Design and Fabrication of a Wet Mechanical Brushing Unit for Lye Pre-treated Cassava Root

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Abstract-
The design and fabrication of a wet mechanical brushing unit for lye pre-treated cassava root was described in this paper. The objective of this work was to determine the time of reaction, the temperature and the concentration of sodium hydroxide solution that will effectively digest the peel and also the speed of the machine, output size, efficiency of peeling and tuber loss. It was determined that using lye solution to digest cassava root peel depends on the severity of the concentration of the solution and the time of root immersion. From the preliminary laboratory tests carried out, the optimal combination of process parameters in terms of concentration, temperature and time of root immersion for UMUCASS44 in lye are 20%, 60°C and 15 minutes, respectively. These values are sufficient to digest the peels of the root for enhanced brushing.

Key words: Cassava, Peeling Efficiency, Output Capacity, Performance, Reaction Time, Brushing

1. Introduction
Cassava (Manihot esculanta Crantz) is a very important economic dicotyledon perennial plant that is from the family of Euphorbiaceous. It originated from South America and from there it has moved to several part of the world. Nigeria is the largest consumer of Cassava as it supplies about 50 million people with 70% daily calories [1], [2]. Cassava has gained so much attention among other food crop because of its inherent ability to grow tremendously in poor soil and can also stay in the soil for a long period of time after maturity. This has made it to become a very important food security crop. The problem of cassava usually arise during production, its problem seems to increase after harvesting but with appropriate technology, this can be minimized. It is an ideal food crop that is good for tropical growing condition [3]. The cortex present in cassava is always removed before it can be processed into other product except when it is to be processed into animal feed where the cortex removal may be not be necessary. Cassava tuber can be turned into a lot of edible and non edible products [4], [5], [6], [7], [8]. As a result of this, cassava processing needs serious attention so as to meet demands both locally and internationally. Cassava peeling requires several unit operations ranging from peeling, milling, frying, drying, extruding, boiling or parboiling, sieving, etc. Though each of this unit operations have almost been perfected except for peeling. Peeling has become a serious challenge in cassava processing and this is because cassava root harvested from the same soil vary in shape, size and weight. Even during peeling, the peels also vary in peel thickness and force of adhesion to the root. This reasons has made cassava a global challenge among design engineers all over the world. Effort has been made in this regard which has led to so many
cassava peeling machine prototypes having relatively low efficiencies and quality [9], [10], [11], [12], [13]. Various unit operational method are used when cassava is to be processed for either industrial or human use of which peeling is one of the most important. Cassava root when harvested do not stay long as they begin to deteriorate immediately they are harvested so due to this, they cannot be left for long without being peeled. The peeling operation of the cassava tuber begins with the removal of the periderm and cortex which are the brown hard cover of the tuber. If the peeling is not properly done well, it will affect the overall quality of the desired product except otherwise if the desired product is animal feed then peeling may not be necessary [3]. Ever since cassava came into existence, peeling has been practiced although the instrument that was being used then was stone and anything with a sharp edge like knife which makes peeling large amount of cassava stressful and tedious. Adetan et al. investigated cassava peeling in Nigeria and realized that peeling of cassava tuber were usually done manually by mostly children and women due to the fact that mechanized cassava peeling machines were absent [14]. Although hand peeling method yields a good result as regard smoothness of the cassava root being peeled but the problem with it is that it is labor intensive and very slow [15]. Peeling will always be a challenge in designing an efficient mechanized cassava peeler for peeling and this is because cassava roots are different in weight, different in shapes, different in sizes, different in peel thickness, different in peel texture and different in a whole lot of properties. As a result of these, the challenges facing peeling will make designing an efficient cassava peeler very difficult to achieve [16]. This research work is aimed at developing a wet mechanical brushing unit for chemical pre-treated cassava root using abrasive method (wire brush) and then the evaluation so as to determine flesh that will be lost as well as its efficiency.

2. Methodology
The cassava roots used were freshly harvested and were also 13 months old. The variety which was used is the high yielding yellow cassava root (Provitamin A) specie UMUCASS44 which has a high pest and disease resistance and also contains B-carotene which is also a precursor of vitamin A.

2.1 Materials Used for the Work
The following materials and apparatus were used for the experiment

Cassava root (UMUCASS44),

Acid [95% concentrated Hydrochloric acid, (HCl)],

Base [Sodium Hydroxide pellets (NaOH)],

Glass rod

Water bath

Plastic bowls,

Acid resistance gloves,

Measuring cylinders,
Volumetric Flasks,
Spatula,
Conical flasks,
Thermometer,
Weighing balance,
Sensitive scale

2.2 Procedure for Preparation of Sodium Hydroxide Solution
About 300ml of distilled water was poured into a conical flask. 150g of sodium hydroxide pellets was measured using a sensitive scale, the sodium hydroxide pellets was poured into the conical flask containing the distilled water. The conical flask immersed in a cold water bath and contents of the flask was stirred using a glass rod till the pellet were dissolved. The solution was poured into a 1000ml volumetric flask and the volume was made up with distilled water. With these steps 15% sodium hydroxide solution (w/v) was prepared. For the preparation of the other concentrations the same procedure was followed. 200g and 300g of sodium hydroxide were used in the place of 150g to prepare 20% and 30% concentration of sodium hydroxide solution respectively.

2.3 Procedure for Preparation of Dilute Hydrochloric Acid
For the dilute acid, about 400ml of distilled water was poured into a 1000ml volumetric flask and the volumetric cylinder was immersed into a cold water bath. 150ml of concentrated hydrochloric acid was measured using a measuring cylinder; the measured acid was added gradually to the volumetric cylinder and the volumetric cylinder was completed with the distilled water. With these steps 15% dilute hydrochloric acid (v/v) was prepared. For the preparation of the other concentrations the same procedure was followed. 200ml and 300ml of concentrated hydrochloric acid were used in the place of 150ml to prepare 20% and 30% dilute hydrochloric acid respectively.

2.4 Pre-Treatment
The pre-treatment involves the dipping of cassava roots in a sodium hydroxide and neutralizing it with dilute hydrochloric acid at specified temperature, time and concentration.

2.4.1 Procedures for Dipping the Cassava Roots in Sodium Hydroxide Solution and Dilute Hydrochloric Acid
Sodium hydroxide solution at 15% and dilute hydrochloric acid at 15% were heated to a temperature of 60°C using a heated water bath. The cassava roots (UMUCASS44) were prepared for testing weighing it using a weighing balance. The cassava roots were then immersed into a plastic bowl containing 15% sodium hydroxide at 60°C for a period of 15minutes. The cassava root was then transferred into a stainless steel bowl containing 15% dilute hydrochloric acid and all observations were recorded. The root was then measured using a weighing after which it was put in the brushing unit for brushing action. After the brushing the roots was measured and observations were recorded. The procedure was repeated for 20% concentration at an immersion time of 20minutes and 30% concentration at immersion times of 10, 15 and 20minutes and temperature of 100°C.
2.5  Design Considerations

2.5.1 Design Analysis for the Wet Mechanical Brushing Machine
The following were identified as needs necessary in order to analyze the component parts of the machine;

2.5.2 Shaft Design
The minimum shaft diameter of medium carbon steel needed to avoid failure of the shaft was calculated using the equation (1) [17]:
\[ T_a = \frac{60P}{2\pi N} \]
Where:
P is power delivered.
N is the speed of the rotation in r.p.m.
The torque on a solid shaft was calculated using equation (2) [17]
\[ T = \frac{\pi}{16} d^3 \tau \]
Where \( \tau \) = the torsional shear stress
\( do \) = the outer diameter of the shaft (medium carbon steel)
\( di \) = the internal diameter of the shaft (medium carbon steel)

2.5.3 Pulley Design
A mild steel pulley was used to connect the motor to the driver shaft. The diameter and the speed of the driver shaft were obtained by the following relationships
\[ \frac{N_1}{N_2} = \frac{D_2}{D_1} = V \cdot R \]
\[ N_1 = \frac{60V_1}{ID_1} \]
Where:
\( D_1 \) = diameter of the driver pulley,
\( D_2 \) = diameter of the driven pulley,
\( N_1 \) = speed of the driver pulley,
\( N_2 \) = speed of the driven pulley and
\( V \cdot R \) = velocity ratio

2.5.4 Spring Design
Helical springs were used to subject the cassava to compressive load. The springs used for this machine had of a diameter of 3mm, modulus of rigidity (G) of 80kN/m² modulus of elasticity (E) of 210kN/mm², and allowable shear stress (\( \tau \)) of 420Mpa (light service) [17]. The solid length of the spring was determined from equation (3) [17].
\[ L_s = n^1 \times d \]
Where:
\( n^1 \) = total number of coils
\( d \) = diameter of the wire
Free length of the spring was determined from equation (4) [17].
\[ L_f = n^1 \cdot d + \delta_{\text{max}} + (n^1 - 1) \times 1 \text{mm} \]
Spring index was obtained from equation (5) [17].
\[ C = D/d \]
Where
D is the mean diameter of the spring coil.
d is the diameter of wire.
The spring rate was obtained from equation (6) [17].

\[
K = \frac{w}{\delta}
\]

(6)

Where:
W is the Load and
\( \delta \) is the deflection of the spring wire.
The resultant shear stress induced in the wire was obtained from equation (7) [17].

\[
\tau = \tau_1 \pm \tau_2 = \frac{8WD}{d^3} + \frac{4W}{\pi d^2}
\]

(7)

Where;
\( \tau_1 \) = Torsional shear stress
\( \tau_2 \) = direct shear stress due to load
D = Mean diameter of spring coil
d = diameter of spring wire

The stresses that can be developed in a cylindrical thin shell due to an internal pressure of the wall were determined.
The wall of the cylindrical shell was subjected to an internal pressure hence; it was able to withstand tensile stresses of the following types.
Hoop stress or circumferential stress was obtained from equation (8) [17]

\[
\sigma = \frac{Pd}{2t}
\]

(8)

Where;
P = Intensity of internal pressure
d = Internal diameter of the cylindrical shell
t = Thickness of the cylindrical shell and

3. Result and Discussions

3.1 Effect of Chemical Pre-Treatment with sodium hydroxide (lye) on Whole Cassava Roots

The whole cassava roots of high yielding yellow cassava variety (UMUCASS44) was used for this experiment. The roots were cleaned to remove soil before treatment with Lye solution of 15%, 20% concentration at 60°C for 15mins and 20mins; and 30% concentration at 100°C for 10mins, 15mins and 20mins. The purpose of treatment of the cassava roots with lye is to enhance digestion and peel removal. The observation obtained at different concentration, temperature and time was recorded as shown in table 1 through 3 below.

Table 1: effect of 15% concentration of lye on whole cassava roots at different predetermined time and temperature
Time | Temperature | Observation
--- | --- | ---
15minutes | 60°C | The color of the solution change from transparent to brown. The periderm softens and was easily removed with wire brush leaving scratched surface of cortex.

20minutes | 60°C | The periderm was completely detached from the cortex and the cortex became softer and was easily removed by brushing with the wet mechanical brushing unit.

For 15% concentration of sodium hydroxide and 15% concentration of hydrochloric acid: As seen in table 1, at immersion time of 15mins and temperature of 60°C the periderm became soft and was easily peeled off from the root while the cortex remained intact. The volume of peel removed from the root was rather low but marked a significant point for peeling of cassava using lye. At immersion time of 20mins the peel removal by brushing increased significantly, the periderm was removed easily and the cortex softened.

Table 2: effect of 20% concentration of lye on whole cassava roots at different predetermined time and temperature

| Time   | Temperature | Observation                                                                 |
|--------|-------------|-----------------------------------------------------------------------------|
| 15minutes | 60°C       | The periderm became darken and the whole peel was removed with wire brush. The scratched surface of the starchy part of the root became brownish in color. |
| 20minutes | 60°C       | The size of peel removed was high after brushing with the wet mechanical brushing unit. The cassava flesh retained a light brown appearance. |

For 20% concentration of sodium hydroxide and 20% concentration of hydrochloric acid: A better peel removal was observed at this concentration. The surface of the peeled cassava changed color from its milky white appearance to a light brown appearance. The change in appearance of the peeled cassava at higher temperature can be attributed to the effect of lye concentration, temperature and immersion time on the peeled product. The discoloration on the root flesh happened when the heat enters into the tissue thereby leading to an increase in temperature which is sufficient enough to activate the respiratory system but not sufficient enough to activate the polyphenoloxidase enzyme. The
polyphenoloxidase enzyme then reacts with 0-dihydroxyphenols which leads to a change in color. As seen in table 2, at immersion time of 15 minutes and temperature of 60°C the periderm and cortex softened; and at immersion time of 20% the periderm and the cortex remained soft and when brushed they were easily removed by the action of the brushing unit.

Table 3: effect of 30% concentration of lye on whole cassava roots at different predetermined time and temperature

| Time    | Temperature | Observation                                                                 |
|---------|-------------|-----------------------------------------------------------------------------|
| 10 minutes | 100°C       | The color of the solution becomes more brownish. The color of the periderm lightens after soaking for 10 minutes. The cortex softens. |
| 15 minutes | 100°C       | The color of the solution becomes brownish. The periderm becomes light in color and breaks off. The cortex becomes softer. |
| 20 minutes | 100°C       | The color of the solution still remains brown. The periderm and the cortex become softer and are easily peeled by the brushes. The cassava roots were cooked. |

At 30% concentration of sodium hydroxide and 30% concentration of hydrochloric acid: The peeling of the root was effective because the periderm and cortex were over soft leading to the cooking of the roots. There was obvious discoloration on the starchy roots from white to light brown due to the high temperature of 100°C and this was noticeable at the different immersion times.

3.2 Summary of Performance Evaluation of Mechanical Brushing unit for Chemically Pretreated Cassava Roots

The cassava roots were washed weighed (the values recorded) and immersed in the chemical: lye solution of 15% concentration at 60°C for 15 and 20 mins, 20% concentration at 60°C for 15 mins and 20 mins; and 30% concentration at 100°C. After the pre-treatment, the cassava roots were washed thoroughly in water before being hand-fed into the machine through the hopper. The peeled roots were weighed and their weights recorded. The peeled roots were again weighed to determine the peeling efficiency of the machine.

Table 4: determination of percentage weight of peel manually
When the machine was used to peel lye pre-treated cassava roots at (15% concentration at 60°C for 15mins and 20mins), the periderm was removed completely and some part of cortex were still attached to the roots. From the results recorded in table 10 and 11 it can be concluded that

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------|---------------------------|------------------------|
| 1           | 0.68                          | 0.56                                          | 0.08                                   | 0.15                                 | 82.35                     | 53.33                  |
| 2           | 0.57                          | 0.51                                          | 0.06                                   | 0.12                                 | 89.47                     | 50.00                  |
|            |                               |                                               |                                        |                                      |                           | 51.67                  |

Table 5: performance of machine brushing on lye pre-treated cassava roots at 15% concentration at 60°C for 15mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------|---------------------------|------------------------|
| 1           | 0.70                          | 0.62                                          | 0.08                                   | 0.15                                 | 88.57                     | 53.33                  |
| 2           | 0.59                          | 0.52                                          | 0.07                                   | 0.13                                 | 88.14                     | 53.85                  |
| Average     |                               |                                               |                                        |                                      |                           | 53.59                  |

When the machine was used to peel lye pre-treated cassava roots at (15% concentration at 60°C for 15mins and 20mins), the periderm was removed completely and some part of cortex were still attached to the roots. From the results recorded in table 10 and 11 it can be concluded that

% Weight of peels = \( \frac{\text{weight of peels}}{\text{Weight of unpeeled roots}} \times 100 \)

Weight of peel removed manually = % weight of peels (0.2178) \times weight of unpeeled roots

The peeling efficiency of the machine = \( \frac{\text{Weight of peels removed by machine}}{\text{Weight of peels removed manually}} \times 100 \)
the peeling efficiency of the machine at that concentration is between 51.67% and 53.59% depending on the weight of the cassava root that was used and the immersion time.

Table 7: performance of machine brushing on lye pre-treated cassava roots at 20% concentration at 60°C for 15mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------|---------------------------|------------------------|
| 1           | 0.62                          | 0.51                                          | 0.11                                   | 0.14                                 | 82.26                     | 78.57                  |
| 2           | 0.58                          | 0.48                                          | 0.10                                   | 0.13                                 | 82.76                     | 76.92                  |
| Average     |                               |                                               |                                        |                                      |                           | 77.75                  |

Table 8: performance of machine brushing on lye pre-treated cassava roots at 20% concentration at 60°C for 20mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------|---------------------------|------------------------|
| 1           | 0.64                          | 0.54                                          | 0.10                                   | 0.14                                 | 84.38                     | 71.43                  |
| 2           | 0.60                          | 0.51                                          | 0.09                                   | 0.13                                 | 85.00                     | 69.23                  |
| Average     |                               |                                               |                                        |                                      |                           | 70.33                  |

When the machine was used to peel lye pre-treated cassava root at (20% concentration at 60°C for 15mins and 20mins), all the peels were removed greatly, and both the cortex and the periderm were removed with each stroke of the wire brush. The peeling efficiency at 15mins immersion time ranged from 78.57% to 76.92% and for 20mins it ranged from 71.43% to 69.23%.

Table 9: performance of machine brushing on lye pre-treated cassava roots at 30% concentration at 100°C for 10mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------|---------------------------|------------------------|
| 1           | 0.56                          | 0.47                                          | 0.09                                   | 0.12                                 | 83.93                     | 75.00                  |
| 2           | 0.61                          | 0.52                                          | 0.09                                   | 0.13                                 | 85.25                     | 69.23                  |
| Average     |                               |                                               |                                        |                                      |                           | 72.12                  |
Table 10: performance of machine brushing on lye pre-treated cassava roots at 30% concentration at 100°C for 15mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|---------------------------------------------------|----------------------------------------|-------------------------------------|---------------------------|------------------------|
| 1           | 0.50                          | 0.42                                              | 0.08                                   | 0.12                                | 84.00                     | 66.67                  |
| 2           | 0.52                          | 0.44                                              | 0.08                                   | 0.11                                | 84.62                     | 72.73                  |
| Average     |                               |                                                   |                                        |                                     |                           | 69.70                  |

Table 11: performance of machine brushing on lye pre-treated cassava roots at 30% concentration at 100°C for 20mins

| Replication | Weight of unpeeled roots (kg) | Weight of completely peeled roots by machine (kg) | Weight of peels removed by machine (kg) | Weight of peels removed manually (kg) | Percentage loss in machine | Peeling efficiency (%) |
|-------------|-------------------------------|---------------------------------------------------|----------------------------------------|-------------------------------------|---------------------------|------------------------|
| 1           | 0.59                          | 0.51                                              | 0.08                                   | 0.13                                | 86.44                     | 69.23                  |
| 2           | 0.63                          | 0.53                                              | 0.10                                   | 0.14                                | 84.13                     | 71.43                  |
| Average     |                               |                                                   |                                        |                                     |                           | 70.33                  |

At 30% concentration at 100°C, there was a drop in peeling efficiency at the three different immersion time as compared to that of 20% as seen in table 9, 10 and 11, although the peels were removed by the machine. The cassava roots also appeared cooked. The peeling efficiency at this stage ranged from 66.67% to 75.00%.

In summary, the mechanical brushing system (using combined brushing) can be effective for removing peels from cassava roots pre-treated with lye solution. But the peeling efficiency depends largely on the concentration of the solution and duration of dipping.

4. Conclusion
As recorded in the above work, using lye solution to digest cassava root peel depends on the severity of the concentration of the solution and the time of root immersion. From the preliminary labouratory tests carried out so far, the optimal combination of process parameters in terms of concentration, temperature and time of root immersion for UMUCASS44 in lye are 20%, 60°C and 15 minutes, respectively. These values are sufficient to digest the peels of the root for enhanced brushing.
5. **Recommendations**

i. Lye dip at 20% concentration of NaOH, at 60°C for 15 minutes is adequate to soften the peel of the cassava roots tested.

ii. Cassava root to be pre-treated should, as much as possible, be free from open cuts and wounds to avoid reaction of the chemical with starch which will result in heat ring formation.

iii. Temperatures above 60°C for immersion will cause light brown coloration on the edible starchy flesh as such altering the color of the processed products.

iv. For an improved model, research should be carried out to come up with a more suitable form of brushes that will reduce the rate at which the wire brushes pierces into the cassava flesh.

v. For an improved model of the brushing unit, the water spray should be introduced and also the trough for the model should be semi-circular in nature, this will give room for free movement of the cassava roots.

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