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Development of a Cassava Peeling Machine: A Tool for Enhancing Food Sustainability

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ABSTRACT

Pupuru is a variety of foodstuff processed from Cassava (Manihot esculenta) tubers. The post-processing of cassava to pupuru involves series of stages and one of these stages is peeling. Traditionally, the peeling operation is mainly done with crude implement, precisely knives and cutlasses; a task which makes it difficult to meet the global demand of the consumers. In view of this, there is need to develop a plan for increasing its quantity, including the quality at reduced human intervention but with improved economy of return. This study focuses on the development of a 20 kg/h cassava peeling machine for use in pupuru processing plant. The machine basically comprises the frame, peeling chamber, and the power transmission system. The results of the performance analysis of the machine revealed that its hourly peeling capacity ranges from 24 - 39 pieces/h; peeling efficiency ranges from 81.94 – 94.40%, and peeling rate ranges from 0.00072 – 0.00096 kg/s when used to peel feedstock whose geometric dimensions (diameters) are in the range of 62.50 – 88.20 mm diameter. Findings from the study revealed that the peeling performance of the machine improves as the geometric dimensions of the feedstock increase. It was concluded that the incorporation of this machine into the pupuru processing line would ameliorate the age-long yearnings of the processors, increase the productivity, and improve the quality of the product and financial benefits of the stakeholders.

1. INTRODUCTION

Cassava, (*Manihot esculenta*), is one of the major sources of carbohydrate in most developing nations of the world; it is second only to sweet potato among the starchy root crops (Diop and Calverley, 1998). Cassava tubers when processed for human consumption, depending on the sequences of the processing techniques, yield different food items, such as: *Garri, Lafun, Fufu*, cassava grit and *Pupuru*. *Pupuru* is the local name of one of the fine white flours obtained from processed cassava tuber (Daramola *et al*, 2010). The act or technique of processing it originated from the Ilajes of the riverine area in Ondo State, Nigeria.

Due to the increase in the consumption of *pupuru,* both within Nigeria and across borders, caused by its recognized nutritional and health benefits; the traditional method employed by its processors has been found incapable of meeting the global demand. However, of all the unit operations involved in the processing, peeling is one of the processing stages. Peeling is the process of removing a thin layer usually called the peel from a stock (Tobiloba *et al.,* 2019).

Cassava peel exists in two layers, namely the outer layer called the periderm or cork tissue, and the inner layer named the cortex (Agbetoye *et al,* 2005). The thickness of the cassava peel ranges between 1.19 – 4.72 mm (Adetan *et al.,* 2003; Oriola and Raji, 2014 Ilori *et al.,* 2017; Ogunnigbo *et al*., 2022).

The peeling stage has proven to be a major challenge in *pupuru* processing due to the fact that most of the producers (are small-scale stakeholder who) rely on the use of traditional tools, sch as knives, to peel the cassava; a task which is laborious, unhygienic (due to contamination arising human contact), ineffective (as the edible part is sometimes severed with the coat) and risky (as it could make the processor to injure itself in case of any slight mistake). Besides, the inconsistent shapes and sizes of the tubers further complicate the peeling process; and this has made it difficult to peel a large amount of Cassava root, according to Igbeka (1985)

Efforts to overcome this hurdle have resulted in the development of different devices to achieve this objective. Ajibola and Babarinde (2016) presented a detailed design and fabrication of a cassava peeling machine, the researchers emphasized the importance of optimizing the peeling mechanism to minimize product loss and ensure safety. Similarly, Francis *et al*, (2022) conducted a review of mechanical cassava peeling methods, with the intension of providing valuable insights into the design considerations for developing effective peeling machines

Oluwole and Adio (2013) developed a batch cassava peeling machine capable of handling one diametric size of cassava tubers at a time. The machine worked on the principle of abrasive peeling using a stationary outer abrasive drum and a rotating inner abrasive drum, based on its batch capacity of 8.5 kg, cut tuber lengths of 200 mm and diameters of 90 mm. Findings revealed that the machine had an average peeling efficiency of 65.6 %; average flesh loss of 5.5 %, and percentage of broken cassava of 2 % when taken at interval of 5 minutes' time durations. It was reported that as the inner peeling drum rotational speed increased from 364 – 394 rpm, peeling efficiency decreased from 70.34 – 60.22 % and tuber flesh loss increased from 5.07 – 5.97 %. Based on this, the researchers recommended that cutting of the tubers should be made at regions very close to the diametric dimensions to facilitate better peeling and minimize manual finishing. Meanwhile, the design was not able to peel all sizes of cassava tubers.

A cassava peeling machine that can efficiently peel all roots from different sources is therefore difficult to design because of the large differences in root characteristics. This research intends to develop a machine capable of reducing this challenge by devising a machine that could peel different sizes of feedstock fed into it.

2. MATERIALS AND METHODS

2.1. Materials Collection

The materials utilized in the study can be classed into: the performance evaluation materials, otherwise termed as the feedstock and fabrication materials, besides the instrumentations. The feedstock, Cassava tubers, were obtained from Ibule-soro Market in Akure, Ondo State. The fabrication materials, such as the electric motor, stainless sheet and electrode were procured from Owode Market in Lagos State and Agodi-Gate spare parts market in Ibadan City, whilst mild steel related materials were procured from Metal Stalls, Cathedral in Akure, Ondo State.

2.2. Design Assumptions

The following assumptions was considered in the course of designing the machine:

(i) The rated capacity of the machine is 20 kg/hr. Acceleration due to gravity (g) is 9.81m/s^2)
(ii) Optimum Peeling Speed of a cassava tuber is 350 rpm.
(iii) Cutting force for fresh cassava tuber is 88.30 N (Yisa *et. al.*, 2017)

2.3. Estimation of the Physical Properties of the Cassava Tubers

For the purpose of having accurate data concerning the feedstock to be processed with the machine and appropriate design parameters for developing it, Samples of the feedstock were randomly picked, and weighed with weighing balance to determine their respective masses/weights, the big -end diameters of the selected samples were measured with vernier caliper to determine their geometric dimensions, both before and after manual peeled with a knife, and estimating the thickness of the coats.

2.4. Determination of Actual Mass Feedstock Required

Assuming φ (%), called the waste factor, denotes the fraction of the tubers peeled off with the coat or washed off with water, the required mass (m_{act}) and pieces of the unpeeled feedstock required to achieve the rated capacity (m_r) was estimated with Equation (1).

$$m_{act} = m_{rf}\left[1.0 + \frac{m_p}{m_u}\right](1 + 0.01\varphi) \quad (1)$$

and the number of unpeeled tubers (N_u)required can be estimated with Equation (2)

$$N_u = \frac{m_{act}}{m_u} \quad (2)$$

2.5. Determination of the Size of the Electric Motor

2.5.1. Force and torque required

The force required to achieve effective peeling, which is the sum of the gravitational force (F_g), centripetal force (F_c) and frictional force (F_f), was determined with Equation (3) (Gupta and Khurmi, 2009) modified by Ayodeji *et al.* (2021):

$$F_T = m_{act}\left[g + \frac{V^2}{r}\left[1 + \left(0.54 - \frac{42.6}{152.6+v}\right)\right]\right] \quad (3)$$

where: v, denotes the rated speed of the cassava peeling machine (v), was estimated with Equation (4)

$$v = \frac{\pi DN}{60} \quad (4)$$

The friction factor (μ) produced as a result of the rubbing action was determined with equation (5), according to (Khurmi and Gupta, 2009)

$$0.54 - \frac{42.6}{152.6+v} \quad (5)$$

and the torque generated (T_T) as a result of the force can be expressed with Equation (6)

$$T_T = F_T r \quad (6)$$

where: r is the radius of peeling shaft (in m).

2.5.2. Electric motor Power Required

The size of electrical power (P) required was estimated with Equation (7).

$$P = T\omega + F_c v = \frac{2\pi NT}{60} + F_c v \quad (7)$$

where: T is the torque generated (in N-m) due to components of the peeling force and ω is the angular velocity (in rad/s).

2.6. Determination of Size of Peeling Chamber

The peeling chamber, which serves as a temporary bin for the feedstock, comprises two sections, a cuboidal top section and truncated-pyramidal-base left-skewed to one side. The geometrical shapes were selected to facilitate adequate relative motion among the power transmission system required for the peeling operation, optimal conveyance of feedstock, and discharge of the peeled and peels. It was fabricated with stainless steel as a result of the nature of the feedstock and the health-related benefits to the consumers. The capacity of the peeling chamber (in kN-h) was determined with modified Equation (8), according to Sadhu (2009) and Ayodeji *et al.*, (2021)

$$Q_P = 3.6\,\frac{\pi}{4}[D_P^2 - (2d_{sh} + t_c)^2]\varphi v_p \rho_c \quad (8)$$

where: d_{sh} is diameter of the two opposing rotating shafts (60.1 mm), D_p is equivalent diameter of the peeling chamber, t_c is the thickness of the cassava tuber (60 mm), φ is the trough loading factor (15 %); v_p is the rotational velocity and ρ_c is density of the feedstock (910 kg/m^3).

2.7. Design of the Power Transmission Components

2.7.1. Gearsets

For the purpose of preventing slipping and reducing the bending component of the moment when pulley with more grooves were employed for transmitting power, two (2) similar sets of gears and sprockets with chain were utilized. Since the centre-to-centre distance between the shafts (l_c) is 132 mm, the properties of the two gears (driver and driven) were determined with Equations (10) – (15), as described by Ballaney (2009), Basu and Rai (2010), and Gope (2012);

The base circle radii of the mating gears can be determined with Equation (10).

$$R_{bi} + R_{b2} -= [R_{pi} + R_{p2}]\cos\emptyset \quad (10)$$

The sum of pitch circle radii of the two mating gears (R_{pi} and R_{p2}) is referred to as the centre distance of the gears.

Addendum (a) denotes the radial height of the tooth above the pitch circle; the circle forming this profile is called the addendum circle and the diameter or radius of this circle is called addendum diameter /radius (D_a or R_a). For a standard tooth gear, according to Ballaney (2009), D_a can be described with Equation (11) as:

$$D_a = D_p + 2m \quad (11)$$

The dedendum (d) is the radial depth of the tooth below the pitch circle. The diameter of the dedendum, otherwise called the dedendum diameter (D_d), was determined with Equation (12).

$$D_d = D_p - 2(1.157 * m) \quad (12)$$

For gears with module m and pitch circle radius R_p, the number of teeth (T) on each of the two equal spur gears was computed with Equation (13).

$$R_{p1} = R_{p2} = \frac{T*m}{2} \quad (13)$$

The gear clearance (c), according to Basu (2010) denotes the radial height difference between the the addendum and the dedendum of a tooth. The value of the standard teeth clearance was determined with Equation (14).

$$t_c = 0.157 * m \quad (14)$$

The contact ratio, otherwise called the number of pair of teeth of contact (n_{tc}) was estimated with Equation (15).

$$n_{tc} = \frac{2\left[\left(R_a{}^2 - R_p{}^2\, cos^2\emptyset\right)^{0.5} - R_p \sin\emptyset\right]}{\pi m cos\emptyset} \quad (15)$$

2.7.2. Sprocket and chain

The sizes of the sprockets and chain with reference to the geometric properties were determined with modified Equations (16) – (20) as described by Fenner (2001); Martin (2011); Tsubaki (2013):

Design power (P_d)

This serves as the basis for selecting respective drive; the design power which is the product of the nominal running power (P_r*f_s) and the service factor (f_s), was determined with Equation (16)

$$P_d = P_r * f_s \quad (16)$$

Speed ratio (r_s)

It is the ratio of the speed of the faster shaft (z_1) to the speed of the slower shaft (z_2). Since the intension was to allow the two shafts, on which the peeling kits were mounted to run at same speed but in opposite direction; It was calculated with Equation (17).

$$r_s = \frac{z_1}{z_2} \quad (17)$$

Chain length (L_p)

The chain length for a chain pitch (L_{cp}) was determined with equation (18)

$$L_p =$$

the pitch circle diameter (PCD or D_p) obtained with equation (19)

$$D_p = L_{cp}/sin\left[\frac{180}{z}\right] \quad (19)$$

And the standard outside diameter, including the teeth bottom diameter (D_{tb}) of the sprocket ()D_{os} for a roller diameter D_r estimated with expressions (20) and (21)

$$D_{os} = L_{cp}\left[0.6 + \cot\left[\frac{180}{z}\right]\right] \quad (20)$$

$$D_{tb} = D_p - D_r \quad (21)$$

2.8. Fabrication of The Peeling Machine

Individual components, besides the bought-outs, of the machine were fabricated in accordance with their specifications as detailed in their respective working drawings. The machine parts were afterward assembled with reference to the assembly drawing. The construction was carried out at the engineering workshop of the Department of Mechanical Engineering, FUTA. Figure 1 and Plate 1 present the isometric view (drawn with Solidworks computer software) and picture of the developed peeling machine.

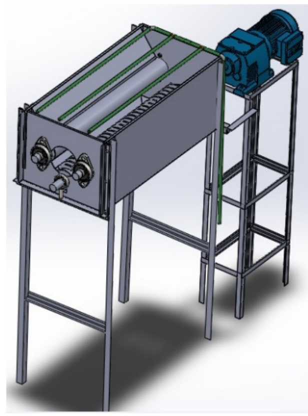

Figure 1: Isometric view of the peeling machine

Plate 1: picture of the peeling machine

2.9. Preparation of Feedstock for Machine Evaluation

Unit sample of the feedstock was picked, and its mass (m_n) noted with a scale balance (Model: SF-400)). The measured feedstock was then sequentially charged into the inlet chute of the developed peeling machine and the operation initiated. The masses of the unpeeled and peeled feedstock, including peeling time taken were recorded with mass balance and stopwatch. The afore-mentioned procedure was replicated to obtain five (5) consecutive trials, as presented in Table 4.

3. RESULTS AND DISCUSSION

3.1. Design Analysis

This section outlines results of the design analysis used for selecting the basic components of the machine and developing the peeling machine, with reference

3.1.1. Measured parameters on the feedstock

The geometric analysis of the samples of the feedstock (Cassava tubers) revealed the following properties (Table 1). Based on the results of the geometric properties obtained through participant observation, a clearance of 65 mm was considered and maintained between the two opposite rotating shafts, as this would facilitate free conveyance of peeled feedstock, but impede the movement of the unpeeled until they are reduced in sized lesser than the space.

Table 1: Results of the measured parameters

S/N	Big diameter (mm)		Length of unpeeled (mm)	Mass (g)		Peel thickness (mm)	Fraction (%)	
	Unpeeled	Peeled		unpeeled	peeled		Coat	Tuber
1	67.00	62.50	323.00	717.00	642.00	2.25	10.40	89.53
2	62.55	60.15	283.00	618.00	559.00	1.20	9.55	90.45
3	67.55	62.45	320.00	751.00	684.00	2.55	8.92	91.07
4	66.25	63.10	340.00	1005.00	889.00	1.63	11.54	88.45
5	67.55	64.00	260.00	597.00	552.00	1.78	7.58	92.46
Average	66.18	62.44	305.20	737.60	665.20	1.88	9.59	90.39

3.1.2. Summary of calculated and adopted data

Table 2 presents summary of the calculated and adopted data obtained using relevant formulae and engineering standards for the purpose of facilitating principle of interchangeability of parts. Table 3 presents geometric properties of the two gearsets.

Table 2: Summary of the calculated and adopted data

S/N	Particular	Equation No.	Calculated `data	Adopted
1	Actual feedstock capacity (kg)	1	23.058	23.058
2	Pieces of unpeeled feedstock required	2	31.26	32
3	Power rating of reduction motor (W)	7	205	358
4	Diameter of the peeling chamber (mm)	8	220	220

Table 3: Geometric properties of the two gearsets

S/N	Property	Equation No.	Calculated	Adopted
1	Base circle radius, R_{bi} (mm)	10	62.02	62.0
2	Addendum circle radius, R_a, (mm)	11	68.00	68.0
3	Dedendum circle radius, R_d, (mm)	12	64.843	64.8
4	Number of teeth (T)	13	66	66
5	Teeth clearance, t_c, (mm)	14	0.314	0.3
6	Teeth contact ratio, n_{tc}	15	1.80	1.8
7	Total depth, d_t, (mm)	11, 12	3.16	3.2
8	Working depth, d_w, (mm)	11, 12 and 14	2.84	2.8

From Table 3 (S/N-6), a contact ratio (n_{tc}) of 1.80 was obtained and adopted; This value (1.80) depicts that almost two pairs of teeth would always be in mesh for every rotation of the gearsets. In order words, the contact ratio of 1.80 signifies that for every rotation of the gearsets, as one pair of teeth is in contact the second pair would be in contact 80 % of the time. These geometric properties were considered acceptable as the calculated value is within the range of the standard values, 1.2 – 2.0, considered for smooth operation. This aligned with the findings of Ballaney (2009) that for continuous power transmission and quick operation to be maintained between mating gearsets in contact, the contact ratio should always be greater than unity. Table 4 presents the details of the geometric properties of the sprockets and chain drive utilized for transmitting motion between the auger and two opposite peeling shafts. Based on the estimated values of the geometric properties, 36 pitches of 08B-1 chain, and 80 – 15 steel plate sprockets (Driver and Driven) with 67 mm outside diameter, 61.08 mm pitch circle diameter and 13 mm minimum bore were selected.

Table 4: Geometric properties of the sprockets and chain

S/N	Property	Equation No.	Calculated	Adopted
1	Design Power, P_d (W)	16	0.385	0.385
2	Speed ratio	17	1.0	1.0
3	Chain length, L_p (pitches)	18	35.79	36
4	Pitch circle diameter, PCD, (mm)	19	61.08	61.08
5	Standard outside diameter, D_{os}, (mm)	20	67.37	67.40
6	Teeth bottom diameter, D_{tb}, (mm)	21	51.16	53.16

3.2. Performance Evaluation

The performance evaluation of the developed peeling machine was carried out on 7th March, 2024 between the hours of 10.00 am – 2.00 pm at the Central Workshop of the Department of Mechanical Engineering of The Federal University of Technology, Akure. Data regarding mass, geometric dimensions (bigger diameter) and peeling time of the feedstock utilized, both before and after peeling with the aid of the machine, were taken with appropriate instrumentations. The obtained data were used to compute the performance properties of the machine, namely: hourly removal capacity, peeling removal rate and peeling efficiency Table 5 presents the results of the experimentations. Columns (vi), (iv) and (iii) of Table 5 present results of the variation in the peeling time with diameters of the feedstock. results revealed that the peeling time ranges from 92.5 – 152.5 s. It was observed that as the diameter of the feedstock increases the peeling time required for the peeling operation also increases.

Table 5. Summary of the experimental results

S/N	`feedstock property before		Feedstock property after		Peeling time (sec)	Difference		Peel removal rate		Hourly capacity (pc/h)
	Mass (kg)	Diameter (mm)	Mass (kg)	Diameter (mm)		(kg)	(mm)	kg/s	kg/min	
1	1,10	81.30	1.00	78.80	105.42	0.10	2.50	0.00095	3.41	34
2	0.72	62.50	0.59	60.20	135.50	0.13	2.30	0.00096	3.46	27
3	1.20	72.80	1.10	70.80	138.40	0.10	2.00	0.00072	2.60	26
4	0.80	88.20	0.69	85.40	152.12	0.11	2.80	0.00072	2.60	24
5	1.25	79.81	1.18	76.90	92.5	0.07	2.91	0.00076	2.72	39

The increase in the peeling time could be attributed to the fact that as the feedstock advanced along by the rotation of the auger shaft, the rubbing action of the feedstock against the walls of the two (2) opposite rotating shafts created a reverse motion, depending on the value of frictional force produced caused by the rubbing action, which caused reduction in the relative motion of the feedstock and caused it to move at speed lower than the rotational speed of the machine, and hence increase in the peeling time or residence time. The results of the analysis also showed that the machine has the least peeling rate of 0.00072 kg/s and maximum of 0.00096 kg/s. The peeling rate increases as the diameter of the feedstock increases. This progressive increase could be traced to the fact that as the diameter of the feedstock increases the geometric surface area of the feedstock rises. Based on this, the increase in the surface area enabled the charged feedstock to firmly occupy the space between and be in contact with the two opposite rotating shafts; this effect caused the feedstock to be properly peeled off or decorticated on both sides by the rotating shafts as they advance along the length of the peeling chamber. This condition also accounted for the reduction in the peeling time of feedstock whose geometric dimensions are in close par with design assumptions utilized in the design analysis. These results align with the findings of Oriola and Raji (2014) that the rubbing of feedstock with each other increases the efficiency. More so, the machine attained the least and maximum hourly peeling capacities of 24 and 39 pieces. However, the increase in the peeling time, peeling rate and hourly peeling capacity when sample with reduced diameters (surface area) were fed into the machine could be attributed to the fact that some of them got stalked/entangled in the clearance between the auger and the two opposite rotating shafts and as such spent longer time (idle) until they got disengaged, and continued afterward, after being bruised, shattered or broken into fragment. This condition also accounted for the abrupt reduction in the mass, geometric dimensions (e.g., diameter) of the charged feedstock, and increase in the peeling rate and hourly peeling capacity of the machine.

4. CONCLUSION

The objective of this study which is the development of a 20 kg/h peeling machine for use in pupuru processing plant has been achieved. The motive for developing the machine centers on the need to facilitate enabling environment for the stakeholders engaging in the processing of *pupuru* so that they can meet its global demand. The machine whose major components, besides the frame, are of stainless materials origin was developed with locally sourced materials. The results of the performance analysis revealed that it has range of hourly peeling capacity of 24 - 39 pieces/h; peeling efficiency of 81.94 – 94.40 %, and peeling rate of 0.00072 – 0.00096 kg/s when used to peel feedstock whose geometric dimensions (diameters) are in the range of 62.50 – 88.20 mm diameter. Findings from the study revealed that the peeling performance of the machine improves as the geometric dimensions of the feedstock increase. Therefore, the incorporation of this machine into the pupuru processing plant would facilitate improvement in the output, quality, financial benefits of the stakeholders and reduction in fatigue experienced by the processors

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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