Development and Performance Evaluation of a Motorized Rotary Sifter for Cassava Cake in Gari Production

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Abstract
In this study, a motorized rotary sifter was designed and constructed to pulverize pressed cassava cake and sift out fibre-free cassava meal for gari and cassava flour production. The effects (in terms of percentage contribution) of sifter screen speed, pulverizing drum speed, pressing time and sifter screen aperture size on material recovery efficiency of the machine were 12.45%, 4.79%, 41.30% and 24.66% respectively. Only the pulverizing drum speed (F< 4) did not have significant effect on the recovery efficiency of the machine. Bulk density and moisture content of cassava cake decreased with increase in pressing time and the optimum throughput capacity and material recovery efficiency of the machine were 231.79 kg/h and 92.98% respectively compared to 56.29 kg/h and 100% for the manual method. The problems associated with the manual method were eliminated and the motorized rotary sifter was readily adopted by cassava processors. The results show that the motorized rotary sifter performs better than the popular manual method in terms of throughput even though there was a slight decrease in material recovery efficiency. The new technology has great potential in helping to industrialize cassava processing in the cassava producing countries of Sub-Saharan Africa.

Keywords: motorized sifter, cassava cake, evaluation, efficiency

PRACTICAL APPLICATION
Processing of cassava tubers into gari and cassava flour is becoming a revolution in the food processing industry in Nigeria and Sub-Saharan Africa. Pulverizing and sifting of pressed cassava cake is a compulsory but laborious step in the cassava processing chain and over 90% of cassava processors in the region use the hand-woven raffia screen. The manual method is time consuming, unhygienic and injurious. The quality and quantity of fibre-free cassava meal produced are low. The motorized rotary sifter is developed to mechanize the process and the problems associated with the manual method are eliminated. The performance of the mechanical cassava sifter is good and the outcome of the work is a major contribution to the development of cassava processing industry. Application of the motorized rotary sifter has contributed to the cassava industrial revolution in Nigeria and has great potential to spread to other cassava producing countries in the region. The new technology is appropriate but depends on electricity, thus limiting its application in rural communities.

INTRODUCTION
Gari is the most popular staple food produced from cassava (Manihot esculenta Crantz.). It is widely reported that over 500 million people around the world derive their daily supply of carbohydrates from gari (Oluwole et al., 2004). With increasing population therefore, the demand for gari is also increasing. High Quality Cassava flour (HQCF) is another food product that is now finding wide application as raw material in the pharmaceutical and confectionary industries (CTA, 2007). In Nigeria alone, the policy of 40% cassava flour substitution in imported wheat flour has created a huge demand for the product and this has encouraged increased local production of cassava. Nigeria now ranks as the largest producer of cassava in the world with an estimated annual production of over 40 million metric tones (Babatunde, 2012).

Gari and HQCF are produced in a similar process described by Nweke et al. (2002). Freshly harvested tubers of cassava are washed and peeled. The peeled tubers are grated into a watery mash and collected in perforated polypropylene bags. For gari production, the cassava mash is left to ferment for a few days before pressing, but for HQCF production, the mash is pressed immediately to prevent fermentation (IITA, 2005; CTA, 2007). The bags of cassava mash are placed under a vertical screw press for some hours, to be dewatered to make further handling and
processing easy. After pressing, the cassava pulp becomes a solid cake due to deformation and creep (Ajibola et al., 1987). The pressed cake is pulverized and sieved into a wet granular meal of 45 % to 50 % moisture content before the final stage of roasting or drying into gari or HQCF respectively.

STATEMENT OF THE PROBLEM

After milling and pressing fresh cassava tubers for gari or cassava flour production, it is necessary to pulverize the compressed cake and remove the fibrous strands from the meal before drying. The popular traditional method of pulverizing the pressed cassava cake is the use of hand-woven sieve of about 3-5 mm aperture as shown in Figure 1. With both palms, the handler pulverizes a small quantity of cassava cake against the screen so that the granular meal is separated from unbroken cassava lumps and strands of fibre. The traditional method is tedious and time consuming and a recent study revealed that it takes an average of 35 minutes for one person to sift 26 kg of wet cassava meal (Sanni, 2014). The majority of cassava processors in Nigeria and other parts of West Africa still use the traditional manual method (Ajibola et al., 1998). The lack of appropriate and efficient technologies to mechanize the cassava processing operations at the small and medium enterprise levels has slowed down the industrialization of gari and cassava flour production in Nigeria. The main aim of this work is to evaluate the performance of a newly developed rotary sifter and compare the results with the popular traditional manual method.

Previous Works on Mechanical Sifters for Cassava Cake

Feeding the pressed cassava cake back into the mechanical grater is a method employed by some to pulverize it into a granular meal before frying to produce gari (IITA, 1990). This method is deficient because it does not remove the fibre and cassava lumps from the cassava meal and thus a low quality gari is produced. Owolarafe et al. (2000) also used a hammer mill for pulverizing and sifting pressed cassava cake, but the machine was only found to be economical for crushing cassava tubers and not pressed cake because of its high power requirement. Sanniet al. (2008) developed a manually operated rotary sifter which produced a well sifted cassava meal comparable with the one from the traditional raffia sieve. At a crank speed of 67 rpm, the throughput of the machine was 227.7 kg/h. The major disadvantage of the manual rotary sifter was the manual rotation of the cake beaters and time wasted in between batch operations. Agbetoye and Oyedele (2007) developed a dual-powered sifter for dewatered cassava mash and reported a sifting capacity of 84 kg/h and power requirement of 0.015 kW when the machine was operated at 60 rpm. The shortcomings of the various mechanical sifters and the urgent need to industrialize gari and cassava flour production led to the design and construction of a motorized rotary sifter that was used in this study.

MATERIALS AND METHODS

The main materials used for the investigation are the motorized rotary sifter which was designed and constructed in the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, the traditional raffia sieve which was used as control, fresh cassava tubers of variety TMS 30572, weighing balance and vertical screw press. The moisture content and bulk density experiments were carried out in the Food Processing laboratory of the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife.

DEVELOPMENT OF THE ROTARY SIFTER

Design considerations

The design of the rotary sifter was based on two main considerations namely: effective pulverization of the pressed cassava cake and effective sifting of the pulverized meal. After pressing the grated cassava mash, the compressed cassava cake contains the useful cassava starch granules which form the highest percentage, fibrous strands from the wooden core of the cassava tuber and in some cases unbroken cassava particles due to inefficient grating of the cassava tuber. The two functions of pulverizing and sifting the cassava cake are expected to separate the useful component (cassava starch meal) from the other constituents (fibre and other solid materials) which are not desired for further processing. The rotary sifter was also designed to remove other problems associated with the popular traditional method, such as exposure of the cassava to contamination, hand contact with the cassava, ergonomic problem due to prolonged bending position of the processor and wastage due to frequent spillage of the cassava (see Figure 1 (a) and (b)).

Construcional and Operational Features Of The Rotary Sifter

Pulverization of the pressed cassava cake was achieved by a rotating rasping drum which was produced by punching several holes on one side of a rectangular stainless sheet of 295 mm by 550 mm. The perforated stainless sheet was rolled around a cylindrical drum which was suspended in a hopper by means of a shaft and two pillow bearings. The shaft of the rasping drum was driven by 2 horse power, 1000 rpm variable speed motor. As the rasping drum rotated, its abrasive surface pulverized the pressed cassava cake that was in contact with it in the hopper. The pulverized meal and its admixtures such as fibre, unbroken pieces of cassava and other solid materials fell by gravity into the sifting section of the machine.
The sifting unit of the machine comprised of a short transport auger (400 mm long) and long cylindrical screen (1000 mm long; 320 mm diameter) both fixed to a shaft (1550 mm long; 50 mm diameter). The shaft was driven by a low speed geared motor of variable speed. As the shaft rotated, the pulverized meal was transported by the augment into the rotating screen which allowed only granules of cassava meal to pass through its aperture while other solid materials (mostly fibre) were transported in a free flowing manner along the inner surface of the screen to be discharged at its open end into the waste discharge chute. The cylindrical screen was incorporated with a wire mesh breaker which further pulverized any lump of cassava cake which may have escaped the action of the pulverizing unit. Directly below the rotating screen was a V-shaped trough which collected the sifted cassava meal. By means of a long auger at the base of the trough, the sifted cassava meal was conveyed to the discharge chute and recovered for further processing into garri cassava flour. The orthographic drawing of the rotary sifter showing its longitudinal cross section is presented in Figure 2.

EXPERIMENTAL METHODS
Production of cassava cake for experiments
Similar to the method used by Ademiluyi et al. (2010) fresh cassava tubers of the variety TMS 30572 were harvested from the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife. The cassava tubers were washed, peeled and milled in a conventional motorized grater. The grated mash was collected in perforated polyethylene bags and placed under a vertical screw press to be pressed for 6 hours, 12 hours and 18 hours. Samples were taken from each batch of pressed cake and used to study the effect of pressing on moisture content and bulk density. The three batches of cassava cake were also used for the performance evaluation of the rotary sifter in comparison with the popular traditional sifting method.

Moisture content of pressed cassava cake
The moisture contents (wet basis) of the cassava cake pressed for 6 hours, 12 hours and 18 hours were determined using the standard oven-drying method S358.2 (ASAE,1982). Equation 1 was used to calculate the moisture content of samples taken from the three batches of pressed cassava cake in three replicates each and their average values were used to investigate the effect of moisture content on the performance of the motorized rotary sifter:

\[
\text{Moisture content (\% w.b.)} = \frac{\text{total weight of meal} - \text{final weight of meal}}{\text{initial weight of meal}} \times 100
\]  

Bulk density of pressed cassava cake
The method used by Sanni et al. (2008) was slightly modified for determining the bulk density of the pressed cakes. Before pulverization three cubes of different sizes were carefully cut out of the pressed cassava cakes of 6, 12 and 18 hours. The dimensions of each cube was measured and used to calculate its volume. Each cube of pressed cassava cake was weighed and recorded. The bulk density of the cassava cake cubes from each batch was calculated in three replicates using Equation 2:

\[
\text{Bulk density of pressed cassava cake} \left( \frac{kg}{m^3} \right) = \frac{\text{weight of pressed cassava cube}}{\text{volume of cube}}
\]  

Determination of performance characteristics
Throughput capacity was one of the performance characteristics of importance in the operation of the rotary sifter. For each experiment 4 kg of pressed cassava cake was taken from the batches pressed for 6, 12 and 18 hours and introduced into the hopper of the motorized rotary sifter. The machine was operated until no more sifted cassava meal came out of the sifting unit. The time of operation was recorded and the throughput capacity was determined using Equation 3. The process was repeated three times for each experiment:

\[
\text{Throughput capacity} \left( \frac{kg}{h} \right) = \frac{\text{weight of cassava cake introduced}}{\text{time taken to recover cassava meal}}
\]  

Another important performance characteristic of the machine was the quantity of cassava meal recovered from the pressed cassava cake. After each sifting operation of the machine, the overflow which contained some unbroken cassava cake was manually pulverized using the traditional raffia sieve and the cassava meal content was recovered and weighed. The motorized rotary sifter was opened up and the material trapped in its auger barrel was also collected and characterized to determine the quantity of cassava meal in it (Sanni et al., 2008). The total weight of cassava meal in the cake was calculated as the sum of weights of cassava meal recovered, cassava meal in overflow and cassava meal trapped.

The cassava meal recovery efficiency ($\eta_r$%) of the machine was calculated using Equation 4. The recovery efficiency of the traditional raffia sieve was used as control because all the cassava meal in the cake was recovered when the manual sifting method was used:

\[
\eta_r(\%) = \frac{\text{weight of cassava meal recovered}}{\text{total weight of cassava meal in the cake}} \times 100
\]  

Study of the effect of process parameters on recovery efficiency
According to Esme (2009) and Sanni et al. (2015), the Taguchi method was used to analyse the effects of four process parameters on the cassava meal recovery efficiency. Effects of speed of the sifting screen (rpm), speed of the rasping drum (rpm), pressing time (hours) and sifter screen aperture size (mm) were investigated at three levels each. To reduce the cost and time of experiments, 9 experiments were conducted according to the Taguchi orthogonal array of Table 1 instead of 81 experiments of a complete 3$^4$ factorial design. The
cassava meal recovery efficiency (%) and throughput capacity (kg/h) of the motorized rotary sifter were determined in three replicates from each experiment. The signal-to-noise ratio (S/N) analysis was based on the Taguchi loss function of greater-the-better for the quality characteristic of recovery efficiency and Equation 5 was used to determine the S/N ratio response for each of the nine experiments. Analysis of variance (ANOVA) was used to significant effects of the parameters. The predictive regression model (Kamaruddinet al., 2004) of Equation 6 was used to predict the values of recovery efficiency and throughput capacity attainable under the optimum levels of the process parameters. The predicted values of both quality characteristics of the motorized rotary sifter were compared with those of the traditional raffia sieve.

The S/N ratio analysis of means in Table 3 shows that the optimum parameter levels at which material recovery can be maximized were sifter screen speed of 60 rpm, pulverizing drum speed of 750 rpm, pressing time of 18 hours (corresponding to moisture content of 46.22 %) and sifter screen aperture size of 5 mm. The average values of recovery efficiency and throughput capacity at the optimum parameter levels were 86.87 %, 86.23 %, 88.14 %, 88.00 % and 186.15 kg/h, 156.03 kg/h, 181.52 kg/h, 181.73 kg/h respectively. The analysis in Table 3 also shows that the effect of pressing time on the material recovery efficiency was highest and ranked first. The fact that the optimum level of pressing time of 18 hours produced a cake with the lowest moisture content of 46.22 % shows that the longer the pressing time to remove water, the less bulky the cassava cake is for pulverizing and sifting. The tangential force on the rasping drum required for pulverizing the cassava cake is reduced and so is its rate of wear. Local cassava processors have claimed that the lower the moisture content of pressed cassava cake the better it is for further processing (CIGR, 1999; Sanni2014). However the long hours of pressing can be reduced by improving on the design of the press.

Effect of process parameters on throughput capacity and material recovery efficiency

Among other factors, the motorized rotary sifter was designed to minimize the long hours taken to pulverize and sift out the granular cassava meal that is free of fibre. The throughput capacity, material recovery efficiency of the machine and corresponding signal-to-noise ratio (determined from Equation 5) are recorded in Table 2. The analysis of the signal-to-noise ratio of the recovery efficiency is presented in Table 3.

The S/N ratio analysis of means in Table 3 shows that the optimum parameter levels at which material recovery can be maximized were sifter screen speed of 60 rpm, pulverizing drum speed of 750 rpm, pressing time of 18 hours (corresponding to moisture content of 46.22 %) and sifter screen aperture size of 5 mm. The average values of recovery efficiency and throughput capacity at the optimum parameter levels were 86.87 %, 86.23 %, 88.14 %, 88.00 % and 186.15 kg/h, 156.03 kg/h, 181.52 kg/h, 181.73 kg/h respectively. The analysis in Table 3 also shows that the effect of pressing time on the material recovery efficiency was highest and ranked first. The fact that the optimum level of pressing time of 18 hours produced a cake with the lowest moisture content of 46.22 % shows that increased amount of cassava meal could be recovered from the cake by further decrease in moisture content. The analysis of variance (ANOVA) of the material recovery efficiency is presented in Table 4. Only pulverizing drum speed (with F < 4) did not have significant effect on the performance of the motorized rotary sifter.

Equation 6 was used to predict an estimate of the two performance characteristics of the rotary sifter when operated at the optimum parameter levels. The estimated optimum values of material recovery efficiency and throughput capacity were 92.98 % and 231.79 kg/h respectively. Manual sieving of pressed cassava cake using the traditional screen (Figure 1) usually achieved a 100 % cassava meal recovery but its throughput capacity was low. Previous works showed that use of the traditional raffia screen produced between 50kg/h and 60 kg/h of cassava meal depending on the skill and strength of the handler (Sanni et al., 2008; Sanni, 2014).

CONCLUSION

Garri and cassava flour are food products widely consumed in Sub-Saharan Africa. Pulverizing and
sifting of pressed cassava cake is a compulsory but laborious step in the processing of cassava into any of the products. The development and performance evaluation of the motorized rotary sifter has mechanized the process and eliminated the shortcomings of the popular traditional method. The output of the work was a major contribution to the development of appropriate food processing machines in the African sub region. Application of the motorized rotary sifter has contributed to the cassava industrial revolution in Nigeria and other cassava producing countries.

REFERENCES


APPENDIX

Figure 1: Popular traditional method of using hand-woven sieve in garri production (Source: Sanni et al., 2008)

(a) manual pulverizing of cassava cake (b) manual sifting of cassava cake

Figure 2: Motorized rotary sifter for compressed cassava cake

1-feed hopper, 2-sifting unit, 3-V-shaped trough, 4-discharge chute, 5-discharge auger, 6-variable speed geared motor, 7-feed auger, 8-rasping drum.

Table 1: Fractional factorial experimental design

<table>
<thead>
<tr>
<th>Number of Experiment</th>
<th>Parameter Levels</th>
<th>Sifter screen speed (rpm)</th>
<th>Rasping drum speed (rpm)</th>
<th>Pressing time (hours)</th>
<th>Sifter screen aperture (mm)</th>
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<tbody>
<tr>
<td>A B C D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1 1 1 1</td>
<td>30</td>
<td>500</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1 2 2 2</td>
<td>30</td>
<td>750</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1 3 3 3</td>
<td>30</td>
<td>1000</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>2 1 2 3</td>
<td>45</td>
<td>500</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>2 2 3 1</td>
<td>45</td>
<td>750</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>2 3 1 2</td>
<td>45</td>
<td>1000</td>
<td>6</td>
<td>3</td>
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<tr>
<td>7</td>
<td>3 3 2 1</td>
<td>60</td>
<td>500</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>3 2 1 3</td>
<td>60</td>
<td>750</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>3 3 2 1</td>
<td>60</td>
<td>1000</td>
<td>12</td>
<td>2</td>
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</tbody>
</table>

A= sifter screen speed; B= rasping drum speed; C = pressing time; D = sifter screen aperture
Table 2: S/N response to material recovery efficiency

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Parameter A</th>
<th>Parameter B</th>
<th>Parameter C</th>
<th>Parameter D</th>
<th>Performance Characteristics</th>
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<td>Sifter screen speed (rpm)</td>
<td>Pulverizing drum speed (rpm)</td>
<td>Pressing time (hours)</td>
<td>Sifter screen aperture (mm)</td>
<td>Material throughput capacity (kg/h)</td>
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<tr>
<td>1</td>
<td>30</td>
<td>500</td>
<td>6</td>
<td>2</td>
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<tr>
<td>2</td>
<td>30</td>
<td>750</td>
<td>12</td>
<td>3</td>
<td>82.58±4.41</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1000</td>
<td>18</td>
<td>5</td>
<td>162.38±7.44</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
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<td>12</td>
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<td>172.24±9.00</td>
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<td>3</td>
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<td>750</td>
<td>6</td>
<td>5</td>
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<td>60</td>
<td>1000</td>
<td>12</td>
<td>2</td>
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Table 3: Analysis of S/N responses to material recovery efficiency

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<th>Parameter</th>
<th>Symbol</th>
<th>Level averages of S/N</th>
<th>Parameter average</th>
<th>Max. – Min.</th>
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<td>38.43</td>
<td>38.66</td>
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<td>38.62</td>
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<td>Pulverizing drum speed</td>
<td>B</td>
<td>38.50</td>
<td>84.28</td>
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<td>Pressing time</td>
<td>C</td>
<td>38.20</td>
<td>81.41</td>
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<td>38.76</td>
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<tr>
<td>Sifter screen aperture</td>
<td>D</td>
<td>38.55</td>
<td>84.73</td>
<td>129.62</td>
<td>38.43</td>
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Table 4: Analysis of variance of recovery efficiency

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<th>Parameter Code</th>
<th>Process Parameter</th>
<th>Degree of Freedom</th>
<th>Sum of Square</th>
<th>Mean Square</th>
<th>F</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sifter screen speed (rpm)</td>
<td>2</td>
<td>48.4785</td>
<td>24.2393</td>
<td>6.674</td>
<td>12.45 (3rd)</td>
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<tr>
<td>B</td>
<td>Pulverizing drum speed (rpm)</td>
<td>2</td>
<td>18.6417</td>
<td>9.3209</td>
<td>2.566</td>
<td>4.79 (4th)</td>
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<tr>
<td>C</td>
<td>Pressing time (hours)</td>
<td>2</td>
<td>160.738</td>
<td>80.3691</td>
<td>22.128</td>
<td>41.30 (1st)</td>
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<td>D</td>
<td>Sifter screen aperture (mm)</td>
<td>2</td>
<td>96.0021</td>
<td>48.1883</td>
<td>13.268</td>
<td>24.66 (2nd)</td>
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<td>Error</td>
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<td>65.3765</td>
<td>3.6320</td>
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