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# Development of a Ceramic Cassava Peeling-and-Washing Machine

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## Abstract

*Manual peeling of cassava is still practiced by the cassava processors due to high mechanical damage of existing cassava peelers. The aim of this study was to develop a cassava peeling-and-washing machine using ceramic mixture as the abrasive surface. The developed machine performs two operations concurrently – peeling and washing. The peeling surface was cast with ceramic mixture, which composed of ceramic, sand and cement (1:3:1). The machine was driven by a 10-hp, 3-phase motor operating at 900 rpm with a pulley ratio of 1:5 and belt. The effect of varying weight capacity of cassava tubers per batch on the performance efficiency of the machine was also studied. It was observed that as the weight of cassava tubers fed into the machine (3.5 to 15.5 kg) increased, the peeling efficiency, quality of performance, and throughput capacity increased, whereas mechanical damage and peel retention decreased. On the contrary, as the weight of tubers in the machine decreased, the peeling efficiency, quality of performance, and throughput capacity decreased while mechanical damage and peel retention increased. Understanding the effect of cassava tubers fed per batch by processors was deemed useful for high performance efficiency during usage of the developed machine.*

***Keywords****:* cassava design, machine design, peeling efficiency, peeling, washing

## 1. Introduction

Cassava (*Manihot esculenta* Crantz) has been regarded as one of the most important tuber crop grown in the tropics, with a huge source of calories for over 500 million people worldwide (Eze *et al.*, 2016). In tropical Africa, cassava has become the most important crop, in terms of the land mass devoted to its cultivation, making its production all year round. It is a good source of carbohydrate to human diet, and has high tolerance to drought and heat (Daniyan *et al.*, 2016). To an African peasant farmer, cassava is very important as rice is to an Asian farmer and wheat or potatoes to a European farmer (Onyenwoke and Simonyan, 2014).

Cassava is a good source of raw material to industry for starch, flour and ethanol production (Onyenwoke and Simonyan, 2014). It was reported that freshly harvested cassava start deteriorating immediately after it is harvested, and it could be stored for only three days. This is due to the fact that cassava tubers have high moisture, over 70% (Egbeocha *et al.*, 2016). Also, it was stated that a substantial part of the food reserve in Africa is lost during peeling, using the manual (knife) method, which is time consuming. Hence, a sound knowledge of the engineering properties of cassava tuber related to its peeling mechanization is paramount in designing and fabricating an efficient peeling machine.

Peeling, as a unit operation in cassava processing, has been referred to as a bottleneck – limiting the complete mechanization of cassava processing – due to the tuber's numerous varieties, tuber sizes and shapes (Jimoh and Olukunle, 2012). The various methods that have been used in cassava peeling include manual, chemical, steaming and mechanical with each of them having their advantage (Abdulkadir, 2012). In cassava peeling, the periderm and the cortex are removed to obtain the parenchyma, which is about 85% of the weight of the tubers (Abdulkadir, 2012). The varieties, shapes and sizes of the root constitute the various properties of cassava peel affecting the efficiency of the peeling machine, thus making the designing much difficult (Oluwole and Adio, 2013).

Abdulkadir (2012) developed a cassava peeling machine that used a folded cylindrical shaped punched medium carbon steel metal sheet as the peeling medium. Ugwu and Ozioko (2015) made a motorized cassava peeling and washing machine. Peeling was achieved by the rotation of a horizontal drum, which houses brushes used in aiding the washing of the peeled tubers when water from the tank is introduced. Olukunle *et al.* (2006) and Jimoh and Olakunle (2012) assembled a single and double gang cassava peelers, which utilized an abrasive peeling medium (punched mild steel sheet) inclined horizontally. Nathan and Udosen (2017) compared two types of cassava peeling machine (type 1 and 2). The peeling medium for type 1 is a rotating cylindrical shaft or drum upon which peeling spikes (nails) of length 26 mm are permanently welded, while the peeling medium for type 2 is same as type 1 but with shorter stainless nails. Nathan *et al.* (2017) compared two types of cassava peeling machine (type 3 and 4). Type 3 cassava peeling machine used two peeling shafts as the peeling tool while type 4 cassava peeling machine used four peeling shafts as the peeling tool.

However, from the pieces of published literature, there is no information on cassava peeling machine that uses ceramic mixture as its abrasive peeling medium. This became the basis of this research work. This research focuses on using ceramic mixture as the peeling medium in a developed cassava peeling-and-washing machine. The effect of cassava weight on the efficiencies and the mechanical damage was also studied.

## 2. Methodology

*2.1 Design Concept*

The cassava peeling-and-washing machine was designed taking into cognizance the differences in physical and engineering properties of the cassava.

As listed by Olukunle (2005) and Jimoh and Olukunle (2012), some design considerations include 1) affordability to local farmers, 2) ability to peel different varieties, shapes and sizes of cassava, 3) construction materials, and 4) capacity in comparison to manual peeling.

*2.2 Machine Components and Operation*

Figures 1 and 2 show both the computer rendering and actual appearance of the ceramic cassava peeling-and-washing machine. The machine consists of an abrasive surface (ceramic mixture) that acts as the peeling medium during operation. The rotary motion of the turn table in the peeling drum gave motion to the tubers inside the drum, thereby allowing the tubers have continuous contact with the underlying layer casted with the ceramic mixture in which peeling is achieved. Peeling was also accomplished due to continuous shear among the tubers as water is let down from the top. The turn table also served as guide for the tubers in motion. The machine was powered by a 10 hp low speed (900 rpm) electric motor and driven by a pulley of ratio 1:6.25 with two V-belts, then supported by a frame made up of 3-inch angle iron. Some of the peeled cassava tubers are shown in Figure 3.

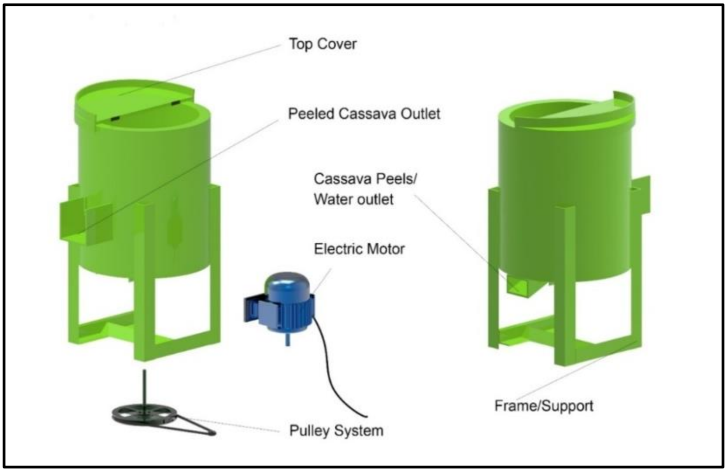


Figure 1. Computer rendering of the cassava peeling-and-washing machine

Figure 2. Actual appearance of the cassava peeling-and-washing machine

Figure 3. Sample of cassava tubers before and after peeling

### *2.3 Machine Design Analysis*

#### 2.3.1 Ceramic Mixture

The ceramic mixture was used in casting the peeling surface. The mixture was a composition of ceramics (crushed toilet sink), and sand and cement, in a ratio of 1:3:1. This mixture, after curing, provided the necessary abrasion needed for removing the periderm and the cortex, which are regarded as the cassava peels. Curing was done after casting to detoxify the heavy metal and acidic component in the cement and ceramic used.

#### 2.3.2 Capacity Design

The machine was designed in a drum shape. Volume of the cylinder is 0.283 $m^3$, density of cassava was 282 $kg/m^3$, and capacity of the peeling drum was 50 kg.

#### 2.3.3 Velocity Ratio for Belt Device

According to Oluwole and Adio (2013) and Akporehe *et al.* (2017), it is the ratio between factoring the velocity of the driver and that of the follower, which is mathematically expressed as:

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \tag{1}$$

where:

$d_1$= driver pulley diameter
$d_2$= follower pulley diameter
$N_1$ = driver speed
$N_2$ = follower speed

$N_1$ = 900 rpm
$d_1$ = 0.08 m
$d_2$ = 0.5 m
$N_2$ = 144 rpm, $N_1$:$N_2$ was 6.25:1

#### 2.3.4 Power Requirement

The power required to peel the tubers is the power driving the turning table and the tubers simultaneously, which was determined using Equation 2 as suggested by Oluwole and Adio (2013).

$$P = Tv \tag{2}$$

where:

$P$ = power required to drive the turning table and cassava tubers
$v$ = speed (15.07 m/s)
$T$ (Torque) = mass× acceleration due to gravity × radial distance (423.79 Nm)
$P$ = 6.39Kw, 8.4 hp, but this study used 10 hp motor

2.3.5 Belt Design

Equations 3, 4, 5 and 6 used for the belt were adopted from Akporehe *et al.* (2017) and Oluwole and Adio (2013).

For open belt, the angle of contact is as in Equation 3.

$$sin\alpha = \frac{r_1 - r_2}{\mathrm{x}} \tag{3}$$

where:

$r_1$= big pulley radius
$r_2$= small pulley radius
x = pulley distance
$sin\alpha = \frac{0.5\text{-}0.08}{0.5}$, $\alpha = 57^0$
$\theta$=180–2α, $\theta$= $66^0$ = 1.15 rad

$$v = \frac{\pi DN}{60} \tag{4}$$

where:

$D$= pulley diameter
$N$= speed of the driven
$v = \frac{\pi \times 0.08 \times 900}{60}$ = 3.77m/s

$$P = (T_1 – T_2)V \tag{5}$$

where:
$(T_1 – T_2)$ = 2.65N

The belt ratio for open belt was ciphered using Equation 6.

$$log\ (\frac{T_1}{T_2}) = \mu \theta \tag{6}$$

where:

$\theta$= open belt wrap angle
$\mu$= frictional co-efficient
$T_1$= tight side belt tension
$T_2$= slack side belt tension
$T_1$= 9.08N
$T_2$= 6.43N

2.3.6 Shaft Design

The shaft size was determined using Equation 7 (Shittu and Ndirika, 2012).

$$d^3 = \frac{16}{\pi \times s_u} \left( \sqrt{(K_t\, M_t)^2 + (K_b\, M_b)^2} \right) \tag{7}$$

where:

$d$= shaft diameter
$K_t$ = stress combine fatigue and shock factor or torsion (1)
$K_b$ = stress combine fatigue and shock factor for bending (1.5)
$s_u$= ultimate tensile strength of steel is 56 MPa
$M_t$ = torsional moment (423.79 Nm)
$M_b$ = bending moment (7.785 Nm)

$$d^3 = \frac{16}{\pi \times 5 \times 10^6} \left( \sqrt{(1.5 \times 423.79)^2 + (1 \times 7.785)^2} \right)$$

$d$ = 0.04 m, $d$ = 40 mm shaft was selected

*2.4 Performance Evaluation of the Machine*

The weight of cassava tubers used was varied and its effect on some of the performance efficiencies was studied. The various performance efficiencies studied were given by Jimoh and Olukunle, (2012).

2.4.1 Throughput Capacity

The throughput capacity (kg/s) of the developed machine was calculated using Equation 8.

$$T_c = \frac{W_t}{T} \tag{8}$$

where:

$W_t$ = mass of cassava fed into the machine (kg)
$T$= time used in peeling (s)

2.4.2 Weight of Peel

The weight of the peel removed from the peeler per batch was computed using Equation 9.

$$P = \frac{M_{pc}}{M_s} \tag{9}$$

where:

$M_{pc}$ = the peel weight collected
$M_s$ = sample weight

2.4.3 Peeling Efficiency

In calculating the peeling efficiency ($\mu$) of the developed machine, Equation 10 was used.

$$\mu = \frac{M_{PC}}{M_{pr}+M_{po}} \tag{10}$$

where:

$M_{po}$ = weight of peel collected through the peel outlet of the machine (kg)
$M_{pr}$ = weight of peel removed by hand after machine peeling (kg)

2.4.4 Mechanical Damage

The mechanical damage ($\lambda$) imposed by the machine on the cassava peeled was calculated using Equation 11.

$$\lambda = \frac{M_f}{M_c + M_f} \tag{11}$$

2.4.5 Peel Retention

To determine the retained peels ($\beta$) after each batch of processing, Equation 12 was employed.

$$\beta = \frac{Mpc}{Mpt + Mpo} \times \frac{Mf}{Mc + Mf} \tag{12}$$

2.4.6 Quality Performance Efficiency

The quality of the peeled cassava tubers ($\Omega$) was assessed by utilizing Equation 13.

$$\Omega = \frac{Mc}{Mc + Mf} \tag{13}$$

where:

$M_f$ = weight of tuber portion which was removed along with the peel by the machine
$M_c$ = weight of completely peeled tuber

*2.5 Cyanide and Trace Element Test*

Due to the ceramic mixture (cement, sand and ceramic) – composition use as the peeling surface in the machine – the peeled tuber was subjected to a cyanide test to determine if there was an increase in the acidity content of the machine peeled tuber using a knife peeled tuber as the control. This experiment was done using the pH meter. The trace element test was also carried out since lead (Pb) is the most poisonous element that might be present in the mixture used. An atomic spectrometer was utilized to conduct this analysis.

*2.6 Preparation of Sample*

Prior to the performance test carried out, the cassava tubers used were freshly harvested from a cassava farm. It was screened for damages and divided into five at different weight; 3.5, 6.5, 9.5, 12.5 and 15.5 kg. All experiments were carried out in three replicates.

## 3. Results and Discussion

### *3.1 Effect of the Weight used Per Batch on the Performance Efficiency of the Developed Machine*

Table 1 shows the raw data of the analysis carried out. From the figures below, it is observed that the effect of weight of cassava fed per batch into the machine on the various parameters evaluated is highly correlated and linear.

Table 1. Result of some performance test on the cassava peeling and washing machine at different feed rate

| Ms (kg) | Tc (kg/s) | P (kg) | µ (%) | ƛ (%) | $\beta$ (%) | Ω (%) |
|---|---|---|---|---|---|---|
| 3.5 | 0.029±0.21 | 0.04±0.03 | 63.64±0.12 | 37.5±0.03 | 23.87±0.06 | 62.5±0.04 |
| 6.5 | 0.036±0.04 | 0.035±0.11 | 63.89±0.16 | 31.82±0.05 | 20.33±0.02 | 68.18±0.02 |
| 9.5 | 0.045±0.16 | 0.031±0.31 | 65.91±0.24 | 25.83±0.11 | 17.02±0.12 | 74.17±0.12 |
| 12.5 | 0.052±0.08 | 0.029±0.22 | 66.67±0.20 | 24.87±0.14 | 16.58±0.24 | 75.13±0.22 |
| 15.5 | 0.062±0.13 | 0.026±0.04 | 68.97±0.09 | 22.38±0.32 | 15.44±0.21 | 77.62±0.04 |

The values were all significant at ($p < 0.05$)

From Figures 4, 5, 6, 7, and 8, as the weight of cassava fed was increased, the throughput capacity, peeling efficiency, and quality of performance increased; mechanical damage, and peel retention decreased and vice-versa. The increase in the peeling efficiency might be due to higher interaction among the tubers. The increase in the throughput capacity is well expected. The increase in the quality performance means that as the number of cassava increases in the machine, the lesser the breakages from the whole peeled cassava tuber. The decrease in the mechanical damage is due to more tubers having continuous contact with the ceramic wall per time.

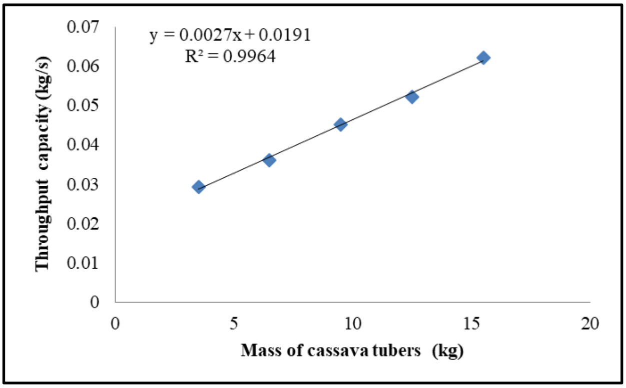


Figure 4. Effect of weight of sample fed into the machine per batch on the throughput capacity at 144 rpm

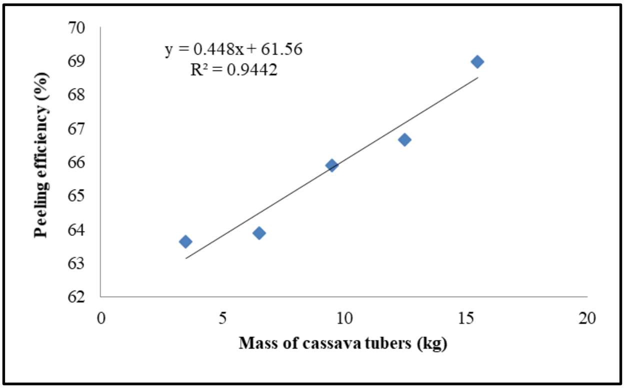


Figure 5. Effect of weight of sample fed into the machine per batch on the peeling efficiency at 144 rpm

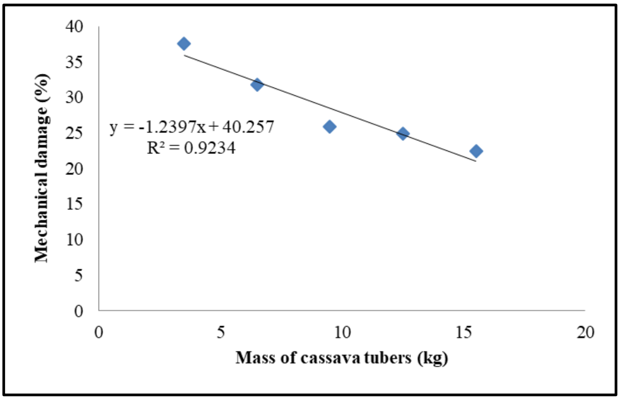


Figure 6. Effect of weight of sample fed into the machine per batch on the mechanical damage at 144 rpm

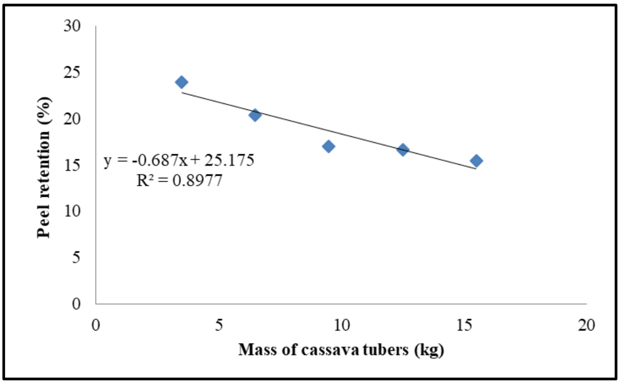


Figure 7. Effect of weight of sample fed into the machine per batch on the peel retention at 144 rpm

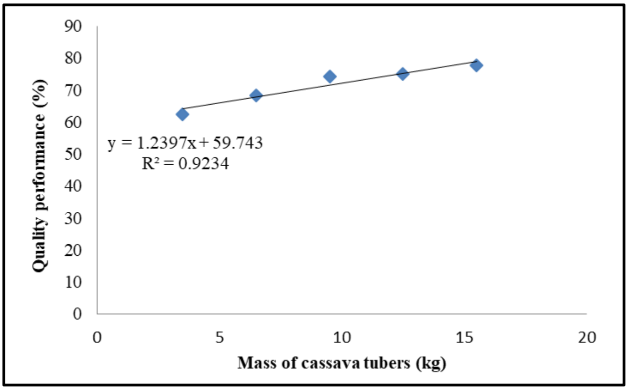


Fig. 8 Effect of weight of sample fed into the machine per batch on the quality performance at 144 rpm

These findings were in agreement with the research carried out by Jimoh and Olukunle (2012), who used cutting blades inclined at an angle, stating that the peeling efficiency, throughput capacity and quality of performance increase with increase in cassava size and decrease in speed. It was also reported that the high peeling efficiency and less mechanical damage were recorded between 100 – 300 rpm, which was also the same speed that the present study used. Whereas, the mechanical damage showed a clear disparity from their work. It was stated that peel retention and the mechanical damage increases with an increase in speed and an increase in size. Also, Oluwole and Adio (2013) used a rotating punched drum for peeling. Based on their findings, it was observed that they operated between two mean weight 3.09 and 3.17 kg. There was an increase in their mean peeling efficiency from 60.22 to 70.34% and a decrease in the flesh loss (mechanical damage) from 5.95 to 5.07% with decreased speed from 394 to 364 rpm.

In Table 2, it can be observed that the pH value of both the machine peeled and control was within the same range. This means that the ceramic mixture did not affect the peeled tuber. Therefore, it is safe for human consumption. The lead test signifies that both the control and the machine peeled are in the same range (Table 3).

Table2. Cyanide test result

| | Machine peeled | Control |
|---|---|---|
| pH | 6.86±0.02 | 6.87±0.03 |

Table 3. Trace element test (Pb test)

| Lead (Pb) test | Machine peeled | Control | Status |
|---|---|---|---|
| Wave length (nm) | 283.3±0.02 | 283.4±0.04 | |
| Absorption (abs) | 0.007±0.01 | 0.007±0.02 | |
| Amount (ppm) | 0.0054±0.03 | 0.0053±0.01 | Safe |

## 4. Conclusion

The cassava peeling-and-washing machine was designed and developed to reduce the drudgery associated with manual peeling and washing of cassava tubers. The machine was evaluated at different tuber weights, which significantly affected the performance efficiency. The highest performance efficiency (peeling efficiency (68.97%), mechanical damage (22.38%), throughput capacity (0.062 kg/s), quality of performance (77.62%), and peel retention (15.44%) were recorded at tuber weight of 15.5 kg. On the other hand, the lowest performance efficiency (peeling efficiency [63.64 %]), mechanical damage (37.5%), throughput capacity (0.029 kg/s), quality of performance (62.5%), and peel retention (23.87%) were penned at 3.5 kg. The cyanide and trace element tests signified that the machine peeled tubers are safe for human consumption.

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