Journal of Agricultural Science and Food Technology
Vol. 5 (5), pp. 102-108, July, 2019
ISSN: 2465-7522
Full Length Research Paper
http://pearlresearchjournals.org/journals/jasft/index.html

Development and Performance Evaluation of a Mini Yam Boiling and Pounding Machine

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Accepted 2 July 2019

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ABSTRACT

Yam is the class of roots and tubers that provides about 200 calories of energy daily. The traditional pounding process is very tedious, laborious and unhygienic. The need for a machine that will combine boiling and pounding of yam to the desired quality with less human effort and time becomes expedient. A mini yam boiling and pounding machine was therefore developed using locally sourced materials for both domestic and commercial purposes. The major components of the machine are pounding chamber, frame, electric motor, shaft with crushing mechanism, heating element, and electrical compartment. Power input, angular speed, torque, power output, machine efficiency, heat transfer, shaft diameter and machine capacity were designed to be 1.54 kW, 146.00 rads^{-1}, 7.88 Nm, 1.15 kW, 74.68%, 2.53 kW, 30 82 mm and 4.36 kgh^{-1}, respectively. Four samples (A, B, C, and D) of pounded yam were presented for sensory evaluation and sample B was preferred using Hedonic scale. The results of the proximate composition of boiled and pounded yam were not significantly different at 5% level of probability. The machine is economically viable and profit-oriented.

Key words: Analysis, design, machine, pounded yam, process and viability.

INTRODUCTION

Yam is the common name for the specie in the genus Dioscorea (family Dioscoreaceae). Sweet potato (*Ipomeabatatas*) has traditionally been referred to as yam in parts of the United States and Canada, but it is not part of the *Dioscoreaceae* family (Mignouna et al., 2003). Yam is one of the oldest known recipes to man. It is a tuber crop, which belongs to the class of carbohydrate and has been a part of the African meal for centuries (Adebayo et al., 2014). The world production of yam was estimated at 28.1 million tons in 1993. Out of this production, 96% came from West Africa, the main producers being Nigeria with 71% of World production; Coted'Ivoire 8.1%; Benin 4.3% and Ghana 3.5% (Ogiemudia et al., 2016). 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 (Odior and Orsarh, 2008). The plant is characterized by a great degree of natural genetic diversity adapted to a wide range of production conditions (Mignouna et al., 2003). The need for the replacement of human energy with machine has been one of the driving forces behind technological development right from the onset. The development of yam pounding machine is one of such ways of replacing human efforts in yam pounding process (FIIRO, 2005). Yam is one of the major staple foods in Nigeria and it is consumed in so many forms; it can be boiled, fried, roasted and eaten as porridge. The various ethnic groups in Nigeria have their unique method of processing yam. Yoruba tribe prefers it dried, milled and then made into a slightly solid paste (Kay, 1987).

There are over 100 ethnic groups and languages in Nigeria, and each has different language names for Yam, "Isu" is the Yoruba translation or "Iyan" when it is been prepared to be consumed as a main source for dinner. The yam is a versatile vegetable which has various derivative products after process, it can be barbecued; roasted; fried; grilled; boiled; smoked; pounded and when grated, it is processed into a dessert recipe (Brand-Miller et al., 2003). Yam is a staple crop of the Igbo people of Nigeria, in their language, it is known as "Iji". Yam is commemorated by having Iri-ji or Iwa-ji festival in southern Nigeria and new yam festival in the Southwestern part of the country. Yam products generally have a lower glycemic index than potato products, which means it will provide more sustainable energy, and gives better protection against obesity and diabetes (Ajibola et al., 1988). Apart from being rich in fibre protecting and bowels against diseases like diverticulitis, it is a source of vitamin C, vitamin B6, Magnesium and phosphorus (FIN, 2018). Walsh (2003) reported that a meal of pounded yam with vegetable soup provides a very rich and balanced diet. The act of pounding yam has been in existence for a very long time, though, it is very tedious due to the energy required to produce the ductility and texture uniformity needed. Pounding of yam with a pestle in a mortar is a special way of producing pounded yam with intermittent addition of water makes the yam softer and finer and increases the surface area upon which digestive enzymes will act, thus bringing about more rapid absorption of glucose (Nweke et al., 2013). The main objective of this study, therefore, is to develop and evaluate a reliable and efficient electric mini yam boiling and pounding machine that will be easy to operate and maintain. The machine is designed to perform the task of converting raw yam into boiled and pounded yam. The possibility of food contamination by sweating while pounding will equally be controlled.

MATERIALS AND METHODS

Material Selection

Consideration for material selection was based on Properties of the material, Availability, Cost, Machinability and Quality (Ogunmoyela et al., 2016). The pulley is made from cast iron. The shaft and the yam beaters are made from stainless steel. The pounding chamber is equally made of stainless steel material. These are the component parts of the machine that directly involved in the processing of the food and the selection is such as to prevent food contamination. The base and the frame are made from mild steel. The electric motor is a flange type with single phase. The yam used for this experiment *Dioscorea rotundata* was purchased in a popular Sango market.

Machine Description and Working Principles

The components include the pounding chamber (pot), the base, frame, electric motor, shaft with crushing mechanism, heating element and electrical compartment. The frame forms the housing of the whole components, including the electric motor. It is fabricated in such a way to withstand all the forces and vibration generated by the machine during the pounding operation. The fresh yam was sliced, peeled and fed into the machine manually. The shaft is designed to transmit power to the yam beaters in the chamber to perform yam pounding operation**.** The primary function of the pulley is to reduce the original speed of the electric motor to the required speed. The yam beaters are two blades and they are the main components that do the real pounding process. These two bars are designed and joined together at angle 90° to each other at the center and they rotate together through angle 360° while pounding the cooked slices of yam. The electric motor is a low-speed flange type (1 Hp, 1400 rpm) with a single phase. A 13 Amps plug is connected to the heating element at the base of the pounding chamber through 1mm cable wire to supply current from the source. This is controlled by on and off switch button. This, in turn, causes the boiling of the yam. After boiling is achieved, the pounding begins by crushing mechanism. As soon as the motor is switched on, electrical energy is converted to mechanical energy in the shaft causing the blade to crush the yam. A valve taps for draining excess water is incorporated to the pot. This rotational motion turns the yam in its solid state to semisolid, which finally becomes the pounded yam. The pounding chamber is designed in such a way that the top cover can be detached so as to carry out thorough washing after use as part of maintenance culture. The isometric view and the component parts of the machine using auto card drawing are shown in Figure 1 and Figure 2, respectively.

Design Analysis and Calculation

Determination of Machine Efficiency

One of the most important laws of physics is the fundamental Ohm's Law. It states that current through the conductor is directly proportional to the applied voltage and is expressed as:

$$\boldsymbol{I} = \frac{\boldsymbol{V}}{\boldsymbol{R}} \quad (1)$$

Where I is the current (A), V is the applied voltage (V), and R is the resistance (Ω).
The resistance of the motor can be calculated by measuring the consumed current and applied voltage. It is basically the resistance of the coil and this can be controlled by the applied voltage. The required electrical power of the motor is defined as:

$$P_{in} = IV \quad (2)$$

Where P_{in} is the power input (W). Since the speed of the machine is 1400 rpm, voltage is 220 Volts, and the current is 0.007 mA (7A). P_{in} = 1.54 kW. The angular speed of the motor could be calculated as:

$$\omega = \frac{rpm2\pi}{60} \quad (3)$$

Where ω is the angular speed (rad/s), rpm is the rotational speed in revolutions per minute. ω = 146.00

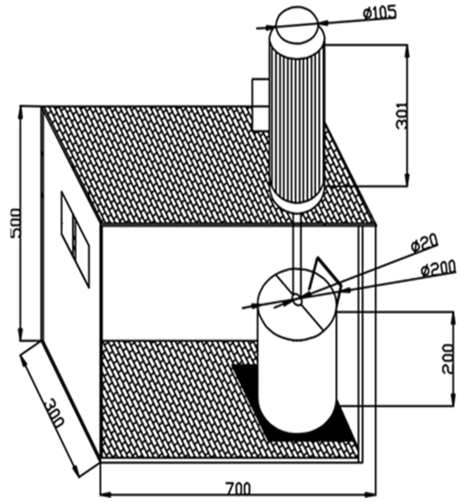
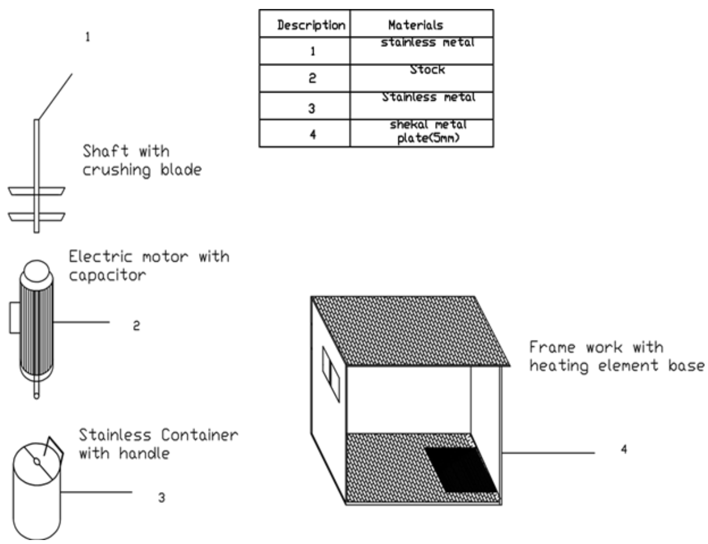


Figure 1. Isometric view of yam boiling and pounding machine (all dimensions are in mm).



Description	Materials
1	stainless metal
2	Stock
3	Stainless metal
4	shekal metal plate(5mm)

Figure 2. Component parts of the yam boiling and pounding machine.

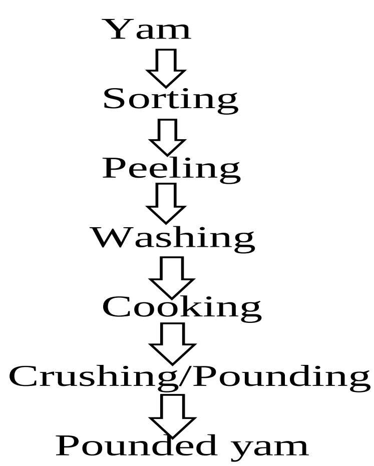


Figure 3. Flow chart for the production of pounded yam.

(rad/s). Torque (τ) can be calculated as reported by Deutschman and Aron, (1985) as:

$$\tau = \frac{IVEX\,60}{rpm2\pi} \quad 4$$

= 7.88 Nm. Mechanical power output can be calculated as:

$$P_{out} = \tau\omega \quad 5$$

Where P_{out} is the power output (W). P_{out} = 1.15 kW. To determine the efficiency of the machine in converting electrical energy to mechanical energy:

$$MachineEfficiency(\%) = \frac{P_{out}}{P_{in}} X100 \quad 6$$

= 74. 68%. The basis of determining machine efficiency in terms of energy transfer is simply because the machine serves a dual purpose; boiling and pounding. Part of the water used in boiling the yam was converted to steam and escaped to the atmosphere by radiation; part was used in pounding while the excess water was drained away through a valve tap. Obviously, the losses cannot be quantified.

Heat Transfer During Boiling

Internal energy (U) during boiling = (1.54 – 1.15) kW. = 0.39 kW.
Work done by the system, W = fl

$$= wgl \quad 7$$

$$W = 1.09X9.81X0.2$$

Since the optimum weight (w) of the pounding yam is 1.09 kg and the length (l) of the pounding chamber is 200 mm, therefore. = 2.14kW. Using the first law of thermodynamics.

$$dQ = dU + dW \quad 8$$

Heat change (dQ) = 0.39 + 2.14
= 2.53 kW

Machine Capacity

Shaft diameter is designed using an expression by Jimoh and Olukunle (2013).

$$D = \sqrt{\frac{1.33X10^6\,XP}{N}} \quad 9$$

Where D is the shaft diameter (m), P is the capacity of the motor (1 Hp) and N is the speed (1400 rpm). D = 30.82 mm. However, 22 mm shaft diameter was selected while the pounding blade was designed is such a way that a little clearance was allowed from the wall of the pounding chamber to prevent rubbing during motion. The pounding chamber has a diameter of 200 mm; the crushing blade was designed to have 190 mm length, 20 mm width, and 3 mm thickness. The processing time for the optimum production of 1.09 kg pounded yam was 15 min. This includes sample preparation, boiling, loading, and crushing. Therefore, the capacity of the machine, C is calculated as:

$$C = \frac{\mathrm{Pr}oduction}{\mathrm{Pr}ocessin\,gTime} \quad 10$$

= 4.36 kgh^{-1}

Proximate Analysis

Standard method of AOAC (2000) was used to determine the crude protein content, total ash, crude fat and moisture content of the samples. Crude protein content (Total nitrogen (%) x 6.25) was determined by Kjedahl method, using 2 g of sample. Crude fat was obtained by exhaustively extracting 5 g of sample in Soxhlet apparatus using n-hexane as the extractor. Ash content was determined by the incineration of 2 g sample in a Muffle furnace maintained at 550°C for 5 h. Moisture content was determined by heating 2 g of sample to constant weight in a crucible placed in an oven maintained at 105°C. The total carbohydrate content was calculated by the difference in protein, fat, ash, fibre and moisture from 100.

Statistical Analysis

The data obtained were made in triplicates and analyzed using one-way Analysis of Variance (ANOVA) of Statistical Package for Social Sciences (SPSS version 17.0). Significant means were separated using the New Duncan's Multiple Range Test (NDMRT) at 95% confidence interval.

Evaluation of Sensory Characteristics

Consumer assessment of overall acceptability of the pounded yam was done, according to Sanni et al. (2016). Forty staff of Bells University of Technology, Ota, Nigeria was chosen. These are regular consumers of pounded yam and were randomly selected for the evaluation. Four samples were provided coded with sample A, B, C and

Table 1. Proximate composition of fresh, boiled and pounded yam.

Composition (%)	Fresh Yam	Boiled Yam	Pounded Yam
Moisture	66.20±0.33^{c}	68.61±0.16^{b}	71.56±0.21^{a}
Carbohydrate	24.61±0.18^{b}	23.59±0.32^{a}	20.21±0.36^{a}
Crude protein	2.26±0.09^{a}	1.82±0.28^{b}	1.80±0.13^{b}
Crude fibre	1.28±0.59^{b}	1.20±0.48^{a}	1.20±0.14^{a}
Ash	4.22±0.26^{b}	3.10±0.21^{a}	3.33±0.04^{a}
Crude fat	1.42±0.31^{a}	1.67±0.20^{b}	1.89±0.42^{b}

Data expressed as mean ± SD (n=3). Mean with different lower-case letter are significantly different (P<0.05).

B

Figure 4. Pounded yam made from 0.41 kg of yam (A- Final product; B- Pounding process).

D. Each sample of the pounded yam was placed in identical tight polythene bags and placed on a clean table. A questionnaire was designed and distributed among the forty respondents to score five textural characteristics namely smoothness, gumminess, presence of lumps, hardness and dough strength on a Hedonic scale of 5 points: 1= too low and not tolerable; 2= low and tolerable; 3= too high and not tolerable; 4= high and tolerable; 5 = normal or same with standard known pounded yam. Each of the four samples was presented at different times to each of the forty respondents to avoid bias of judgement. The responses were collated to compare the consumer preferences of the pounded yam produced.

RESULTS AND DISCUSSION

The recipe for the production of pounded yam made from white yam (*Dioscorea rotundata*) includes yam and water at ratio 6:1 as shown in Figure 3. The heat change during boiling, shaft diameter, machine efficiency and machine capacity were calculated to be 2.53 kW, 30.82 mm, 74.68% and 4.36 kgh^{-1}, respectively. The total cost of the complete combine machine is N26, 000 (approximately US $70) compared to N28, 912 (approximately US $78) as cost of producing pounding machine alone developed by Odior and Orsarh, (2008). Proximate composition of fresh, boiled and pounded yam as shown in Table 1 revealed that moisture content of pounded yam was 71.56%, this was higher than that of raw and boiled yam; 66.20 and 68.61%, respectively. This could be as a result of the combine effect of boiling water and the yam during processing. Besides, the results showed that the moisture content for the three samples analyzed were significantly different (p<0.05). However, carbohydrate, crude protein, crude fibre, ash and crude fat for boiled and pounded yam were not significantly different.

The results obtained were closely related to 71.1% moisture, 1.2% crude protein, 1.0% crude fat, 1.6% crude fibre, 2.7% ash and 22.4% carbohydrate reported by Ologunye et al. (2018). Performance of the machine was evaluated on the basis of weight production. Four samples of pounded yam were considered for the experiment. These include sample A (0.41 kg), sample B (0.56 kg), sample C (0.70 kg) and sample D (1.09 kg) as shown in Figure 4 to 7. The sensory result revealed that the assessment by all the respondents for quality

Figure 5. Pounded yam made from 0.56 kg of yam (A- Final product; B- Pounding process).

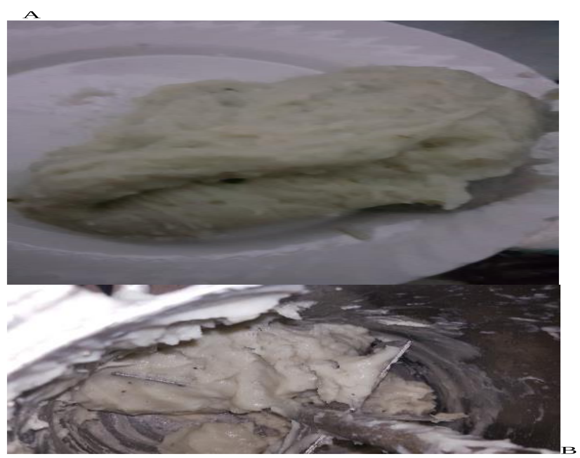


Figure 6. Pounded yam made from 0.7 kg of yam (A- Final product; B- Pounding process).

Figure 7. Pounded yam made from 1.09 kg of yam (A- Final product; B- Pounding process).

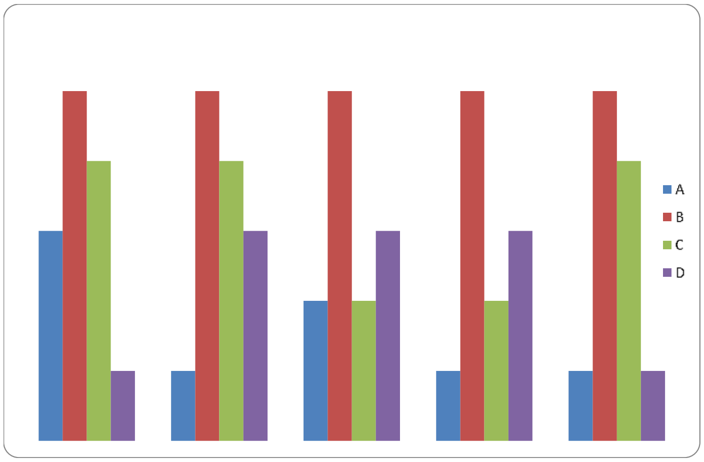


Figure 8. Textural characteristics of pounded yam. (A- 0.41kg B- 0.56 kg, C- 0.70 kg, D- 1.09 kg).

pounded yam followed the same trend with a preference for sample B as shown in Figure 8. Smoothness, gumminess and dough strength in sample C was high and tolerable. Gumminess, presence of lumps and hardness in sample D was too high and not tolerable. Smoothness in sample A was equally too high and not tolerable. Presence of lumps and hardness in sample C was low and tolerable. Presence of lumps in sample A was equally low and tolerable. Gumminess, hardness and dough strength in sample A was too low and not tolerable. Smoothness and dough strength in sample D was equally too low and not tolerable.

CONCLUSION

The mini boiling and pounded yam machine were found to be effective and produces 4.36 kg of pounded yam per hour. Around Agbara industrial area of Ogun State, Nigeria, where an average of 300 g of pounded yam is sold for N500 (approximately US $1.35), the machine would, therefore, generate N58,000 (approximately US $156) per 8 working hours per day. It is therefore recommended for small and medium scale industries. The choice of low-speed electric motor facilitated high machine efficiency.

ACKNOWLEDGEMENT

The author acknowledges the technical assistance of D.D. Awosile, O.T. Gbadebo, O.S. Fanimokun, N.A. Muyibi, O. Muritala, A.U. Abu, A. Umar and S. Ibrahim during the experimental stage of the study.

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