kg/hr. The maximum Percentage of Lump remaining (Lp) and time taken for pounding were 2.34% and 2.5 minutes respectively. The developed machine, apart from minimizing the drudgery associated with traditional mortar and pestle method of pounding yam is useful for dual purposes of cooking and pounding yam at the same time. The performance of the machine was satisfactory; households and restaurant operators will find more comfort in using it for pounding yam.

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