Development and Performance Evaluation of a Sieving Machine for Poundo Yam Process Plant

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Abstract
Limited or poor food preservation techniques and capacity causes post-harvest losses of food crops and initiates the problem of food and nutritional insecurity in the country. In other to solve this problem, food crops needs to be processed into a lasting and nutritious consumable form, through the use of mechanization. In this research an easily operated and user friendly sieving machine was developed to sieve poundo yam flour in a process plant. The components parts of the machine was designed and a detailed material selection analysis was done. The cost of producing the machine was estimated to be N40,000 while the capacity of the machine was derived as 0.4 kg/s. The performance of the machine was evaluated by estimating the ratio of the filtrate produced by the machine to the mass of Poundo yam loaded in the machine. The nature of the filtrate produced from the machine was compared to the product loaded in the machine before sieving. The efficiency of the machine was evaluated to be 85%. The article will assist in reduction of stress encountered in manual sieving. The waste of poundo yam flour during sieving operation will also be eliminated. The machine will achieve the production of fine particles of poundo yam.

Keywords: sieving machine, poundo yam, design analysis, development, performance evaluation, process plant.

INTRODUCTION
In other achieve technological advancement and gain international recognition a nation must be able to feed the citizens using local technologies that can be adapted from her own raw materials. Regrettably food and nutritional insecurity in Nigeria is as a result of poor upgrading of traditional foods and preservation techniques. Small scale food industries in the country are hampered by adoption of inefficient and inappropriate technologies, poor management, inadequate working capital, limited access to banks and other financial institutions, high interest rates and low profit margins. In other to reduce post-harvest food losses, traditional foods have to be improved using technological food processing techniques. One of these techniques is processing of yam into instant yam flour.

Yam, *Dioscorea (spp)*, a dicotyledonous perennial plant, is one of the major food crops in West Africa, the Caribbean, Asia, India and part of Brazil. It is an important source of carbohydrate for many people of the sub-Saharan region especially in the yam zones of West Africa. (Ihekoro and Ngoddy, 1985; FAO, 2008; Purseglove, 1999, Almenteros and Del-Rossatio, 1984). Yam tuber is essentially a starchy food which produces energy, its principal nutritional function being the supply of calories to the body (Onwueme, 1998; Nweke et al., 1991). It grows up to 2.5m (8.2ft) in length and weigh up to 70kg (154lb) with a tough stem which softens after heating. Yam deterioration occur due to ineffective or inappropriate food processing technology, careless harvesting and inefficient post-harvest handling practice, poor transportation media, bad market practice; and lack of storage facilities (Hulse, 1983; Coursey and Ferbe, 1979).

*Poundo* yam which is referred to as instant pounded yam flour (IPYF) is a processed white powdery form of yam (dehydrated yam flour) which is produced by different machines performing various operation in the process plant. It is a fast means of making pounded yam which is done by pouring a measured quantity of the yam flour into boiling water, which is stirred continuously until the required texture and taste is achieved. *Poundo* yam processing leading to size reduction includes peeling, slicing, parboiling, milling, drying, and sieving. (Ihekoro and Ngoddy, 1985; Abioye et al., 2008). This processes are carried out using different machines that are synchronously integrated together in the process plant (Ayodeji et al, 2012).

Sieving is the separation of fine material from coarse ones by means of meshed or perforated vessel. It is usually final operation of a high quality powdery product, it sometimes depicts the texture quality of the product. Manual sieving is done by pouring the grounded *poundo* yam powder unto a surface containing regularly arranged apertures of uniform shape and size mounted in a frame. This process is essential in the process plant for producing *Poundo*...
yam because it dictates the smoothness of the final product. Manual sieving process is laborious, time consuming and pose a health risk to the operator because the weight of the frame and the powder substance needs to be carried by the operator who faces the dust produced during the process. In essence a sieving machine is incorporated into the system to solve the problem.

In essence, the factors that affect sieving operation are; energy consumption, product waste, coarse particle production, and fatigue experienced in manual sieving. This article presents the development of a sieving machine that will assist in solving the problems encountered during sieving operation. The article did not consider the optimisation of the machine, and analysis of the control system for the machine as well as other machines in the process plant.

LITERATURE REVIEW

Yams (Dioscorea species) are annual or perennial tuber bearing and climbing plants. The genus Dioscorea has over 600 species but only a few are cultivated for food or medicine (IITA, 2008; Burkhill, 1960). The major edible species of African origin are white guinea yam (D Rotundata poir), yellow guinea yam (D. Cayenensis lam), and trifoliate or bitter yam (D Dumetorum kunth) (Ike and Inoni, 2006; Mignouna, 2003). Edible species from Asia include water or greater yam (D Alata L) and lesser yam. (D Esculenta) Cush-cush yam (D Trijeda L). The vegetable has a rough skin which varies in colour from dark brown to light pink (Kay, 1987). White guinea yam and water yam are the most important food yams in terms of cultivation and utilization. Yam tubers may be eaten with sauce directly after boiling, roasting or frying in oil. The tubers may also be mashed or pounded into dough after boiling, processed into flour or cooked into pottage with added protein sauce and oils. In addition to their food and market values, yams play a major role in social-cultural life for a wide range of small holder’s households especially in the dominant production zone of West Africa.

Yams are high in vitamin C, dietary fibre, vitamin B6, potassium, manganese and minerals. The lesser known yams are rich in crude protein than other varieties and are relatively high in Ash, which are concentrated in the peels (Eka, 1998). The protein produced by the lesser yam is low in histidine, cystine, methionin and valine, calcium, sodium, and zinc but high in iron. The Protein and moisture level increases from head to tail end of the tuber. The peel contains more fibre, ash, protein, calcium, and iron, than the edible parts of tubers (Ketiku et al.,1973) One cubed yam contains 15.5% of the daily value for vitamin B6, minerals and other essential vitamins, some of the proportions may be lost during processing (Eka, 1998; coursey, 1967(a)). Vitamin B6 is needed by the body to breakdown a substance called homocysteine, which can directly damage blood vessels walls. Individuals who suffer from heart attack despite having normal or even low cholesterol levels are often found to have high levels of homocysteine. Since high homocysteine levels are significantly associated with increased risk of heart attack and stroke, having a good supply of vitamin B6 makes a great deal of sense. High intakes of vitamin B6 have also been shown to reduce the risk of heart disease (coursey, 1967(b)). The edible, matured yam does not contain any compounds however, bitter components tends to accumulate in immature tuber tissues of D. Rotundata and D. Cayenensis. They may be polyphenols or tannin-like compounds. Wild forms of D. Dumetorum contain bitter compounds and bitter compounds, alkaloid dihydriodioscorine, while that of Malayan species D. Hispida is dioscorine. These are water-soluble alkaloids, which on ingestion produce severe and distressing symptoms. It is poisonous and is boiled before use so that the alkaloid is leached from the tuber (Mas-Yamaguchi, 1983).

![Figure 1: Unit Operations for Production of Poundo Yam](source)
The processing of yam tuber is a long established practice. Traditionally, yam is prepared in several processes of boiling, frying, drying, fermentation, milling, pounding, roasting and steaming (Iwuoha, 2004). Raw yam flour has also found increasing use in bakery as dough conditioner in ice-cream and as thickener in soups. Yam can be processed into different forms for home use and commercial purpose. These include: boiled yam, Roasted yam, fried yam, yam balls, pounded yam, yam flour (Elubo), and instant pounded yam flour (Ige and Akintunde, 1981; Coursey, 1967(a); Ekwu, 2003). The production process of instant pounded yam flour consist of simple operations which can be mechanized (FIIRO, 2005; Ayodeji et. al, 2012). The units operation can be shown in Figure 1;

Several efforts have been made to develop sieving machines for various purposes. Uthman, (2011), designed and fabricated a motorized lump breaking and sieving machine at a relatively low cost. The machine performed satisfactorily in breaking and sieving of the cassava lumps. It gave an efficiency of 97% and throughout capacity of 1.91kg/hr. The materials for fabricating the machine are sourced locally which make it maintenance friendly. The performance evaluation test was carried out using grated cassava which has been pressed. The results obtained revealed that the efficiencies of the machine increases with decrease in speed of the feed rates. The highest efficiency was obtained at feed rate 2kg/min with a value of 97% and at an optimum speed of 265rpm.

A motorized starch extracting machine was designed, fabricated and evaluated, based on shaking mechanism to solve the problem associated with sieving of starch and other agricultural crops in Nigeria. The machine consists of a hopper, a mixing compartment, a sieving compartment operated by a crank and spring arrangement, collecting trays and outlets. The volumetric flow rate and the capacity of the machine are 0.0206 m³/h and 22.45 kg/h respectively. The evaluation considered concentration at three levels which were 12.2 %, 14.44 % and 22.77 %. The study showed that the machine performance coefficients and sieving capacity increased with decreasing concentration. Also, highest performance coefficients of 98% was obtained for sieving of maize while sieving capacity of 16.90g/s.m² was obtained when the machine was used to sieve cassava. A unit of the machine costs nineteen thousand four hundred and eighty naira (N19, 480.00). The maintenance of the machine is simple and recommended for small holders, local processors and home use (Fayose, 2008).

Tabatabaeefar et al, (2003) developed an auxiliary chickpea second sieving and grading machine at Tehran University in Iran to sieve and grade chickpea a second time. The design considerations of the developed machine were economy (relative low cost), technical complexity, and ease of maintenance and usage. The machine was specifically developed for the Iranian farmers considering the physical properties, terminal velocity, and coefficient of friction of five different varieties of Iranian chickpea. The terminal velocity of a whole chickpea was 10 - 15m/s. For the dried leaves and stems, the averages were 3.0 m/s and 5.5 m/s, respectively. The minimum coefficient of friction occurred on galvanized steel and was 0.28, and the maximum coefficient of friction value of 0.33 occurred on fiberglass. The cleaning, grading, and overall efficiency of the machine were evaluated with 2 kg of hand-cleaned peas (debris-free) mixed with 15 grams chaff and stem and 100 grams of clouds and stones. The cleaning efficiency of the whole chickpea was 93 % and the debris was 91 %. Overall, the machine efficiency was 84 %.

**METHODOLOGY**

The machine is made of two sieves which are attached to wooden frame, a reciprocating rod, the sieve case, cam and follower, springs, and a delivery chute. The sieves are constrained to reciprocate by converting the rotary motion from a low speed electric motor with the help of a cam. The follower is attached to the frame of the sieves and as soon as the lobe of the cam comes in contact with the follower it produces the required reciprocating motion. Returning action of the follower is achieved with the help of a spring at the top of the sieve frame. The springs are welded to the sieve case so as to provide a quick return action for the sieve frame after every forward stroke of the cam. The reciprocation of the sieves gives rise to shaking force on the sieves. The filtrate falls on the delivery chute positioned at the base of the sieves. The factors considered in the design of the sieving machine were machine positioning, stability, and rigidity, ergonomics, material selection and cost of installation, power consumption, and maintenance. Figure 1 and 2 shows the pictorial and exploded view of the machine respectively.

Figure 1: Pictorial view of the sieving machine
The volume of the wood was determined by considering the cross section of the wood which is a cube shape. Figure 3 shows the cross section of the wood.

The total volume of the wood used for the sieve frame was obtained as $0.00356\text{m}^3$ using equation 1. The value of the volume was used to determine the mass of the wood using the density of wood, and from which the weight of the sieve frame was determined to be $25\text{N}$.

The volume of the sieving chamber was determined in order to obtain the capacity of the machine. The capacity of the machine is the amount of Poundo yam the sieving chamber can contain without overflow or...

\[ V_{TW} = 0.00356 \left( L_{DE} \cdot L_{AB} \right) \]  

(1)
wastage. The volume of the sieving chamber \( V_{sc} \), was obtained as \( 0.008 \text{m}^3 \) using equation 2.
\[
V_{sc} = (L_{DE} - 2(L_{CD})) \times L_{DB} \times L_{EC}
\]
(2)
The maximum shear stress \( (\tau_s) \) in the spring was obtained as \( 1.17 \text{MN/m}^2 \) using equation 3.
\[
\tau_s = \frac{4F_{sd}}{\pi D d^2}
\]
(3)
Where:
- \( F_{sd} \) = Correction factor \( = \frac{4c-1}{4c-6} + \frac{0.06}{c} \) (Thomas, 2005; Hall, et al, 1961)
- \( C \) = Axial load on the spring = the weight of the sieve frame
- \( D \) and \( d \) = mean diameter of the coil and the diameter of the wire respectively.
The axial deflection and stiffness of the spring was determined as \( 1.56 \text{mm} \) and \( 0.09 \text{N/m} \) using equations 6 and 7 respectively.
\[
Y = \frac{PF_{sd}}{4\pi G}
\]
(4)
\[
K = \frac{G}{c} + \frac{2}{\pi\rho}
\]
(5)
Where:
- \( Y \) = Axial deflection (mm).
- \( n \) = Number of active coils.
- \( G \) = Modulus of rigidity of the material of the spring.
The materials required for the fabrication of the sieving machine was selected for optimum performance of the machine. The design factors taken into consideration for selecting materials for the machine were cost, availability of material, rigidity and strength, overall weight, corrosion resistance and rust. The materials selected for the component parts of the sieving machine are as shown in Table 1.0

<table>
<thead>
<tr>
<th>S/N</th>
<th>MACHINE COMPONENT</th>
<th>CRITERIA FOR SELECTION</th>
<th>MATERIAL USED FOR THE DESIGN</th>
<th>MATERIAL SUITABLE</th>
<th>REASONS FOR SELECTING THE MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reciprocating rod</td>
<td>Strength, machinability, cost, availability</td>
<td>Mild steel</td>
<td>Mild steel, stainless steel, cast iron</td>
<td>Strength, low cost, machinability</td>
</tr>
<tr>
<td>2</td>
<td>Sieve</td>
<td>Corrosion resistance, lightness, surface finish, cost</td>
<td>Wood</td>
<td>Wood, cast iron mild steel</td>
<td>Lightness corrosion resistance</td>
</tr>
<tr>
<td>3</td>
<td>Machine Frame</td>
<td>Welding ability machinability, surface finish cost, strength</td>
<td>Mild steel</td>
<td>Mild steel, aluminium, stainless steel</td>
<td>Welding ability, cost strength</td>
</tr>
<tr>
<td>4</td>
<td>Cam</td>
<td>Strength, machinability</td>
<td>Mild steel</td>
<td>Mild steel stainless steel</td>
<td>Strength cost</td>
</tr>
<tr>
<td>5</td>
<td>Bearing</td>
<td>Strength, type of load, cost</td>
<td>Ball bearing</td>
<td>Ball bearing Roller bearing thrust bearing</td>
<td>Cost, type of load</td>
</tr>
<tr>
<td>6</td>
<td>Delivery Chute</td>
<td>No contamination, strength</td>
<td>Galvanized mild steel</td>
<td>Mild steel, aluminium stainless steel, Galvanized mild steel</td>
<td>Low cost, Availability Suitability</td>
</tr>
<tr>
<td>7</td>
<td>Mesh wire</td>
<td>Corrosion resistance, lightness, no contamination</td>
<td>Galvanized mesh</td>
<td>Stainless mesh</td>
<td>Low cost, non-contaminant</td>
</tr>
</tbody>
</table>

The cost of producing the sieving machine is derived by summing the material cost, the cost of components, machining and non-machining jobs. These are shown in Tables 2-5

<table>
<thead>
<tr>
<th>S/NO</th>
<th>MATERIAL</th>
<th>SPECIFICATION</th>
<th>QUANTITY</th>
<th>UNIT COST (₦)</th>
<th>TOTAL COST (₦)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Angle iron</td>
<td>50mm x 50mm</td>
<td>1 length</td>
<td>2550</td>
<td>2250</td>
</tr>
<tr>
<td>5</td>
<td>Mild steel Sheet metal</td>
<td>0.7 mm thick</td>
<td>1</td>
<td>6200</td>
<td>6200</td>
</tr>
<tr>
<td>2</td>
<td>Galvanize steel plate</td>
<td>4 x 4</td>
<td>1</td>
<td>5200</td>
<td>5200</td>
</tr>
<tr>
<td>3</td>
<td>Wood</td>
<td>2 inch by 2 inch</td>
<td>2</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td>Mild steel rod</td>
<td>50mm</td>
<td>½ length</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>5</td>
<td>Mild steel plate</td>
<td>50mm x 50mm x 5mm</td>
<td>1</td>
<td>550</td>
<td>550</td>
</tr>
</tbody>
</table>

Subtotal A 15 650
Table 3: Bought Out Cost

<table>
<thead>
<tr>
<th>S/NO</th>
<th>COMPONENT PART</th>
<th>SPECIFICATION</th>
<th>QUANTITY</th>
<th>UNIT COST (₦)</th>
<th>TOTAL COST (₦)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bolt and nuts</td>
<td>6, 8 and 10</td>
<td>50 pieces</td>
<td>200</td>
<td>10 000</td>
</tr>
<tr>
<td>2</td>
<td>Gloss paint</td>
<td>Blue</td>
<td>14 pieces</td>
<td>75</td>
<td>750</td>
</tr>
<tr>
<td>3</td>
<td>Plugs</td>
<td>1500</td>
<td>30</td>
<td>500</td>
<td>15 000</td>
</tr>
<tr>
<td>4</td>
<td>Electrodes</td>
<td>10</td>
<td>1/2 pack</td>
<td>1800</td>
<td>2 700</td>
</tr>
<tr>
<td>5</td>
<td>Conductor</td>
<td>2000</td>
<td>1 piece</td>
<td>1800</td>
<td>1 800</td>
</tr>
<tr>
<td>6</td>
<td>Spring</td>
<td>0.30mm × 5mm</td>
<td>4</td>
<td>300</td>
<td>1 200</td>
</tr>
<tr>
<td>7</td>
<td>Electric motor</td>
<td>1 hp /300rpm</td>
<td>1</td>
<td>7 000</td>
<td>7 000</td>
</tr>
<tr>
<td>8</td>
<td>Mesh wire</td>
<td>500mm/500mm/1 mm</td>
<td>1</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>9</td>
<td>Mesh wire</td>
<td>500mm/500mm/0.5 mm</td>
<td>1</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>10</td>
<td>Tarpaulin</td>
<td>1 sheet</td>
<td>1</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>11</td>
<td>Paint</td>
<td>1 liter</td>
<td>1</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>12</td>
<td>Body filler</td>
<td>1</td>
<td>1</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>13</td>
<td>Belt</td>
<td>v-belt</td>
<td>1</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>14</td>
<td>Pulley</td>
<td>v-shaped</td>
<td>2</td>
<td>600</td>
<td>1200</td>
</tr>
</tbody>
</table>

Subtotal B = 35 950

Table 4: Machining Job

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>MACHINE USED</th>
<th>TIME SPENT (hrs)</th>
<th>LABOUR COST/hr</th>
<th>TOTAL COST (₦)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marking out</td>
<td>Scriber</td>
<td>7</td>
<td>800</td>
<td>5600</td>
</tr>
<tr>
<td>Cutting</td>
<td>Power hacksaw</td>
<td>8</td>
<td>900</td>
<td>7200</td>
</tr>
<tr>
<td>Filing</td>
<td>Grinding machine</td>
<td>3</td>
<td>200</td>
<td>600</td>
</tr>
<tr>
<td>Turning</td>
<td>Lathe machine</td>
<td>2</td>
<td>2500</td>
<td>2500</td>
</tr>
</tbody>
</table>

Subtotal C = 15 900

Total cost of the sieving machine = Subtotal A + Subtotal B + Subtotal C + Subtotal D = 58 250

PERFORMANCE EVALUATION AND DISCUSSION OF RESULTS

The performance of the sieving machine was evaluated by estimating the mass of Poundo yam the machine can sieve at a particular time. The machine was run for 15 minutes without load to confirm that all components part of the machine were properly working to the designed standard. After the test running of the machine it was loaded with poundo yam flour grated to a fine texture with varying amount and the time spent was recorded so as to determine the efficiency of the machine. Table 6 gives the details of the results obtained from the test.

The capacity of the machine was determined from the ratio of the mass of poundo yam flour the machine can contain to the time spent in sieving the flour. The mass of poundo yam the machine can contain is obtained from the volume of the flour that the sieving chamber can contain. Since the volume of the sieving chamber is 0.0006 m³, then the mass of poundo yam the machine can contain is 0.8 kg.

Considering the results obtained from the performance of the machine, the capacity of the machine (SINC) is obtained as follows;

\[
S_{INC} = \frac{\text{Average Mass of Poundo yam loaded}}{\text{Average time taken}}
\]

\[
S_{INC} = \frac{7.4}{20.4} = 0.4 \text{ kg/s}
\]

The efficiency of the sieving (YSM) machine is the ratio of the poundo yam filtrate produced by the machine to the mass of poundo yam loaded to the machine. Considering the results obtained from the performance test, the efficiency of the sieving machine is obtained as follows;

\[
YSM = \frac{\text{Average mass of Poundo yam filtrate}}{\text{Average mass of Poundo yam loaded}}
\]

\[
YSM = \frac{6.8}{7.4} = 0.9 = 88\%
\]
In essence the efficiency of the machine is 88%, which shows that it has a high sieving capability. In addition observing the capacity of the machines it can be easily depicted that the volume of poundo yam it can sieve at a time is considerably high compare to the time spent during the processing.

CONCLUSION
The critical role that mechanization of traditional food processing techniques plays in national development cannot be overemphasized, because high-post harvest food losses arise largely from limited food preservation capacity. In essence an easily operated low cost and user friendly sieving machine was developed to sieve poundo yam flour in a process plant. The components parts of the machine was designed and a detailed material selection analysis was done. The cost of producing the machine was estimated to be 8000 Naira while the capacity of the machine was derived as 0.4 kg/s. The efficiency of the machine was evaluated to be 88%.

REFERENCES


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