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Evaluation of Cassava Peeling Machine using Dimensional Analysis Technique

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Abstract

Cassava processing for various products requires an efficient peeling process. However, peeling – the first step in its processing – has been considered laborious and time-consuming; hence, the need for full mechanization. Several mechanical peeling approaches have been exploited by researchers toward achieving ideal peeling. In this study, an innovative abrasive cassava peeling machine, combining chemical and mechanical peeling methods, was used for the experiment using TMS 30572 and TME 419 cassava cultivars. The physical and technological characteristics of the motion of the roots within the peeling compartment were subjected to analysis. Model equations based on dimensional analysis were adopted to predict the functionalities between cassava and the peeler variables. The following cassava roots properties were established: distal diameter (TME 419: 15.20-26.50 mm; TME 30572: 10.20-35.10 mm), peel thickness (TME 419: 1.60-4 mm; TME 30572: 1.80-4 mm) and moisture content (TME 419: 59.20-61.18%; TME 30572: 58.40-60.40%). The machine's peeling efficiency (μ), mechanical damage (λ), peel retention (P) and throughput capacity (η) were 62.02-86.45%, 1.26-2.90%, 8.26-11.63%, 900-1,210.5 kg/h, respectively, for both cultivars. A linear relationship was found between the machine speed, velocity of conveyance and peeling time. The study revealed that the machine resulted in the careful removal of the cassava peels achieving good peeling efficiency at a speed of 1,600 rpm < Nt < 2,600 rpm depending on the variety. It is recommended for peeling operations in cassava processing factories.

***Keywords**:* abrasive peeling, cassava, dimensional analysis, postharvest technology

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1. Introduction

The Food and Agricultural Organization of the United Nations (FAO) reported that Africa, Asia, Latin America and the tropical region consume cassava (*Manihot esculenta* Crantz). Cassava is rich in starch, commonly grown in tropical regions, a source of income among people, and considered a food security crop due to its food and non-food applications. Millions of people are involved in its production, processing, marketing and distribution (Food and Agriculture Organization Corporate Statistical Database [FAOSTAT], 2016, 2020; Parmar *et al*., 2017). According to FAOSTAT (2016), cassava is the second most widely planted food crop in Sub-Saharan Africa, and it is cultivated on approximately 17 million hectares. Acreage under cassava cultivation is expected to increase, which underscores the crop's importance on farmers and processors' livelihood in the continent (Jarvis *et al*., 2012). Cassava is the most important staple tropical root crop, the third most significant source of calories in the tropics and the sixth most important global food crop after sugar cane, maize, rice, wheat and potato (Tomlins and Bennett, 2017; Adegoke *et al*., 2020). Similarly, it is a major staple food in Nigeria wherein it is consumed daily by over 100 million people with an average daily capital consumption of 230 g per person (Phillips *et al*., 2004). The edible part of the fresh root contains 32-35% carbohydrate, 2-3% protein, 75-80% moisture, 0.1% fat, fiber and 0.70-2.50% ash (Oluwole *et al*., 2004); it also contains micronutrients such as beta carotene, Fe and Zn. Nigeria is the largest producer of cassava in the world with a production level estimated at 57,134,478 tons per year (Uthman, 2011; FAOSTAT, 2020). Nearly 70% of cassava is processed into household staples (Phillips *et al*., 2004); hence, tapping into the micro-industry and rural processing of cassava is the more effective pathway to commercialization.

Cassava is mostly processed traditionally in Nigeria into local foods like *gari*, *lafun*, *fufu*, *abacha* and *akpu*, while the sweet varieties are boiled and pounded into a dough and consumed with vegetable soup (Oriola and Raji, 2013). In Ghana, cassava is further processed into *kokonte* and *agbelima* (Quaye *et al*., 2009). Oriola and Raji (2013) also reported that cassava is a veritable food crop in Nigeria viewing the expanse of its cultivation, production and volume of cassava the country turns out every year. It has a great potential of yielding exports in exchange for foreign currencies. It is an emerging industrial and food security crop across the globe and its importance cannot be downplayed. The abovementioned positions were corroborated by Adegoke *et al.* (2020) and Adetunji and Quadri (2011), who claimed that cassava has numerous value-added products all over the world with home use consumptions and industrial applications. On a global scale, not less than 800 million people get a chunk of their daily dietary energy from cassava and its products. Out of this multitude, around 500 million people are domiciled in sub-Saharan Africa (Sowmyapriya *et al*., 2017).

Cassava roots have a very short shelf life often attributed to the postharvest physiological deterioration (PPD), which commences as a natural response to bruises on the roots often associated with harvest practices (Sánchez *et al*., 2013; Parmar *et al*., 2017; Zainuddin *et al*., 2018). It affects the quality of starch granules obtainable from the roots as well as the good quantity that may be needed. It makes cassava inedible, thereby reducing its market value and acceptability for processing operations into value-added products. As a result, the volume of trade for cassava is lower compared with other crops such as maize and wheat, primarily because fresh cassava has a short shelf-life of 48 h (Bennett, 2015; Tomlins *et al*., 2021). The FAO reported 30% losses in cassava while other reports are lower. Naziri *et al*. (2014) reported 8% losses in Nigeria. Conversion in the form of processing operations of freshly harvested cassava roots is the panacea to its preservation and reduction of postharvest losses associated with it. In its processed form, cassava can be made available on the shelf as glucose syrup, ethanol, high-quality cassava flour, chips, and pellets, among others (Tomlins *et al*., 2021).

Processing cassava into finished and semi-finished products involves peeling and other unit operations. Peeling cassava is as old as the crop itself, but peeling devices have progressed from stone and wooden flight through basic household knives to motorized machinery. This makes peeling a significant amount of cassava a chore (Igbeka, 1985; Parmar *et al*., 2017). Due to a variety of reasons, including the physical qualities of cassava tubers, like uneven shape, mechanized peeling has yet to be fully developed to match the worldwide best practices (Agbetoye, 2005; Anjali, 2019). However, there has been a slew of cassava peelers in the market, with varying degrees of efficiency and restrictions (Ejovo *et al*., 1988; Adetan *et al*., 2003; Adegoke *et al*., 2020). Mechanizing cassava processing operations requires the design and development of equipment such as cassava peelers. Several attempts have been made at solving these problems, which resulted in the development of various types of cassava peeling machines (Odigboh, 1976; Ezekwe, 1976; Nwokedi, 1984; Ejovo *et al*., 1988; Itodo, 1999; Sheriff *et al*., 1995; Olukunle, 2005; Olukunle and Ademosun, 2006). However, most of these machines have been widely acknowledged as inefficient (Adetan *et al*., 2006; Davies *et al*., 2008; Kolawole *et al*., 2010; Olayanju *et al*., 2019).

As mentioned previously, the widely reported difficulty in developing a cassava peeling machine has been the irregular shape of the cassava tuber. Very often, the peeling across the length of the cassava root is not evenly done. Effective peeling could be done at the proximal end while the same may not be observed at the middle and distal ends of the cassava root. Adetan *et al.* (2003) and Oriola and Raji (2013) reported the properties of cassava roots. They posited that surface taper angle, thickness of the peel, proportion by weight of peel, peel penetration force, tuber shape and size are critical properties of cassava roots that affected the effectiveness and performance of a mechanical peeling machine. Some of the problems with these machines also include the peeling-off of an unacceptable percentage of useful flesh during mechanical peeling and a reduction in peeling efficiency with increased time of operation (Oriola and Raji, 2013). As such, one of the goals of many researchers is to develop new methods and improve existing ones to produce perfect peeling conditions by utilizing the physical and mechanical qualities of the product (Ohwovoriole *et al*., 1988; Oluwole and Adio, 2013). Various product qualities have been employed to improve the efficiency of proposed peeling processes or devices depending on the suggested approach. Despite various attempts, some food components, such as mangoes, are regularly peeled by hand, and peeling methods for others, such as cassava, potato, yams and pumpkin, are far from optimal (Emadi, 2005; Egbeocha *et al*., 2016). Olayanju *et al.* (2019) reported that Odigboh (1976) also identified the time of the year when the tuber is harvested, as well as the time that passes before the tuber is peeled, as some of the elements that cause wide differences in the peel properties of tubers.

Odigbo (1976; 1983) developed a manually operated cassava peeler with no peeling time. The peeler had high peeling loss and consumed a lot of human energy. A rotary peeler was developed by Ohwovoriole *et al.* (1988) with little loss of useful flesh; however, it still retains the arduous efforts of manual peeling. Ejovo *et al.* (1988) created a rotational batched cassava peeler that worked by compressing the unpeeled tuber against a sharp-edged rig and rolling off the skins without harming the tuber meat (peel-flesh separation through compression). Although the tubers were chopped into straight segments before being placed into the machine, a peeling efficiency of 92% was reported with minimal flesh loss. They did note, however, that the maturity of the roots had a significant impact on the machine’s performance. Abrasive peeling using drums and brush peeling techniques was attempted by several researchers like Nwokedi (1984), Akintunde *et al.* (2005) and Ugwu and Ozioko (2015); their demerits were low speed and high residence time.

Agbetoye *et al.* (2006) also developed a single and double-gang cassava peeling machine which was reportedly easy to operate and easy to work on but with an attendant low output capacity, and the tuber have to be cut into shapes. Double-action self-feeding and knife edge peelers were also developed (Adetan *et al.*, 2005; Olukunle *et al.*, 2010; Olukunle and Jimoh, 2012) with complex mechanisms, inability to peel small sizes of cassava and high tuber loss but with less power and energy consumption as merits.

Excellent operation and low cost were achieved using the 'lathe machine' principle by Abdulkadir (2012) despite its high mechanical damage. Other works (Olukunle and Jimoh, 2012; Olukunle and Akinnuli, 2012) adopted simplicity, maintainability and cost; however, the difficulty in peeling small sizes and highly technical operation were the disadvantages of the machine. The fixed outer peeling drum principle was used by Oluwole and Adio (2013), and they achieved a fast, reliable and effective peeler that needed low maintenance cost but tuber losses and the grating of cassava tubers were highlighted. Adegoke *et al.* (2020) has recently carried out some research works on the development of cassava peeling machine by Jimoh (2014), Ugwu and Ozioko (2015), Ajibola and Babarinde (2016), Jimoh *et al.* (2016), Aji *et al.* (2016) and Olayanju *et al.* (2019) where there were continual efforts to improve on the existing body of knowledge.

There are several disadvantages of the aforesaid machines as highlighted in the preceding texts. Some of them have not been adopted for use by small and medium-scale cassava processors due to cost and technology. In turn, manual and complex peeling operations cause larger material loss. The machine recently developed by Adegoke *et al.* (2020) achieved results that were very close to the 'ideal' peeling because of its very high efficiency, minimal flesh loss and mechanical damage, and its capacity to peel cassava irrespective of size and shape. However, the said hybrid peeling method entails the handling of a large number of roots that may be too much for village-level processors. Adegoke *et al*. (2020) made one of the latest efforts that deplored another approach to evaluate the machine's efficiency and other functionalities of cassava. Hence, this work used a dimensional analysis technique to develop the relationship between machine functional properties and some identified cassava characteristics and machine variables during the mechanical peeling process using two improved cassava varieties (TME 419 and TMS 30572). Having accurate knowledge of the engineering properties of agricultural products plays a vital role in designing and handling post-harvest equipment. This study analyzed the physical characteristics of cassava tuber and provided empirical information on the shape of cassava in relation to the cassava peeling process.

2. Methodology

2.1 Machine and Operation

The abrasive cassava peeling machine used for this study was developed by Adegoke *et al.* (2020) at the Department of Food Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The peeler was a hybrid peeling machine that effectively combined chemical and mechanical peeling methods. In this experiment and evaluation, the relationship between the cassava peeler and crop parameters was used for the evaluation according to the method of Jimoh *et al.* (2016). Only the mechanical peeling method which truly expressed the machine parameters was used.

The three fundamental quantities of mass (M), length (L) and time (T) were used to denote and express the mechanical quantities in this study. The symbols M, L and T were utilized to indicate fundamental dimensions. The concept of dimensional analyses was employed to predict the relationship between dimensionless functional properties, cassava (crop) and machine variables using some established model equations. The cassava peeling machine was designed to remove the entire peel of tubers at different feed rates. The machine was divided into the following parts: the hopper, peeling unit, outlet unit, diesel engine, peeler seat or hanger, driving and driven pulley (power transmission) and water pump/sprinkler jet. The machine had a variable speed of 1,600-2,600 rev/min with a diesel engine of 4.85 kW maximum power rating. The design of the machine was based on the development and modification of the peeling tool of previous cassava peeling machines as reported by Egbeocha *et al.* (2016). The machine was aimed at achieving a good configuration to achieve 90% cassava tuber flesh recovery irrespective of the size, shape, variety and orientation of the tuber. The main components of the peeler, described by Adegoke *et al.* (2021), included a peeling chamber, abrasive peeling drum, frame, hopper and the transmission system. A sprinkler at high pressure sprays water on the roots when the machine was running. After the machine ran for 20 to 25 min, the recycled water turned into 'fruit water.'

The high pressure water and the tubers were propelled by the centrifugal force against the walls of the perforated stainless drum resulting in abrasion of the tubers and eventual removal of the cassava peel. It took 4 to 6 min to peel a batch of cassava in the machine. At the start, clean water of pH 7 was used but as the peeling operation continued, the recovered fruit water was reused as water jet in the peeling. The pH of the cassava fruit water ranged from 3.6 to 4.5. The fruit water had a mild acidity with a positive impact on the peeling process. It gave the peeling tubers a mild chemical pre-treatment effect to augment the mechanical peeling process. The roots were propelled by centrifugal force courtesy of the drive system consisting of belt and pulley arrangement with a speed ratio of 1: 4 between the drive and the driven pulley.

The peeling chamber was designed to accommodate 30-100 kg of fresh cassava roots at a batch with a discharge gate to offload peeled roots. The base of the peeling machine conjoined with the driven system of the machine had a little clearance that disallowed clogging of the peels and other extraneous materials to go through. A guard in the form of a lid was constructed to guard the roots from falling off during operation and with an opening for the water jet or sprinkler. The machine was constructed to maintain good engineering practices in the food processing outlets as the machine's water jet sprinklers cleaned up the machine before and after every use, with high water economy, bearing in mind the water recovery system. The cassava peeler, shown in Figures 1 and 2, is one of the latest efforts in the development of cassava peeler in Nigeria.

2.2 Determination of Physical and Engineering Properties of Cassava Root

In this study, some engineering properties of improved cassava varieties related to their peeling mechanization were determined. Two improved cassava varieties (TME 419 and TMS 30572) (Figure 3) utilized for the research work were harvested from the cassava demonstration plots of Cassava Adding Value for Africa 2 (CAVA 2) plots at the Federal University of Agriculture, Abeokuta, Ogun State. The selection of TME 419 and TMS 30572 cassava varieties was based on their classification as improved cassava varieties. They are also commonly grown cassava varieties in Nigeria, and their cultivation is being promoted by many government agencies and development partners/projects in the country. The high demand for these varieties by industrial end users was also a major factor. All instruments used were calibrated by AVOLAD Nigeria Limited, Ikeja, Lagos, Nigeria according to the Nigeria Industrial Standards (2019) to ensure accuracy and precision.

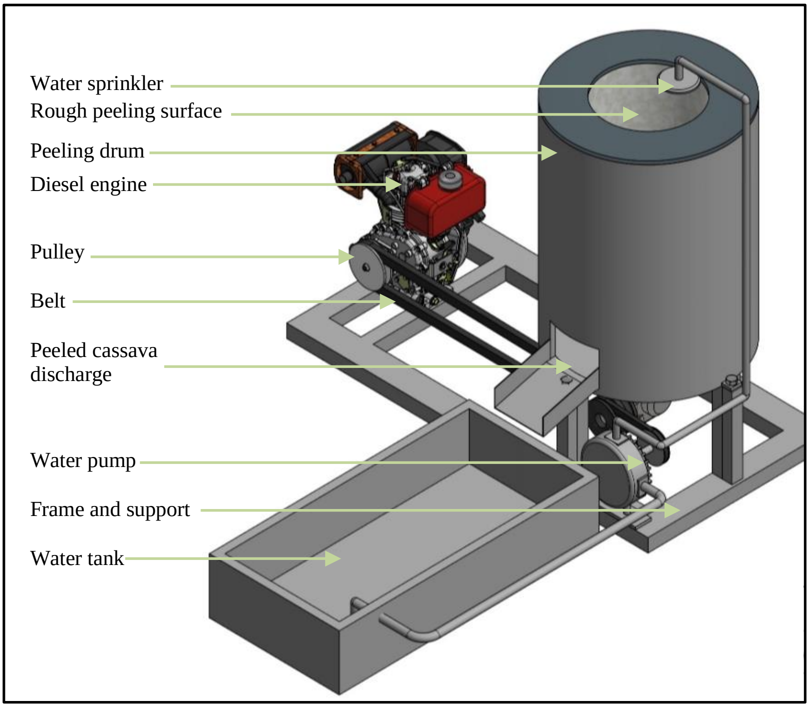


Figure 1. The peeling machine with its labelled parts

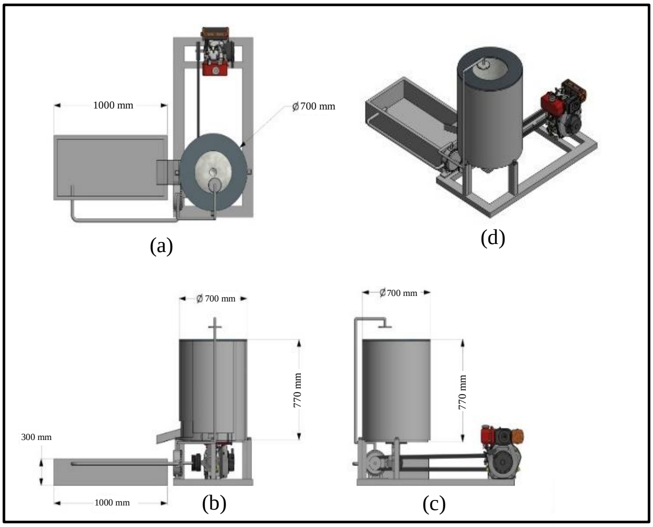


Figure 2. The top (a), back (b), side (c) and isometric (d) views of the developed cassava peeler

Figure 3. The TME 419 (a) and TMS 30572 (b) cassava varieties

2.2.1 Weight of Cassava Roots

The weight of 15 cassava roots was taken using a weighing scale (DBTW, Avolad Engineering, United Kingdom) (0-150 kg) for each variety. The mean weight of the cassava roots was determined by dividing the sum of the weights by the number of roots (Arisa, 2014).

2.2.2 Diameter of the Cassava Roots

The diameter of the proximal end, distal end and middle of the two cassava varieties were determined using a Vernier caliper (Vigor, Germany). This was done by measuring the diameter of the distal and middle ends of the selected 15 roots of each variety. The means of the diameters were calculated, and the mean values were obtained (Arisa, 2014).

2.2.3 Peel thickness of the Cassava Roots

A Vernier caliper was used to measure the thickness. The peel thickness was calculated using Equation 1 (Arisa, 2014).

$$Peel\ thickness = \frac{Ttcrp}{Ttcrs} \quad (1)$$

where *Ttcrp* means the total thickness of cassava peel and *Ttcrs* stands for the total number of cassava roots sampled.

2.2.4 Length of the Cassava Roots

The lengths of the two cultivars were determined using a measuring tape (Arisa, 2014). Fifteen tubers for each variety were measured, and the lengths were calculated using Equation 2.

$$Length\ of\ cassava\ root = \frac{Tlcr}{Tncrs} \tag{2}$$

where *Tlcr* is the total length of cassava roots sampled (mm) and *Tncrs* is the total number of cassava roots sampled.

2.2.5 Moisture Content Determination

The AOAC International's (2005) method was adopted in the determination of the moisture content of the samples. Clean crucibles were heated and dried in an oven at 105 °C, later cooled at room temperature in desiccators using dry silica gel for 40 min and weighed as W_1. Five grams of each sample was weighed into the crucible and the weight was recorded as W_2. The crucibles and their content were transferred into the hot air oven (Gallemkamp, England) at a temperature of 105 °C for 3 h. Subsequently, the samples were cooled and weighed. The final weight and the crucible were taken as W_3. The dry basis moisture content in percentage was deduced using Equation 3.

$$\%\ Moisture = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100 \tag{3}$$

2.2.6 Starch Content Determination

The method described by International Starch Institute (2014) in Denmark was adopted for the determination of the starch content of the cassava roots. This hydrostatic method/under-water method can be applied to potato and cassava.

2.3 Mathematical Modeling of Mechanical Peeling

A mathematical model of the mechanical peeling process was developed. The applicability of the model to the peeling industry was emphasized. The variables of input and output of the model were chosen from important effective parameters related to the product and the peeling machine as described by Emadi *et al.* (2007). The evaluation of the mechanical peeling process was studied using a mathematical model in which the relationship between the cassava peeler and crop parameters were used as subordinate and insubordinate variables for the evaluation according to the method (Jimoh *et al.*, 2016). The concept of dimensional analyses was adopted in predicting the connection between dimensionless functional properties, cassava (crop) and machine parameters using the Buckingham Theorem established model equations.

2.3.1 Theoretical Analysis

The tuber movement in the mechanical system was analyzed and characterized by a continuous movement of the tuber in the peeling chamber. It is worth noting that the crop, machine and operational variables were in a close relation such that changing one variable would automatically affect other variables. The analytical approach, according to Jimoh (2014), reported that the subordinate parameters can be readily observed as the function of some insubordinate variables.

Subordinate parameters were mechanical damage (λ), peel retention (P), peeling efficiency (μ) and throughput capacity (η). Insubordinate parameters were moisture content, peel shear stress (τ), the mass of tuber (t_w), length of tuber (t_l), the proportion by peel (w_p), thickness of the peel (t_p), the force of penetration in peel (f), moisture content (φ), speed of the machine (s), conveyance velocity (v) and residence time in the peeling chamber (t).

Well noted was the motion tending to move away from the center of the co-rotating cavity, the cassava root possessed a cumulative force exerted on it toward the center of the circle having a quantitative relation of v^2/R, where v is the speed of transmission and R is the radius of the cassava root (Jimoh *et al.*, 2016).

Equation 4 gives the summation of forces. According to Jimoh (2014), the cumulative force is parallel and the stationary force produced by friction F_s gives the force toward the center that holds the cassava roots from sliding in the direction of the tangent surface of the abrasive tool (Equation 5).

$$\sum F = \frac{t_w \ v^2}{R} \tag{4}$$

$$F_s = t_w a \tag{5}$$

Force due to friction, F_s, is a relation of the conveyance speed. Combining Equations 4 and 5 gives Equation 6.

$$F_s = \frac{t_w v^2}{R} \tag{6}$$

Notably, the force due to friction, F_s, increases as the speed of conveyance, v increases and the maximal frictional force gives maximal conveyance speed in Equation 7.

$$v_m \text{ is } F_{s.max} \frac{t_w v^2}{R} = F_{s.max} = \mu F_N = \mu_s t_w g \tag{7}$$

Deriving v_m from Equation 7 above gives Equation 8.

$$v_m = \sqrt{\mu_s gR} \tag{8}$$

Thompson (1999) reported that μ_s is the ratio of the weight of the cassava roots being moved along the surface of the peeler and the force that maintains contact between the peeler and cassava roots surfaces; and F_N is the vertical force acting perpendicularly.

2.3.2 Theoretical Model

Dimensional analysis and similarity prerequisites requiring the peeling machine and cassava root parameters to be the same in the motion of parts were used to obtain the dimension and performances of the prototype peeler from cassava roots and the peeling machine parameters. The connection of subordinate and insubordinate variables was constituted by parameters that affected the performance of the machine intending to determine efficiency.

Buckingham Π Theorem proves the conclusion, that, if a functional relationship contains *m* variables with a total of *n* basic dimensions, on the application of dimensional analysis, the relationship will contain *m-n* groups of dimensionless groups. Denoting the variables irrespective of being insubordinate or subordinate a functional series will comprise variables x_1, x_2, …, x_m using Equations 9 and 10 (Jimoh *et al.*, 2016).

$$f(x_1, x_2, \ldots, x_m) = 0 \tag{9}$$

Procedurally, using the dimensional analysis on the assumption of the variables having *n* basic dimensions, the function is then transformed to Equation 10.

$$f(\Pi_1, \Pi_2, \ldots, \Pi_{m-n}) = 0 \tag{10}$$

Evaluating the Π's, *n* of the variables is selected as re-occurring variables. It then reflects *n* as a basic dimension as shown in Equations 11, 12 and 13 (Jimoh *et al*., 2016).

$$\Pi_1 = (x_1^{a11} x_2^{a12} \ldots . x_n^{a1n}) x_{n+1} \tag{11}$$

$$\Pi_2 = (x_1^{a21} x_2^{a22} \ldots . x_n^{a2n}) x_{n+2} \tag{12}$$

$$\Pi_{m-n} = (x_1^{a(m-n)1} x_2^{a(m-n)2} \ldots x_n^{a(m-n)n}) x_m \tag{13}$$

The fundamental dimensions then become the basic dimension and are expressed as an exponential equation raised to the power of zero in all the equations. The variables are denoted with respect to the fundamental dimensions; the Π is equally symbolized. Equations 11, 12 and 13 with the exponents are solved by equating the exponent of each basic dimension to the power of zero.

Using the principle of dimensional commonality in modeling, the efficiency of the cassava peeling machine is shown in Equations 14 and 15 (Jimoh *et al.*, 2016).

$$\mu = f(w_p, t_p, F, \tau, \varnothing, v, s, t_{cb}, t) \tag{14}$$

$$f_1 = (\mu, w_p, t_p, F, \tau, \varnothing, v, s, t_{cb}, t) = 0 \tag{15}$$

With ten variables and mass (M), length (L) and time (T) as the three principal dimensions in Equations 14 and 15, the solution gives seven Π terms. To select the re-occurring variables, it is better to select one that showcases the conveyance of the tubers, another to depict the mass of moving tubers and the last to denote the characteristic dimension of the peel (Jimoh *et al.*, 2016).

Consequently, v, F, t_p were obtained (Equations 16, 17 and 18).

$$f_2\left(\mu, \frac{v^2 w_{p,}}{F t_{p,}}, \frac{\tau,}{F}, \phi, \frac{s}{v}, \frac{t_{cb},}{t_p}, \frac{vt}{t_p}\right) = 0 \tag{16}$$

$$\lambda = f(t_w, l, t_{p,}\ F, \tau, \phi, v, s, t_{cb,}\ t) \tag{17}$$

$$f_1 = (\lambda, t_w, l, t_{p,}\ F, \tau, \phi, v, s, t_{cb,}\ t) = 0 \tag{18}$$

There are eleven variables and three basic dimensions M, L and T as shown in Equations 19, 20 and 21. However, the solution yielded eight Π terms. Therefore,

$$f_2\left(\lambda, \frac{t_w v^2,}{F t_p}, \frac{l,}{t_p}, \frac{\tau,}{F}, \phi, \frac{s}{v}, \frac{t_{cb},}{t_p}, \frac{vt}{t_p},\right) = 0 \tag{19}$$

In modelling of peel retention, P is depicted in Equation 20 (Jimoh *et al.*, 2016).

$$P = f\left(l, w_{p,}\ t_{p,}\ F, \tau, \phi, v, s, t\right) \tag{20}$$

$$f_1 = \left(P, w_{p,}\ t_{p,}\ F, \tau, \phi, v, s, t\right) = 0 \tag{21}$$

There are ten variables and three basic dimensions M, L and T. Hence, the solution yields seven Π terms in Equations 22 and 23 according to Jimoh *et al.*, (2016).

$$f_1 = \left(P, \frac{l,}{t_p}, \frac{w_p, v^2}{Ft_p,}, \frac{\tau,}{F}, \phi, \frac{s}{v}, \frac{vt}{t_p}, \right) = 0 \tag{22}$$

$$\eta = f_1(t_w, v, s, t) \tag{23}$$

Modelling of throughput capacity is obtained in Equations 24 and 25.

$$\eta = f_1\left(\frac{v}{t_w}, \frac{s}{t_w}, \frac{t}{t_w}\right) \tag{24}$$

To render the variables dimensionless from the functional relationships, Equation 24 gives the throughput capacity.

$$\eta = f_2\left(\frac{v}{t_w}, \frac{s}{t_w}\right) \tag{25}$$

2.3.3 Evaluation Procedure

During the peeling operation, it was established that an accurate length and diameter of tubers could not be achieved based on the report of Jimoh *et al.* (2016). To this effect, the weight of the tubers was chosen as the constant variable. The machine was evaluated on the basis of weight classification using gear motor speeds of 1,600, 2,100 and 2,600 rev/min. Feeding of two varieties of cassava into the hopper was carried out and mass peeling processes at 30 and 50 kg for each of the machine speeds were also carried out.

The tuber flesh was collected at the outlet of the peeling machine while the peels were retained on the wire mesh strainer. The peeling machine parameters such as the peeling efficiency (%) (Equation 26), mechanical damage (%) (Equation 27), peel retention (%) (Equation 28) and throughput capacity (kg/h) (Equation 29) were duly obtained.

$$\mu = \frac{w_{pr}}{w_{pr} + w_{prh}} \tag{26}$$

$$\lambda = \frac{w_{trp}}{w_{trp} + w_{tc}} \tag{27}$$

$$P = \frac{w_{prh}}{w_{prh} + w_{pr}} \tag{28}$$

$$\eta = \frac{w_{pr} + w_{prh} + w_{trp} + w_{tc}}{t} \tag{29}$$

where w_{pr} is the weight of peel removed by the machine, w_{prh} is the weight of peel removed by hand after machine peeling, w_{trp} is the weight of tuber flesh removed along with peel, w_{tc} is the weight of tuber flesh completely peeled and t is the peeling time. It is imperative to generate a set of data validating the efficiency, performance and operationability of the developed cassava peeler.

2.3.4 Model Development

Mechanical peeling was carried out mostly based on applying abrasive and cutting forces. The peeling process can be split into two main stages namely fracturing of the skin and scratching along with removing the peel as formed chips. These operations are the main energy expenditures in mechanical peeling using abrasive surfaces.

The following assumptions were applied: (a) removing the peel occurred in layers and in the form of chips; (b) the peeling rate was in linear proportion to the peeling energy; (c) the angular velocity of the product was zero; (d) the size and the weight of products for each variety was the same.

2.4 Statistical Analysis

The experimental design using a four-level, two-factor central composite model and response surface methodology (RSM) was achieved using Design-Expert version 6.0.8 (Stat-Ease, n.d.) to investigate the effect of insubordinate variables. The insubordinate variables included loss due to the peeling, speed of the machine (rpm), flesh loss and weight of the peeled samples. Variables (e.g., peeling loss, unpeeled surface area and flesh loss) mass of the sample (30-50 kg) and machine speed within 1,600-2,600 rpm were taken as the response of the designed experiment. The responses were subjected to two-sample t-test distribution at a significant level of 5% using the Statistical Package for Social Science (version 21.0) (IBM Corporation, 2012).

3. Results and Discussion

3.1 Engineering Properties of TME 419 and TMS 30572 Cultivars

The results in Table 1 showed that the thickness values at the distal and proximal ends as well as the middle ranged from 1.6 to 4 mm for TME 419 cassava cultivars while the thickness values for TMS 30572 ranged from 1.8 to 4 mm. The thickness of the cassava peels tapers from the head to the apex or tip of the tuber. Any peeling technique to be used must be adjusted to suit these characteristics. The results obtained in this study are the same as the one's found by Ejovo *et al.* (1988) who reported an average thickness of 1.6 mm. Other scholars also highlighted peel thickness that concurs well with the present study (1.93-mm mean peel thickness [Aniedi *et al.*, 2012]; and peel thickness ranges: 1.25-3.95 mm [Ademosun *et al.*, 2012] and 1.20-4.15 mm [Adetan *et al.*, 2003]). This is a very important property needed for the design and fabrication of cassava peeling machines. If these exceed during mechanical peeling, the tuber's flesh sustains more damages.

On the other hand, the thickness of the peel at the distal, middle and proximal end by Ejovo *et al.* (1988) was observed to be considerably within the range (1.90, 1.60 and 1.40 mm, respectively) obtained in this study. Adetan *et al.* (2003) also reported an average peel thickness value of 2.21 mm which was also within the values obtained in the present work. It was observed that increased peel thickness (1 to 4 mm) decreased the peeling efficiency from 88.73 to 53.40%. The peel thickness consists of the periderm and the cortex. The peel thickness of the two varieties TME 419 and TMS 30572 was not significantly different ($p > 0.05$). The results obtained in this study showed that the tuber lengths were 213 to 286.20 mm for the two varieties. The tuber lengths of the TME 419 variety were within 213 to 251.30 mm, while TMS 30572 variety gave 213 to 286.20 mm. The results were within the range (120 to 400 mm) reported by Oriola and Raji (2013) and Adetan *et al.* (2003) for TMS 30572 and TMS 30555. They were also in good agreement with the range (190 to 490 mm) given by Ejovo *et al.* (1988) for a local cultivar of the bitter variety harvested 20 months after planting although they reported a considerably higher mean length (316 mm). This difference may be due to variations in the tuber age and the cassava cultivars used. The range of the diameter they reported was 18.80 to 88.50 mm; these were, however, slightly higher than those obtained in this study. Similarly, considerable differences were observed in the tuber diameter and peel thickness reported by Ejovo *et al.* (1988) compared with those obtained in the present work. The differences in the tuber age and the cassava cultivars used may be responsible for these variances.

Table 1. Properties of TME 419 and TMS 30572 cultivars

Cassava variety	Proximal diameter (mm)	Middle diameter (mm)	Distal diameter (mm)	Length (mm)	Moisture content (%)	Peel thickness (mm)
TME 419	54.60	41.30	23.50	213.80	60.12	2.00
	27.00	73.00	26.50	245.30	60.18	4.00
	64.30	51.80	24.50	251.30	60.29	3.00
	27.30	31.60	15.20	213.80	59.88	2.00
	29.10	40.00	23.50	213.80	60.12	1.80
	27.40	42.20	26.50	245.30	61.20	2.20
	45.80	63.00	24.50	251.30	59.20	3.20
	27.50	41.30	15.20	213.80	59.88	3.60
	53.70	70.00	23.50	213.80	60.12	2.20
	31.30	50.80	26.50	245.30	61.18	2.00
	26.80	30.60	24.50	251.30	60.29	4.00
	43.50	40.00	15.20	213.80	59.88	3.00
	27.00	42.20	23.00	213.00	60.12	2.00
	27.20	63.00	24.00	245.30	60.18	1.60
	54.00	41.30	23.40	251.30	60.29	2.00
TMS 30572	64.50	56.30	23.50	213.80	59.80	1.90
	54.80	41.60	21.60	241.80	59.53	3.40
	64.40	58.10	35.10	260.00	59.61	3.00
	54.30	40.20	24.40	286.20	59.62	2.80
	53.50	56.30	23.50	251.30	59.88	4.00
	49.40	41.60	26.50	213.80	59.53	3.00
	53.60	58.10	24.50	213.80	59.61	2.00
	60.50	40.20	10.20	245.30	59.62	1.80
	54.00	56.30	23.50	251.30	59.88	2.20
	49.00	41.60	28.50	213.80	59.53	2.40
	56.00	58.10	24.00	213.00	59.61	3.00
	63.50	40.20	16.20	245.30	59.62	2.80
	63.00	56.30	23.00	251.30	60.40	5.00
	57.20	41.60	27.00	213.80	58.40	2.40
	50.00	58.10	24.40	260.00	60.00	3.00

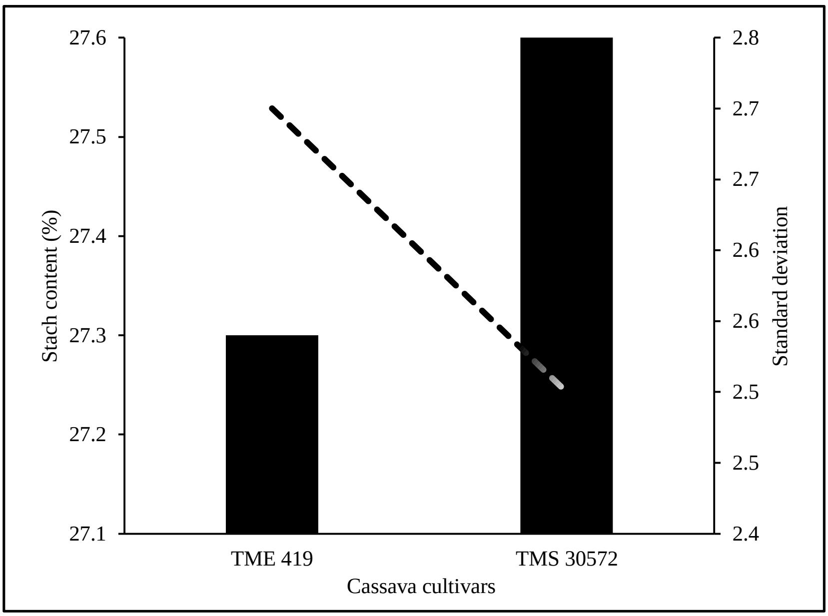
The results in Table 2 depicted the T-test between the physical and engineering properties of TME 419 and TMS 30572 cultivars. The distal end, middle diameter, proximal end, length, peel thickness and moisture content for TME 419 were 37.8, 48.1, 22.6, 232.1 and 2.60 mm and 60.2%, respectively, while it was 56.5, 49.6, 23.7, 238.3 and 2.8 mm and 59.6%, respectively, for TMS 30572. A significant difference ($p < 0.05$) was observed between the mean values properties of TME 419 and TMS 30572 except for distal and moisture content ($p > 0.05$).

Table 2. Comparison using T-test between physical and engineering properties of TME 419 and TMS 30572 cultivars

Parameters	TME 419	TMS 30572	t	Sig. (2-tailed)
Proximal end (mm)	37.8 ± 13.4	56.5 ± 5.4	-5.621	0.00*
Diameter (mm)	48.1 ± 13.3	49.6 ± 8.4	-0.365	0.72
Distal end (mm)	22.6 ± 4.0	23.7 ± 4.6	-1.072	0.30
Length (mm)	232.1 ± 18	238.3 ± 23.1	-0.685	0.51
Peel thickness (mm)	2.60 ± 0.8	2.8 ± 0.6	-0.604	0.56
Moisture content (%)	60.2 ± 0.5	59.6 ± 0.4	3.175	0.01*

*Significant difference ($p < 0.05$)

Figure 4 shows the mean and standard deviation of the starch content of TME 419 and TMS 30572 cultivars. TME 419 and TMS 30572 had starch content of 27.3 and 27.6%, respectively, with no significant difference ($p > 0.05$) between their mean values. The processing of cassava root for industrial or human use involves the consideration of different physical and engineering parameters for effective operations, especially in the development of peeling machines. Cassava root distal end, middle diameter, proximal end, length and peel thickness obtained in this study showed that TMS 30572 had higher physical and engineering properties values than TME 419.



Means are considered significant at $p > 0.05$.

Figure 4. T-test results of the starch content of TME 419 and TMS 30572

The comparison test, however, indicated an insignificant difference ($p > 0.05$) between the cassava varieties except for the distal end ($p < 0.05$). Ilori and Adetan (2013) reported that cassava root damage decreased with increasing peel thickness during the peeling process.

Meanwhile, the peeling adhesion to the flesh is a function of the amount of moisture content present in the cassava root and could serve as part of the determinant for peeling efficiency. Therefore, the higher the moisture content, the lesser is the peel adhesion to the root flesh; hence, the easier for the peels to be removed (Olukunle and Akinnuli, 2012). The moisture content of fresh cassava root obtained in this study was lower than the values reported by Omosuli *et al.* (2017). The moisture content of TME 419 and TMS 30572 was significantly different ($p < 0.05$). The difference may simply be due to the difference in terms of the variety. Although a similar range of values was observed in starch content (SC) with higher SC values obtained in TMS 30572 than in TME 419, there was no significant difference ($p > 0.05$) between the roots.

3.2 Evaluation of the Machine

Figure 5 also shows some portion of whole cassava roots soaked in fruit water generated from the recycling of feed water used in the peeling operation, and the peeled roots from combined effects of the mechanical operation with mild pretreatment in the form of soaking in fruit water as reported by Adegoke *et al.* (2021).

Mechanical damage in the peeling operation increased as the feed rate increased. Increasing the speed of the peeling machine resulted in an increased rate of mechanical damage. The adhesion between the peel of the cassava and the resilient nature of the cassava tuber flesh as a result of high moisture content may be responsible for the above report, knowing fully well that fresh cassava roots were used for these experiments. From the model equations used in this study, tuber weight and residence time were directly related to the throughput capacity of the peeling machine. In essence, the throughput capacity was increased with the machine speed and weight of the cassava tuber at a short residence time in the peeling chamber. These characterizations of the machine (machine speed, speed of conveyance of the tuber and its residence time) and the cassava tuber features are dimensionless insubordinate parameters.

Figure 5. The hybrid peeling process: the weighing of peeled cassava roots (a), pre-treatment of cassava roots with fruit water (b), the peeled cassava roots (c) and the cassava peels retained on the strainer (d)

Tables 3 and 4 show the dimensionless functional characteristics of the cassava peeler using the indented rough surface of abrasion during the peeling of two improved cultivars of cassava: TME 419 and TMS 30572. As the feed rate increased from 30 to 50 kg, the efficiency of the peeling machine slightly increased, and the peel retention slightly decreased particularly at low velocity (1,600-2,600 rev/min). The aforementioned can be attributed to the continued interaction between the cassava tubers and the abrasive surface. During the spinning and collision course of the tubers, there was a collision among the roots, which resulted in a very low velocity of conveying the roots at high feed rates. Jimoh *et al.* (2016) and Adegoke *et al.* (2020) disclosed similar trends in their works. At speeds of 2,100 and 2,600 rev/min rate of feeding the cassava roots (30-50 kg), the efficiency of the peeling process decreased while the retention of the peel was increasing. There was low interaction between the cassava roots and the rough abrasive wall of the peeling chamber of the machine. The reverse of the above played out at a higher speed with minimal contact between the wall of the peeler and the cassava roots.

Table 3. Dimensionless machine functional parameters during peeling of TME 419

Speed (rev/min)	Feed rate (kg)	Peeling efficiency (%)	Mechanical damage (%)	Peel retention (%)	Throughput capacity (kg/h)
1,600	30	76.80	2.89	10.20	957.14
	50	84.96	1.51	11.32	974.10
2,100	30	69.84	1.26	8.26	1210.50
	50	81.20	1.34	11.63	993.30
2,600	30	62.30	1.34	9.34	960.30
	50	86.45	1.42	10.35	971.43

Table 4. Dimensionless machine functional parameters during peeling of TME 30572

Speed (rev/min)	Feed rate (kg)	Peeling efficiency (%)	Mechanical damage (%)	Peel retention (%)	Throughput capacity (kg/h)
1,600	30	72.01	2.85	10.5	950.00
	50	86.42	2.32	9.06	992.50
2,100	30	64.20	2.90	10.62	950.00
	50	68.50	2.04	9.85	900.00
2,600	30	59.00	1.34	9.05	900.00
	50	62.02	2.36	9.43	1,110.42

4. Conclusion and Recommendation

Some physical and engineering characteristics of the freshly harvested two improved cassava varieties used in this study were determined, thereby providing broad-based engineering data hindering the successful mechanization of the peeling operation. By using dimensional analysis, model equations were established to predict the relationship between dimensionless functional properties, crop and cassava peeling machine parameters. Thus, this study has provided a scientific approach for the mathematical modeling of the mechanical peeling of cassava a progressive way forward towards the simulation of the cassava peeling operation. The force of attachment of the cassava periderm, sclerenchyma and parenchyma is weak in freshly harvested cassava roots. During the peeling operation, it will be good that peeling is done as a matter of expediency and urgency, that is, peeling should commence immediately after the cassava is pulled from the ground to minimize peeling loss and mechanical damage. As a way forward, determining the limits of the dimensionless functional machine characteristics and features across locations, edaphic conditions and landscapes using control charts is advised. The optimum performance was achieved when the speed and feed rate were about 1,600 rev/min and 50 kg, respectively. This information is important in cassava peeling mechanization. The use of this developed machine is strongly recommended for peeling operations in small, medium and large-scale cassava processing factories. Meanwhile, further work should be carried out using the following variables: weight (100-150 kg), time of peeling/period and more speed variations of the machine. To improve the performance of this machine, the machine speed should be kept at 2,100 rev/min with a standardized feed rate of 50 kg. The machine's size and appendage parts should also be improved; moving the machine around is currently difficult and requires too many hands or technicians to disassemble the parts. The food safety issue has to be studied as well using hydrocyanic acid to determine the cyanide that is inherent in bitter cassava varieties.

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6. References

Abdulkadir, B.H. (2012). Design and fabrication of a cassava peeling machine. IOSR Journal of Engineering, 2(6), 1-8. http://doi.org/10.9790/3021-02630108

Adegoke, A.F., Oke, M.O., Oriola, K.O., Adekoyeni, O.O., & Sanni, L.O. (2021). Experimental studies of a hybrid peeling process for cassava *(Manihot esculenta* crantz) roots and its effects on quality characteristics of some products. Proceedings of the 5th CIGR International Conference of the Canadian Society of Bioengineering, Quebec, Canada.

Adegoke, A.F., Oke, M.O., Oriola, K.O., & Sanni, L.O. (2020). Design, construction and performance evaluation of an innovative cassava peeling machine. Food Chain, 9(2), 107-131. http://doi.org/10.3362/2046-1887.18-00011

Ademosun, O.C., Jimoh, M.O., & Olukunle, O.J. (2012). Effect of physical and mechanical properties of cassava tubers on the performance of an automated peeling machine. International Journal of Development and Sustainability, 1(3), 810-822.

Adetan, D.A., Adekoya, L.O., & Aluko, O.L. (2003). Characterization of some properties of cassava root tubers. Journal of Food Engineering, 59(4), 349-353. http://doi.org/10.1016/S0260-8774(02)00493-4

Adetan, D.A., Adekoya, L.O., & Aluko, O.B. (2006). Theory of a mechanical method of peeling cassava tubers with knives. International Journal of Agrophysics, 20(4), 269-276.

Adetunji, O.R., & Quadri, A.H. (2011). Design and fabrication of an improved cassava grater. Pacific Journal of Science and Technology, 12(2), 120-129.

Agbetoye, L.A.S. (2005). Improving the technology of cassava harvesting and processing mechanization for food security in Nigeria. Proceedings of the International Conference on Science and Technology, Akure, Nigeria, 196-204.

Agbetoye, L.A.S, Ademosun, O.C., Ogunlowo, A.S., Olukunle, O.J., Fapetu, O.P., & Adesina, A. (2006). Developing indigenous machinery for cassava processing and fruit juice production in Nigeria. In J.A. Mwakali & G. Taban-Wani (Eds.), Proceedings of the 1st International Conference on Advances in Engineering and Technology, Entebbe, Uganda, 375-384.

Aji, I.S., Emmanuel, S., Abdulrahman, S.A., & Franklyn, O.F. (2016). Development of an electrically operated cassava peeling and slicing machine. Arid Zone Journal of Engineering, Technology and Environment, 12, 40-48.

Ajibola, W.A., & Babarinde, F. (2016). Design and fabrication of a cassava peeling machine. International Journal of Engineering Trends and Technology, 42(2), 60-64. http://doi.org/10.14445/22315381/IJETT-V42P214

Akintunde, B.O., Oyawale, F.A., & Tunde-Akintunde, T.Y. (2005). Design and fabrication of a cassava peeling machine. Nigerian Food Journal, 23, 231-238.

Anjali, A.V., Anjitha, P.K., Neethu, K.P., Arunkrishnan, A., Abdul Vahid, P., & Santhi, M.M. (2019). Development and performance evaluation of a semi-automatic pineapple peeling machine. International Journal of Current Microbiology and Applied Sciences, 8(11), 325-332. https://doi.org/10.20546/ijcmas.2019.811.041

Aniedi, O.E., Linus, O.A., Ime, A.E., & Benjamin, R.E. (2012). Mechanization of cassava peeling. Research Journal in Engineering and Applied Sciences, 1(5), 334-337.

AOAC International. (2005). Official methods of analysis of the Association of Official Analytical Chemists (20th ed.). Virginia, United States: AOAC International.

Arisa, N.U. (2014). Chemical peeling of some cassava cultivars (*Manihot esculenta* Crantz) and evaluation of the physicochemical and sensory characteristics of their products (Dissertation). Faculty of Agriculture, University of Ibadan, Ibadan, Nigeria.

Bennett, B. (2015). Guest editorial: Smallholder cassava production and the cassava processing sector in Africa. Food Chain, 5, 1-3.

Davies, R.M., Olatunji, M.O., & Burubai, W. (2008). Mechanization of cassava processing in Iwo local government area of Osun State, Nigeria. World Journal of Agricultural Sciences, 4(3), 341-345.

Egbeocha, C.C., Asoegwu, S.N., & Okereke, N.A.A. (2016). A review on performance of cassava peeling machines in Nigeria. FUTO Journal Series, 2(1), 140-168.

Ejovo, O.N., Oboli, S., & Mgbeke, A.C. (1988). Studies and preliminary design for a cassava tuber peeling machine. Transactions of the American Society of Agricultural Engineers, 31(2), 380-385.

Emadi, B. (2005). Experimental studies and modeling of innovative peeling process for tough-skinned vegetables (Dissertation). Queensland University of Technology, Brisbane City, Australia.

Emadi, B., Abbaspour-Fard, M.H., & Yarlagadda, P. (2007). Modeling of mechanical peeling of vegetables on the basis of energy consumption. In V.M. Salokhe, H.P.W. Jayasuriya & P. Soni (Eds.), Proceedings International Agricultural Engineering Conference, Bangkok, Thailand.

Ezekwe, G.O. (1976). A feature for achieving a constant depth of peel in the mechanical peeling of cassava. Nigerian Journal of Engineering, 1(3), 174-181.

Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). (2016). Statistical data base of the FAO. Rome, Italy: FAO.

Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). (2020). Statistical data base of the FAO. Rome, Italy

IBM Corporation. (2012). Statistical Package for the Social Sciences [Computer software]. New York, United States: IBM Corporation.

Igbeka, J.C. (1985). Storage practices of yam in Nigeria. Agriculture Mechanization in Asia, Africa and Latin America, 16, 55-58.

Ilori, O.O., & Adetan D.A. (2013). A study of the peel penetration pressure of two cassava varieties. African Institute for Science Policy and Innovation, Middle-East Journal of Scientific Research, 16(6), 884-889.

International Starch Institute. (2014). Starch technology. Retrieved from http://www.starch.dk/isi/starch/img/TM1-10e%20Tapioca%20starch.pdf

Itodo, I.N. (1999). Peeling rate of a manually-operated cassava (*Manihot esculenta* Crantz) peeling machine. African Journal of Root and Tuber Crops, 3(2), 3-7.

Jarvis, A., Ramirez-Villegas, J., Campo, B.V.H., & Navarro-Racines, C. (2012). Is cassava the answer to African climate change adaptation? Tropical Plant Biology, 5(1), 9-29. https://doi.org/10.1007/s12042-012- 9096-7

Jimoh, M.O. (2014). Effects of crop and machine parameters on the performance of an automated cassava peeling machine (Dissertation). Agricultural Engineering Department, Federal University of Technology, Akure, Nigeria.

Jimoh, M.O., Olukunle, S.I., & Manuwa, S.I. (2016). Modelling of cassava peeling performance using dimensional analysis. CIGR Journal, 18(2), 360-367.

Kolawole, O.P., Agbetoye, L.A.S., & Ogunlowo, A.S. (2010). Sustaining world food security with improved cassava processing technologies: The Nigerian experience. Sustainability, 2, 3681-3694. http://doi.org/10.3390/su2123681

Naziri, D., Quaye, W., Siwoku, B., Wanlapatit, S., Viet Phu, T., & Bennett, B. (2014). The diversity of postharvest losses in cassava value chains in selected developing countries. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 115(2), 111-123.

Nigeria Industrial Standards. (2019). Standards and specifications of the standards organization of Nigeria. Nigeria: Law Nigeria Admin.

Nwokedi, P.M. (1984). Performance of a cassava peeling machine. In E.R. Doku, E.V. Arene & Mahungu, N.M. (Eds.), Proceedings of the second triennial symposium of the International Society of Tropical Root Crops-Africa Branch, Doula, Cameroon.

Odigboh, E.U. (1976). A cassava peeling machine: Development, design and construction. Journal of Agricultural Engineering Research, 21, 361-369.

Odigboh, E.U. (1983). Cassava production, processing and utilization. In: H.T. Chan Jr. (Ed.), Handbook of tropical foods (pp. 145-200). New York, United States: Mercel Decker Incorporated.

Ohwovoriole, E.N., Oboli, S., & Mgbeke, A.C. (1988). Studies and preliminary design for a cassava tuber peeling machine. Transaction of the ASAE, 31(2), 380-385.

Olayanju, A.T., Moses, O.I., Clinton, E.O., Adewumi, S.A., & Muyiwa, G.F. (2019). Development of a ceramic cassava peeling-and-washing machine. Mindanao Journal of Science and Technology, 17, 84-97.

Olukunle, O.J. (2005). Development of cassava peeling machine. Proceedings of the Conference on the Global Food and Product Chain-Dynamics, Innovation, Conflicts, Strategies, Stuttgart-Hohenheim, Germany, 11-13.

Olukunle, O.J., & Ademosun, O.C. (2006). Development of a double action self-fed cassava peeling machine. Journal of Food, Agricultural and Environment, 4, 3-4.

Olukunle, O.J., & Jimoh, M.O. (2012). Comparative analysis and performance evaluation of three cassava peeling machines. International Research Journal of Engineering Science, Technology and Innovation (IRJESTI) 1(4), 94-102.

Olukunle, O.J., & Akinnuli, B.O. (2012). Performance evaluation of a single action cassava peeling machine. Journal of Emerging Trends in Engineering and Applied Sciences, 3(5), 806-811.

Olukunle, O.J., Ogunlowo, A.S., & Sanni, L. (2010). The search for effective cassava peeler. The West Indian Journal, 32(1&2), 42-47.

Oluwole, O.O., & Adio, M.A. (2013). Design and construction of a batch cassava peeling machine. Journal of Mechanical Engineering and Automation, 3(1), 16-21.

Oluwole, O.B., Olantunji, O., & Odunfa, S.A. (2004). Process technology for conversion of dried cassava chips into *gari*. Nigerian Food Journal, 22, 66-77.

Omosuli, S.V., Ikujenlola, A.V., & Abisuwa, A.T. (2017). Quality assessment of stored fresh Cassava Roots and '*fufu*' flour produced from stored roots. Journal of Food Science and Nutrition, 3(1), 9-13.

Oriola, K.O., & Raji, A.O. (2013). Trends at mechanizing cassava postharvest processing operations. International Journal of Engineering and Technology, 3(9), 1-5.

Parmar, A., Sturm, B., & Hensel, O. (2017). Crops that feed the world: Production and improvement of cassava for food, feed, and industrial uses. Food Security, 9, 907-927, https://doi.org/10.1007/s12571-017-0717-8

Phillips, T.P., Taylor, D.S., Sanni, L., & Akoroda, M. (2004). A cassava industrial revolution in Nigeria: The potential for a new industrial crop. Rome, Italy: International Fund for Agricultural Development Food and Agriculture Organization of the United Nations Rome

Quaye, W., Gayin, J., Yawson, I., & Plahar, W. A. (2009). Characteristics of various cassava processing methods and the adoption requirements in Ghana. Journal of Root Crops, 35(1), 59-68.

Sánchez, T., Dufour, D., Moreno, J., Pizarro, M., Aragón, I., Dominguez, M., & Ceballos, H. (2013). Changes in extended shelf life of cassava roots during storage in ambient conditions. Postharvest Biology and Technology, 86, 520-528.

Sheriff, J.T., Kurup, G.T., & Nanda, S.K. (1995). Performance evaluation of cassava peeling machine. Journal of Root Crops, 21(1), 30-35.

Sowmyapriya, S., Kalarani, M.K., Jeyakumar, P., Kennedy, Z.J., & Velmurugan, M. (2017). Assessment of biochemical changes during postharvest physiological deterioration in cassava tubers. International Journal of Pure and Applied Bioscience, 5(2), 732-739. https://doi.org/10.18782/2320-7051.2514

Stat-Ease. (n.d.). Design-Expert version 6.0.8. [Computer software]. Minnesota, United States: Stat-Ease.

Thompson, D.E. (1999). Design analysis: Mathematical modelling of nonlinear systems. Cambridge, United Kingdom: Cambridge University Press.

Tomlins, K., & Bennett, B. (2017). New uses and processes for cassava. Cambridge, United Kingdom: Burleigh Dodds Science Publishing.

Tomlins, K., Parmar, A., Omohimi, C.I., Sanni, L.O., Adegoke, A.F., Adebowale, A.R.A., & Bennett, B. (2021). Enhancing the shelf-life of fresh cassava roots: A field evaluation of simple storage bags. Processes, 9(4), 577-588. https://doi.org/10.3390/pr9040577

Ugwu, K.C., & Ozioko, R.E. (2015). Development and performance test of cassava peeling and mashing machine. International Journal of Scientific and Engineering Research, 6(6), 1572-1579.

Uthman, F. (2011). Design and fabrication of cassava lump breaking and sieving machine. Oasis Journal of Research and Development, 1(2), 42-50.

Zainuddin, I.M., Fathoni, A., Sudarmonowati, E., Beeching, J.R., Gruissem, W., & Vanderschuren, H. (2018). Cassava post-harvest physiological deterioration: From triggers to symptoms. Postharvest Biology and Technology, 142, 115-123.