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Review

A Review on the performance of some cassava peeling machines developed

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Abstract: Different operations are involved in the processing of cassava tubers for consumptive or industrial purposes. Most of the operations have been mechanized successfully except the peeling process, which still poses to be a major global challenge to engineers, henceforth, full attention is needed to develop a scientific solution to boost cassava production in the world market. The objective of this work presents some Strengths and limitations, performance evaluations, theoretical models, different functions, future areas of focus, and factors affecting some cassava peeling machines developed like the abrasive peelers, knife-edge peelers, stationary outer-drum peelers, etc. The peeling machines reviewed operated within 40-1500 rpm speed range, have 45-100% peeling efficiency, 2.7-2400 kg/hr throughput capacity, and 0-44% flesh losses. Several factors like the tuber physic mechanical and the machine properties affected the performance of the machines, of which some were the parameters of the theoretical models developed. Generally, increased machine speed increased the flesh losses and the throughput capacity, but the peeling efficiency increased in some machines and got decreased in others. The mechanical and the chemical methods combined in some of the works could not yield the desired result, it rather increased food losses. From the study, cassava peeling machine with a 100% peeling efficiency and 0% flesh losses, that is capable of giving the desired result has not been developed yet, hence, an artificial intelligence and biosensing technology should be considered in future developments.

Keywords: *Cassava Peeling Machine, Peeling efficiency, throughput capacity, flesh losses, and Cassava.*

List of Abbreviations

Abbreviations/Acronyms	Meanings
NCAM	National Center for Agricultural Mechanization
IITA	International Institute of Tropical Agriculture

PRODA	Project Development Institute
FAO	Food and Agriculture Organization
IFAD	International Fund for Agricultural Development
FUTA	Federal University of Technology Akure
FINIC	Fomel Industry & Industrialization Centre
NaOH	Sodium Hydroxide
M_{ce}	Effective machine capacity
l_1	Length of the line of contact of a knife with the root
l	Length of root slice
d_a	Average root diameter
F_p	The force that pressures the root
V	The linear velocity of the root-conveying belt
r_1	The radius of the tuber for the first section
ρ	Density of tuber
C_v	Conveyor speed
V	Brush speed
r_2	The radius of the tuber for the second section
Pe	Peeling Efficiency
Lt	Tuber length of tuber or theoretical length of tuber
La	The actual distance covered by the tuber
C	Peel removal efficiency
K	Proportionality constant
Bv	Force provided by the peripheral speed of the peeling brush
Mc	Machine efficiency
t	Peel thickness
L	Conveyor length

1.0 INTRODUCTION

Cassava is a perennial and edible root crop that originated from Southern America, western Brazil (shown in fig. 1). It is one of the consumed foods in the Amazon region, and it is grown in the tropical and the subtropical regions across the globe. In the 16th and 17th centuries, explorers and traders of Portugal, firstly, introduced the crop to Africa, close to the mouth of the Congo River. Thenceforth, over a period of two to three hundred years ago, it spread across the Continent (Africa) especially in the sub-Sahara regions like Ghana, Nigeria, Uganda, etc. (Gaffney et al., 2012; Le, 2012; Oluwole & Adio, 2013). Southern provinces of China produce cassava Guangxi, Hainan, Guangdong and more recently Yunnan, mostly planted on the hillsides with little production inputs (FAO & IFAD, 2001).

Brazil, Nigeria, Indonesia, and Thailand are the major producers of cassava in the world currently due to their current food systems, farming, and climate. Nigeria is the largest producer of cassava amongst all, and Africa contributes about 55% (more than 88 million tons) of the annual cassava production, globally (Egbeocha et al., 2016; Olukunle et al., 2010).

Over 500 million people around the world depend on cassava as a major source of food, and it is the third-largest source of calories as well as the sixth major staple crop in the world after corn, wheat, rice, sweet potato and potato (Egbeocha et al., 2016; Gro Intelligence, 2015).

Cassava products are exported in many countries due to their current demands. The top exporters of Cassava are Thailand ($1.19B), Vietnam ($277M), the United States ($211M), Costa Rica ($93.6M) and China ($82.5M). The top importers are China ($1.37B), the United Kingdom ($114M), the United States ($110M), the Netherlands ($89.9M) and Canada ($57.8M) (OEC, 2017).

Typically, Cassava is grown on small-scale by the use of traditional means, hence, inadequate production and processing input has been given to it. Currently, demand for cassava products like chips and pellets from countries like China has ever been increasing, hence, it has gradually moved from a poor man's food to an export commodity (Kolawole et al., 2010; Olukunle et al., 2010).

In Africa, cassava is believed to be widely grown for consumption as a subsistence crop by most farmers, especially for its roots, and it is mainly grown for industrial purposes in Asia like ethanol and commonly used as animal feed in the Caribbean and in the Latin America (FAO & IFAD, 2005; Gaffney et al., 2012).

Fig.1: Harvested cassava with many tubers(IITA, 2016)

For consumptive purposes, cassava requires more processing than all the tuber crops. Amongst the root and tuber crops, cassava is the most perishable crop with two to three days of deterioration after harvest, and for it to be consumable, the cyanide content must be reduced to an acceptable and safe level. Henceforth, it is mostly sold in a processed state (Diop A. & Calverley., 1998; Jimoh et al., 2014). According to Abdulkadir (2012), basically, a cassava tuber consists of the

Periderm (the outermost of the tuber, rind, consists mainly of the dead cells which cover the tuber), the cortex (lies 1.5-2.5 cm thick below the periderm), and the starchy flesh/central portion (the greater portion of the tuber and it stores the starch) as shown in fig. 2.

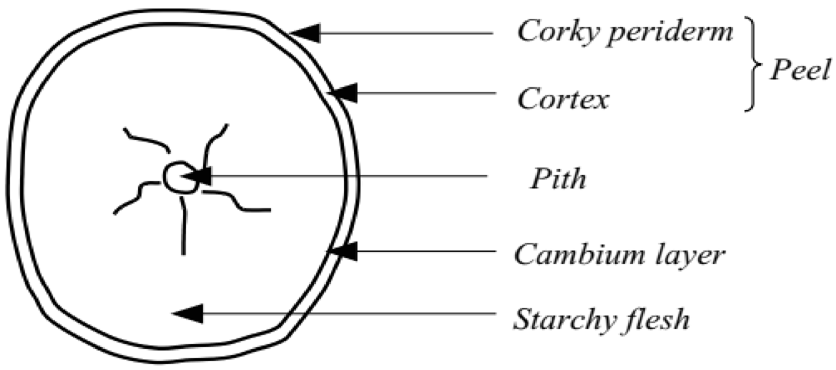


Fig. 2: Transverse view of a cassava tuber (Adetan et al., 2006)

2.0 CASSAVA TUBER PROCESSING

Peeling, milling, grating, frying, drying, boiling/parboiling, sieving, frying and extrusion are some of the basic unit operations involved in cassava processing, which is for consumption (Abdulkadir, 2012).

Successfully, several processes have been mechanized for the unit operations stated, yet the cassava peeling mechanism is a serious global problem for engineers (involved in cassava processing) to design. Several cassava peeling machines have been developed as a result of efforts put in to research field, yet relatively low-quality performance, including peeling efficiency, has been the outcome of the prototypes due to the irregular shapes and sizes of the tubers (Abdulkadir, 2012). The root significantly contains some amount of iron, phosphorus, calcium and relatively low content of protein and vitamin, and the peel contains 83% of cyanide (cyanogenic glucosides) in the whole tuber, which is very toxic to the human body. Henceforth, before cassava tubers are been processed into any food for human consumption, the peels (the cortex and the periderm) must be removed completely without taking off the central portion, but for animal feeding, peeling might not be relevant (Diop & Calverley, 1998; Ebomwomyi et al., 2017; Igbeka, 1985). This gives us the best definition for an effective and efficient cassava peeler, which is a designed mechanism that removes the peels completely without taking off the central portion of the cassava.

2.1 Cassava Peeling

For human consumption, cassava peeling is the first operation carried in cassava processing. Since the existence of cassava, the peeling process has evolved from the use of stones, wooden flint to the simple household knife. The cassava peel contains about 20% of the total weight of the whole tuber (Nwokedi, 1983). Due to the variations in the size, weight, length, and shape of the cassava root as well as the peeling texture, thickness, and adhesion strength to the flesh; designing a 100% efficient cassava peeling machine has been a major global challenge at the processing stage (Igbeka, 1985; Oluwole & Adio, 2013). Cassava peeling has been categorized into four methods:

- ***Manual***: Sharp objects, like knives, are slit along the length of the tuber and the peels are taken off with the help of the hands. This is very tedious and drudgery, yet this method yields the best results (Diop & Calverley, 1998).
- ***Chemical***: This involves the use of chemical solutions like lye ($NaOH$) to soften and loosen the peel from the flesh to enhance easy peeling. This method has been argued to be ineffective, hence, wasteful because immersing tubers in a highly concentrated solution for some times increases processing cost and food poisoning. Heat rings sometimes form on the flesh, and also might not work effectively since the peel of cassava is tougher than potato (Diop & Calverley, 1998; Igbeka, 1985).
- ***Steaming***: This is the process of applying high stem pressure to the cassava tuber over a short period of time. Due to the irregularity of the tuber shape, there might not be even distribution of heat over the tuber, and also if time is not regulated accurately, the whole tuber will end up cooked (Abdulkadir, 2012).
- ***Mechanical***: This method mainly aims at a larger number or batch of tubers at a time. It includes mechanized means of peeling which involves the use of conveyors, abrasive objects, etc (Abdulkadir, 2012). This method seems to be the most effective and convenient to use for cassava peeling on a commercial basis, but its major challenges are the irregular shapes, sizes, and lengths of the tubers, as well as the different properties of the peels like thickness, texture, etc. Also, tuber losses and mechanical damages are very high during its operation, which increases food loss and food insecurity (Egbeocha et al., 2016; Jimoh et al., 2014).

Though the manual method has peeling speed limitations, high injury rate, and very exhaustive, yet it yields the best result of which local processors or small-scale farmers still prefer. This is because the mechanical method which is aimed at peeling batch cassava tubers doesn't yield the desired results after spending huge sums of money on purchasing and on operation cost, *fig. 3 & 4* respectively show the peeled cassava tubers using the manual and abrasive mechanisms.

Research works have been conducted since the 1970s and have tunneled through till now to design an effective and efficient cassava peeling mechanisms, which will enhance the commercial production of cassava in the world market.

The mechanical method has been advanced on most among all the methods, yet the ultimate goal of designing an effective and efficient cassava peeler, which will automatically peel off all sizes, shapes, and weights of cassava tuber, hasn't been reached amidst the researches and designed that have been made by the pioneers till now.

Fig 3: Manually-Peeled cassava tubers (Munchkin, 2015)

Fig 4: Peeled cassava with abrasion (Le, 2012)

The objective of this review work presents some strengths and limitations, performance evaluations, theoretical models, different functions, future areas of focus, and some factors affecting the cassava peeling machines.

3.0 REVIEW OF CASSAVA PEELING MACHINES

There have been several developments to efficiently mechanize cassava peeling in bulk quantities at a time. This has brought up many designs that use the abrasive, Knife-edged, or both mechanisms, of which most of the designs are being powered manually or by an electric/diesel motor at a specific operating speed. In the search of efficient cassava peeling machines, there have been other designs that use two methods of peeling (i.e Mechanical and Chemical methods). Several private researchers, research institutions, and Cassava Processing machine manufacturers have really contributed to the development of cassava peeling machines.

Some institutions like PRODA, NCAM, FUTA, and IITA are pioneers who massively contributed to the early search of efficient cassava peeling machines since the late 1970s, of which theirs efforts yielded out some machines which couldn’t produce the desired output because of the high loss of cassava tuber (Egbeocha et al., 2016). Henceforth, the search for efficient cassava peeling machines still continues to bring cassava production on the commercial market especially for the purpose of consumption; some research works and designs improve on previous works, whiles others come out with new designs with different approaches. The performance summary is shown in tables 1a and 1b.

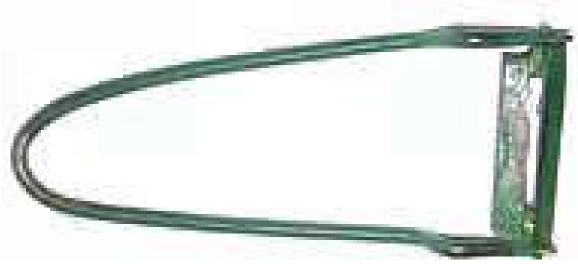


Figure 5: Cassava peeling tool by NCA

Figure 6: Knife-peeling tool by IITA

Henan Doing Machine Co. Ltd developed an automated cassava peeling and washing machine as shown in *fig. 7*. The machine is driven by an electric motor that causes rotation of the peeling brush; cassava tubers are peeled by friction principle. It consists of a screw conveyor, a peeling brush, a water-spraying system, a transmission system, a motor, and a frame.

Fig. 7: A prototype of the Henan Doing Machine

Table 1a: Performance summary of some peeling machines developed by some institutions

Company	**Author**	**Machine Operation(s)**	**Performance**
Henan Doing Machine Co. Ltd.	Henan Doing Machine Co. Ltd. (2019)	Peeling and washing	>95% peeling rate Model: • DYTP 40: 453.6-907.2 kg/hr • DYTP 60: 907.2-1814.4 kg/hr • DYTP 80: 2721.6-3628.7 kg/hr
IITA	Integrated Cassava Project (2020)	Peeling cassava (handle-made)	Up to 30 kg/hr capacity
NCAM		Peeling cassava (handle-made)	35 kg/hr capacity
PRODA		Peeling cassava (automated)	1500 kg/hr

Fig. 8: PRODA cassava Peeling machine

Fig. 9: The Action Zone/A&H Cassava peeler (Kolawole et al., 2017)

Table 1b: Performance summary of some peeling machines developed by some institutions through collaborations

Machine Name	Author(s)	Speed (rpm)/ Required Power	% Peeling efficiency	Capacity (kg/hr)	% Tuber loss
FUTA Model A, B, & C	Olukunle et al. (2006); Olawale et al. (2006)	-	<80	453.59	0.5-9.4
FUTA self-fed model		50-150 (auger) 1000-1400 (brush)	82-92	≤1000	
Fataroy		--	-	725.75	
A&H		-	-	544.31	
FUTA Hand-fed model		-	-	226.8	0.25-1.84

(a) **(b)**

Fig. 10: (a) Fataroy peeling machine (b) The improved version (Kamal & Oyelade, 2010)

According to Odigboh (1976 & 1985), the first cassava peeler was developed in 1975 (*Fig. 11*). It is a continuous process machine that has peeling tools parallelly mounted 20 mm apart on an inclined frame, the peeling tools are a knife cylinder and a cylinder with a roughened surface. The cassava tubers (cut in 100 mm long pieces) are introduced into the machine, and the knife cylinder and the solid cylinder are rotated simultaneously at 200 rpm and 88 rpm respectively powered by a 1-hp electric motor, of which the cassava tubers are pressed against the two cylinders in an opposite direction of rotation. The peeling efficiency and the throughput for mixed and sized roots were calculated to be about 75% and 165 kg/hr, and over 95% and 180 kg/hr respectively. This machine combines the knife and abrasive peeling mechanism.

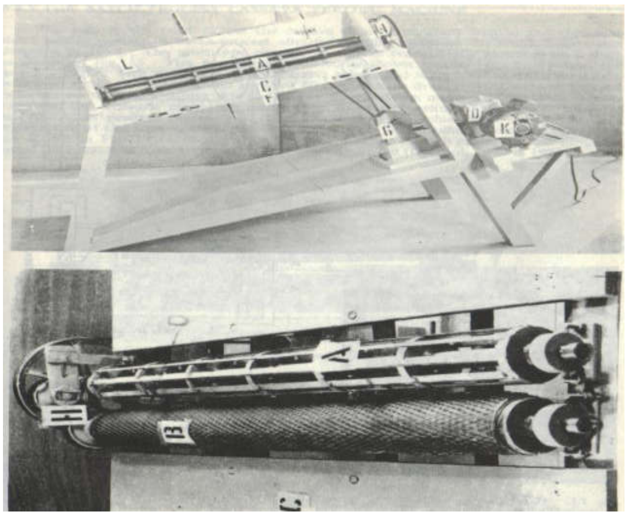


Fig. 11: The Continuous-process peeling machine

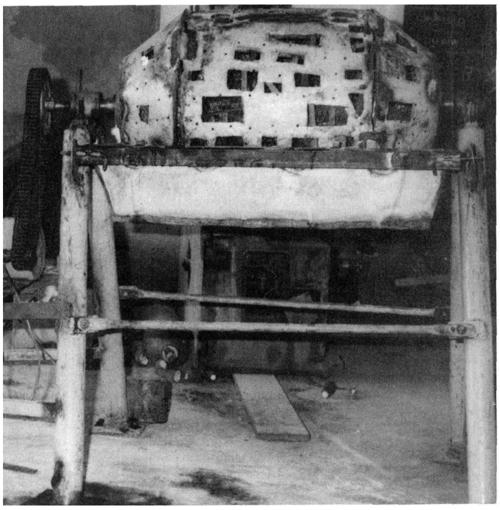
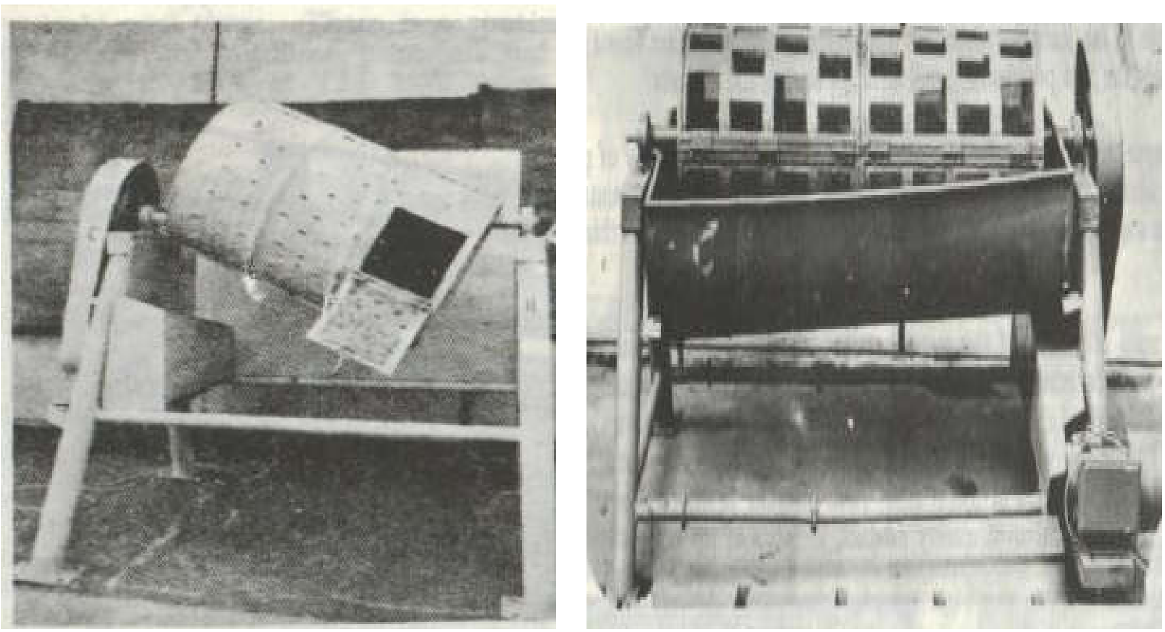


Fig. 12: The cassava peeling machine

To eliminate the cutting of cassava tubers into pieces before peeling, the model I and II batch-abrasive machines were designed in 1978 and 1980 respectively, as improvements of the previous work in 1975 (Odigboh, 1985). Each consists of a drum eccentrically mounted on a shaft, the drum is loaded with some inert abrasive materials and cassava tubers; the drum is rotated at a speed of 40 rpm whiles water is sprayed onto the cassava roots. The roots, irrespective of the shape and size, are been peeled as they come in contact with the abrasive materials as the drum rotates, and the throughput improved to 80 kg/hr.
According to Odigboh (1988), the model III cassava batch peeling machine, developed in 1986, was evolved from the model I and model II (*Fig. 13*). Four abrasive cylinders of expanded metal are mounted, which are in a drum unit of expanded metal and mounted eccentrically on a shaft, and are driven by a planetary gear. The drum is rotated at 40 rpm after the cassava tubers and some abrasives are loaded into it, the throughput was recorded to be 300 kg/hr. The model I, II, and III were different from the peeler designed in 1975.

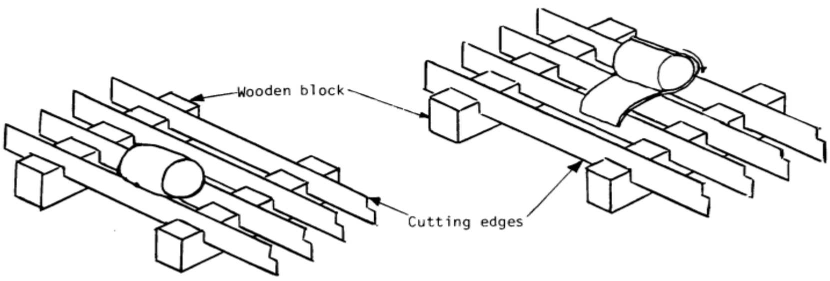


(a) Model I **(b) Model II**

Fig. 13: The Continuous-Batch Peeling Machines (Odigboh, 1985)

Nwokedi (1983) developed a cassava peeling machine (*Fig. 12*) of an egg-shape cylindrical drum, lined with wire gauze on the inner surface, that has hole-cuts and a water-filled pan is placed below it to wash the tubers as the drum rotates. A 5-hp diesel engine powers the machine, that causes the peeling drum to rotate clockwise to exert abrasion on the tubers to peel them off. The peeling efficiency and the throughput capacity for unsized cassava were recorded to be 45% and 15 kg/hr respectively, but get improved to 68% efficiency by hand trimming small tubers. For sized cassava tubers (80-100 mm length), the peeling efficiency and the throughput capacity were also recorded to be 80% and 1200-2400 kg/hr respectively. The machine performs better on medium, large and sized/graded cassava roots.

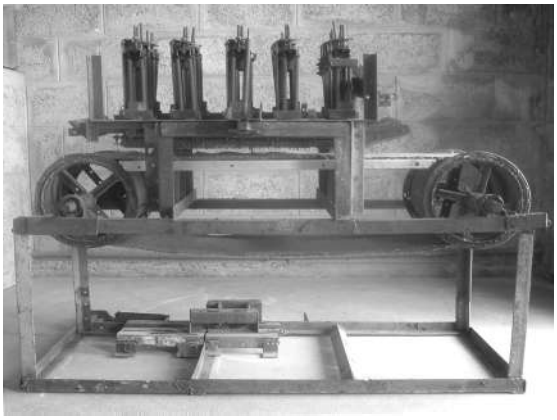
Ohwovoriole et al. (1988) came up with a new concept by designing a rotary batch cassava peeling machine with an efficiency of 92%. Some cutting edges/blades are fixed longitudinally on a shaft, of which the shaft is eccentrically mounted on a frustum-like drum; the cassava tubers fed into the machine are been peeled as a result of the cut and roll principle of the machine. No tuber loss was recorded, which was attributed to the stage of maturity of the roots used in testing its performance (70% moisture content).



(a) (b)

Fig. 14: The manual cassava Peeler test rigs (Ohwovoriole et al., 1988)

Adetan et al. (2005) improved on this new concept by experimentally designing and fabricating a mechanical peeler with many knives which are spring-loaded, but of different features involved like the conveyor belt, two cylindrical drums, etc (*Fig. 15*). 100% peel removal efficiency was achieved for cassava roots with less 60 mm diameter without any broken root recorded, however, 34.4-93.9% peel removal efficiencies were recoded for 41-94 mm diameter sizes of roots after performance test at a drum speed of 100 rpm. According to Adetan et al. (2006), the machine applies enough compressive pressure to generate shear stress at the interface of the peel-flesh to loosely break the peel from the flesh. The machine slits knives through the tubers and carefully unwrap the peels from the flesh as they pass through the peeling unit with the assistance of the root-conveying belt. The peeling performance is greatly influenced by the speed of the conveyor; slow conveying speed creates enough peeling time for the knives to penetrate the peels effectively for better peeling. The peeling efficiency increased from 52.4-75.8% as the speed of belt conveyor reduced from 2.29-0.20 m/s.



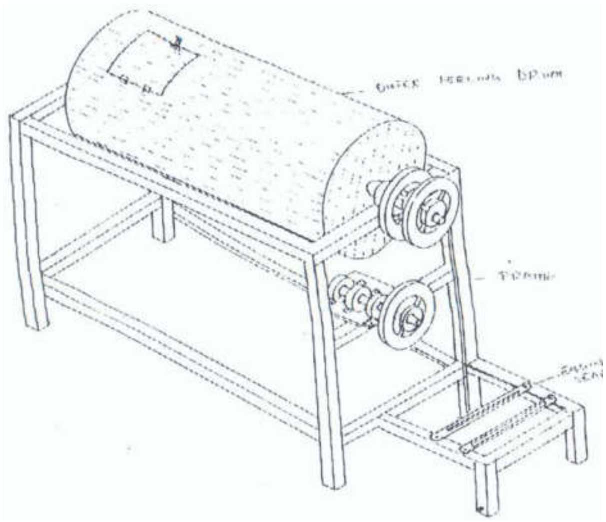


Fig. 15: side-view of the mechanical peeler **Fig. 16: A model of the peeling machine**

Thayawee (2005) developed a cassava peeling machine with the same concept of rolling the cassava roots mechanically over fixed blades. The throughput and efficiency of the machine are 224 kg/hr and 75% respectively at optimum conditions of 0.22 m/s conveyor linear speed, 4.5 m/s blades linear speed, 120 mm and 41-70 mm length and diameter of cassava tubers respectively.

A machine (*Fig. 16*) that peels off soaked cassava tubers was designed by Akintunde et al. (2005). The peeling process takes place as a result of the abrasive surfaces of the two metallic drums, rotate in the opposite direction, come in contact with the cassava tubers at a required operating power of 0.36-hp. The average peeling efficiency, throughput and tuber losses are 83.0% (81.2-85.4% range), 44.5 kg/hr (35-60 kg/hr range), and 5.38% (3.87-7.10% range).

The hand-fed double and the single gang cassava peelers (*fig. 17*) were designed by Olawale (2005) which use brush-auger arrangement that impacts rotary motion on the tuber; the peeling chamber has abrasive brushes which rotate at 500 to 1500 rpm, whiles the auger rotates oppositely to the brushes at 120 to 450 rpm which causes rotary and linear motion on the tubers. A spring-loaded guide was provided to take care of the difference in tubers size and shapes, moreover, trimming and cutting were considered to the effective operations of the machine. The machine has a throughput capacity of 8 tons/day, and it is capable of peeling and grating cassava tubers. The machine has been improved to remove manual feeding to 10 tons/day capacity. The self-fed single and double gang is the improvement of the hand-fed type that uses the same designing and operational principles of the hand-fed (Olawale et al., 2006).

Fig.17: The Double and Single Gang Peelers

Fig 18: The Double Action peeler

Fig. 18: The Self-fed cassava peeler (Olukunle et al., 2010).

IITA and FUTA made a technical collaboration with some research institutions and some private agencies, to develop an effective automated cassava peeler (Olawale et al., 2006). Previous models of self-fed cassava peeling machines from A&H, Fataroy, and FUTA were accessed to determine the strengths and weaknesses of these designs in comparison to hand peeling.

The A&H and Fataroy models have similar orientation and length, the A&H consists of two spring-loaded rollers fitted with flat bars of length 3 mm, which are wounded neatly around the rollers to form augers. The springs serve as monitoring tools for varied tuber sizes; also, the feeding rate, the efficacy of the spring-loaded devices, and the auger speed influence the peeling efficiency.

Compared to the A&H, the Fataroy has a shorter length; the Fataroy has an abrasive component similar to the abrasive surface of a grater.

FUTA has the double-action/self-fed and models A, B,& C cassava peeling machines. The double-action machine consists of two 60 cm long rotating brushes and two auger conveyors, transmission system, tuber monitor, hopper, protective hood, frame, and tuber monitor, and chute. Tubers are fed into the two hoppers simultaneously, and the linear/rotary motion impacted causes the rotating brushes to effect peeling as they come in contact with the tubers. The elastic object on the tuber monitor causes high slippage and increases resident time. An increase in brush length increases the brush-tuber contact, and this machine increases the peeling capacity at a lower cost.

The double-action/self-fed peeling machine is an improvement of the self-fed cassava peeling machine (models A, B, and C) Olukunle et al. (2006). The machine capacity and peeling efficiency at 50-150 rpm auger speed and optimized brush speed of 1000-1400 rpm to be 1000 kg/hr (maximum) and 82-92% respectively.compare to 500 kg/hr hand-feed peelers and 23 kg/hr manual peeling, and these feasible at 0.8 kg average weight of tubers.

The results of the shows that the minimum peel retention was 5.7%, 6%, 11 %, 0%, and 0% for A&H, FUTA, Fataroy, hand-fed model, and manual method respectively. Tuber losses ranged from 0.5-9.4 % for the three models (FUTA, A&H, and Fataroy), 0.25-1.84% for the hand-fed and 0.05-1.0 for hand/manual peeling. The throughput capacities of the self-fed cassava peelers are 907.19, 453.59, 544.31, 725.75 kg/hr for Double Action FUTA model, FUTA models A, B & C, A&H and Fataroy respectively. The capacity of the FUTA hand-fed model was 226.8 kg/hr compared to 22.68 kg/hr for manual peeling. The peeling efficiency has increased from 55-85% and the tuber losses reduced from 45% to 5% in general from the search (Olukunle et al., 2010).

Olawale (2007) developed a cassava peeling machine (*Fig. 19*) for cottage industries which consist of a rotary knife mounted on an electric motor which does the chipping; cassava tubers are graded according to length and diameter before been fed into the machine for peeling, and the machine has an abrasive brush fixed eccentrically on the shaft, which is driven by the motor. The machine has a throughput capacity of 45 to 80 kg/hr at an optimum rotary speed of 1000-1400 rpm. The variations in tuber diameter and length, as well as the moisture content, affect the capacity of the machine, especially for <6 cm diameter tuber. Henceforth, it is advisable to feed the machine with tubers beyond 10 cm of length to enhance peeling efficiency.

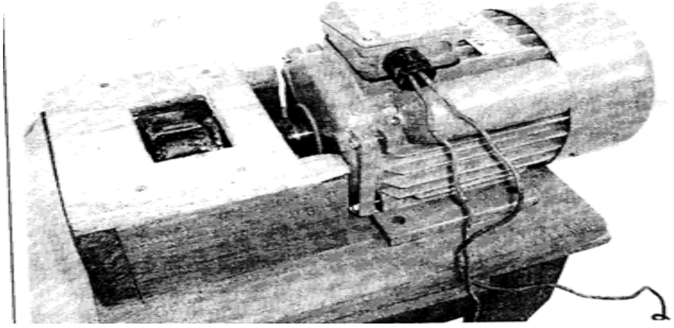
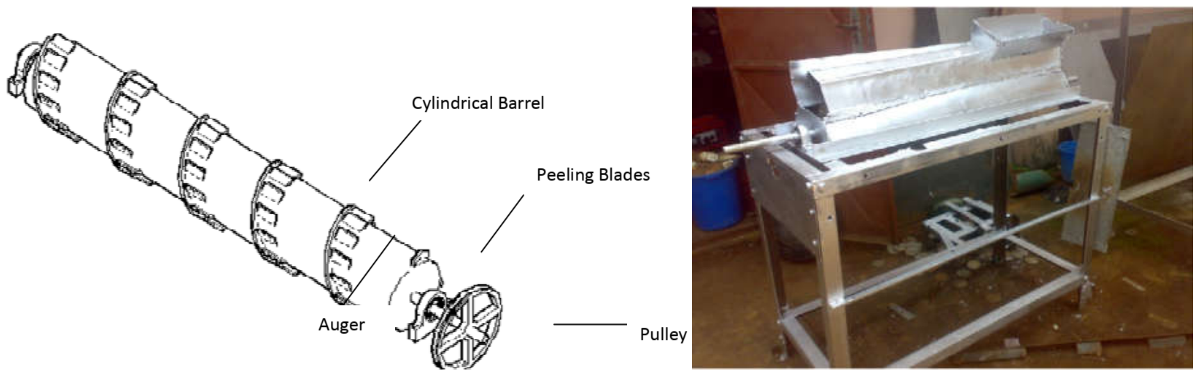


Fig. 19: The cassava peeler for Cottage Industries **Fig. 20: A Model of the cassava peeler (Aniedi et al., 2012)**

Aniedi et al. (2012) developed a machine (*Fig. 20*) that applies the efficient impact factor on the tuber to remove the cortex at a specific moisture range of tubers without significant loss of the starchy flesh. The peeling strokes mechanism of the machine peels off regularized-shape tubers fed into the machine; this machine applies the manual concept of peeling in its concept, and it is capable of peeling cassava tubers at about 98% peeling efficiency at 60 rpm blades speed. It is capable of peeling off 50 mm per cycle, and 500mm length of cassava in less than a minute. Henceforth, the capacity of the machine was accessed based on the feeding rate after sorting, the number of peeling strokes and the number of peeled cassava per cycle.

Olukunle & Jimoh (2012) made a comparative analysis and performance evaluation of three cassava peeling machines developed at the FUTA, Nigeria. Blades are welded on a rotating cylindrical drum in an auger-like manner which serves as the peeling tool of the knife-edged automated peeler type-1, and metal stripe is fixed between the blade columns to serve as a conveyor. The peeling chamber and the peeling tool are mounted on a frame which is powered by a 1-hp electric motor.



(a) (b)

Fig. 21: (a) The peeling tool (b) The Type-1 peeler (Olukunle & Jimoh, 2012)

The knife-edged automated cassava peeling machine type-2 is similar to the type-1, but has the following different features: the peeler unit is shorter, the cutting blades are continuous and much longer (peeling tool), and has lager cylindrical drum that gives the peeling tool large contact surface area. The abrasive-tooled cassava peeling machine type-3 has three peeling rollers which have some perforated holes. It has an auger fixed above the three rollers to convey the tubers through the peeling chamber, and it rotates at 7 rpm speed. During the machine performance evaluation, the cassava tubers were graded into small, medium, and large sizes with 150, 550, and 1150g weight respectively. The machine was driven by a 1 hp electric motor at different speeds of 300, 500, and 700 rpm. The optimum peeling efficiency, peeling time, tuber losses, and peeling retention of the type-1 machine were 91.87%, 24.03 seconds, 24.17%, and 16.00% respectively; that of the type-2 machine were 82.5%, 19.6 seconds, 25.42%, and 28.26% respectively; and 71.11%, and 50.00 seconds, 18.11%, and 38.78% respectively for the type-3 machine. In less than 25 seconds, the result shows up to 91.87% is achieved using the mechanical peeling method.

(a) (b)

Fig. 22: (a) The Type-2 peeler and (b) The Type-3 peeler (Olukunle & Jimoh, 2012)

Jimoh & Olukunle (2012) designed the automated cassava peeling machine that is a modification and development of the peeling tool of previous cassava peeling machines and uses impact as its peeling principle. This single-action cassava peeling machine consists of cutting blades, mounted on a roller 70 mm away from each other and inclined at 30°, which receives its rotary motion from a petrol engine through a shaft that runs through the roller eccentrically. The machine has peeling efficiency, throughput capacity, and mechanical damage ranged from 50-75%, 76-442 kg/hr, and 12-44% respectively. The machine was evaluated at 100-600 rpm speed for big size tubers ranging from 100-300 mm length, and the highest evaluated results were achieved at 600 rpm and 260-300 mm length of big cassava tubers; high operational speed also results in high breakages of tubers. The performance of this same machine was evaluated by Olukunle & Akinnuli (2012) and similar results were recorded.

An automated machine (with variable speed) for peeling cassava was developed at the FUTA, Nigeria (Ademosun et al., 2012). Modification and development of the peeling tool of previous machines were the design basis of this peeling machine. The machine has a peeling chamber with a peeling tool, supported on a frame, transmission system and a hopper. The machine was evaluated with two varieties of cassava tubers to investigate the effect of the physical and mechanical properties of cassava on the performance of the automated machine. The results shown 70.82-96.21% machine quality performance, 0.17-1.85N/mm peel penetration force, and 0.85-9.25N/mm^2 shear stress at 76.27% moisture content for one the varieties, whereas results for the other variety shown 67.27-92.25 % machine quality performance, 0.65-7.70N/mm^2 shear stress, and 0.13-1.54N/mm penetration force at 70.97%. Henceforth, the results confirm that mechanical peeling is greatly influenced by the physical and mechanical properties of cassava tubers.

Abdulkadir (2012) designed and fabricated a hand-fed cassava peeling machine (*Fig. 24*) that uses abrasive surface as its peeling tool. It consists of a cylindrically-rolled metal that has spikes achieved by punching holes outwardly; the abrasive rolled-metal is connected to a shaft eccentrically, which is then connected to a motor which drives the machine during its operations. The performance of the machine was evaluated, of which 58.5-77.5% and 240-300 kg/hr were recorded to be the average peeling efficiency and throughput capacity ranges respectively.

The pedal cassava peeler (*Fig. 23*) was designed by Le (2012). The machine is made up of a cylindrical drum, has a capacity of 20 kg, which is made by bars of wire brushes; the drum is connected to the pedal by a chain. The tubers are washed before loading them into the drum (should not be full), the machine should be pedal slowly to prevent damages and also to enhance peeling efficiency; the tubers are peeled as they move in the drum and rotate over the wire brushes (the door must be locked first). Though it involves pedaling, it peels more tubers of cassava at a given time compared to manual peeling. It has a capacity of 60-100 kg/hr (compared to 20-35 kg/hr peeling by hand), average percent flesh loss of 5% (compared to 25% peeling by hand), average peeling efficiency of 95%.

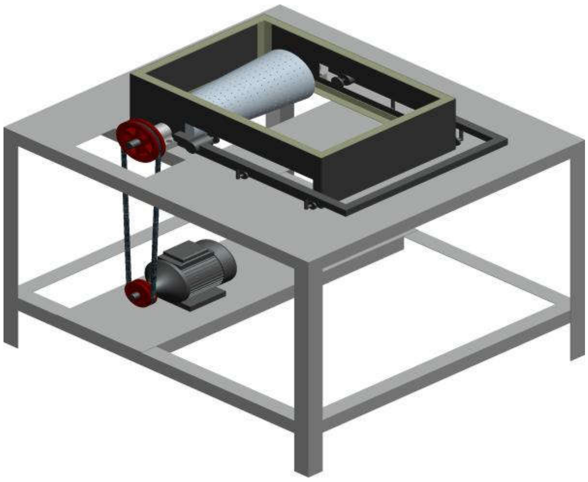


Fig. 23: The Pedal Peeling Machine **Fig. 24: The hand-fed cassava peeling machine**

Olukunle & Akinnuli (2013) developed an automated cassava peeling machine (*Fig. 25*) that is based on the principle of continuous tuber feeding system. The peeling unit has peeling tools of a peeling brush and a conveyor (with brush fixed on it) which rotates in opposite motions. The opposite motions cause forward linear velocity and shear stress on the tubers, dropped into the unit, to turn and peel. The maximum peeling efficiency of 88.50% was recorded at 3000 rpm brush speed and 150 rpm conveyor speed, and minimum peeling efficiency of 83.80% at 500 rpm brush speed and 150 rpm conveyor speed. This indicates that brush speed is directly proportional to the peeling efficiency while the conveyor speed is inversely proportional.

Fig. 25: The automated peeling machine **Fig. 26: The batch abrasive peeling machine**

Oluwole & Adio (2013) designed and constructed a batch cassava peeling machine (*Fig. 26*) that uses the abrasive mechanism, and it does not peel all sizes of tubers. The machine has a stationary abrasive drum and a rotating inner drum with a batch capacity of 8.5 kg. When the machine was tested with 200 mm and 90 mm cassava length and diameter respectively, at a rotational speed of 394 rpm the peeling efficiency and flesh losses were recorded to be 70.34% and 5.09% respectively, and at a rotational speed of 364 rpm, the peeling and flesh losses were 60.22% and 5.95% respectively. Okorie (2016) develop the same machine with little modifications to handle a single diameter of cassava tubers and it as well does not peel all sizes of tubers. The capacity of the peeling drum was reduced to 5.1 kg, and with a tuber length and diameter of 200 mm and 70 mm respectively, the average peeling efficiency and the flesh losses were 70.45% and 5.09%. The performance of this modified machine is almost the same as that of the design made by Oluwole & Adio (2013).

Olawale & Oluwatoyin (2013) developed an automated peeling machine (*Fig. 27*) for large scale industries that is capable of peeling off both cassava and cocoyam tubers. The peeling unit of this machine uses an auger to convey the tubers through the peeling chamber and a peeling brushes cover on a rotating, and this is similar to the previous design. This work is a modified design that elongates the peeling tool to 1.2-2.4m, hence, increases the residence time of the tubers within the peeling chamber which remarkably influences the peeling process. Tubers of diameter 8-10 cm and 20-25 cm length produces 79.5% peeling efficiency and 95 kg/hr at brush speed of 1200 rpm and 150 rpm auger speed.

Ebunilo et al. (2013) designed and fabricated a mechanical cassava peeler that uses the lathe principle in operation, it is powered by an electric motor at a speed of 3 revs/sec, and it takes less than 10 seconds to complete the peeling section of the tuber. This machine has the advantage of peeling all kinds of tubers regardless of their stored age (fresh or rotten) compared to the previous designs that operate efficiently on fleshly harvested tubers, as well as minimal fresh loss. There are limitations on the feeding/loading time, irregularities of the tuber shapes and difficulty in identifying the center of the tuber to be peeled. Performance results show over 70% of peeling efficiency for all categories of cassava tubers.

Ebegbulem et al. (2013) combined the mechanical and chemical methods of peeling. Cassava tubers are first pre-treated by dipping them in NaOH solution for a specific time and temperature and then dipped into an acidic solution (HCl) to neutralize them, this is done to loosen the cassava roots. The tubers are then transferred into the designed rotary brushing machine, consists of a hopper, a conveyor, a peeling chamber, a rotary brush, a slitted and inclined tray, a collection tray a transmission system and a 2-hp engine to peel off the cassava tubers. The moisture content and the throughput capacity of the mechanism are 55.96% and 1836 kg/hr under optimum conditions of 15%, 600ºC, and 20 minutes NaOH solution concentration, temperature, and immersion time respectively.

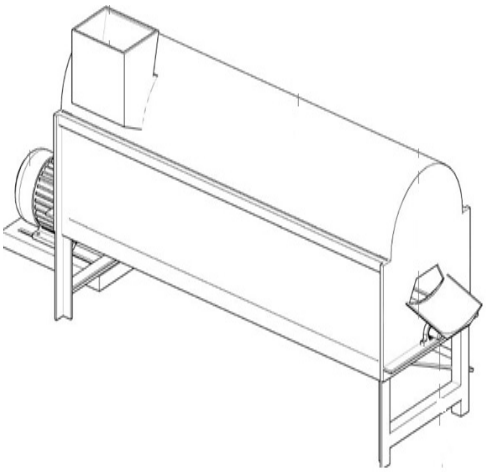


Fig.27: An automated cassava peeler Fig. 28: A prototype of the combined automated peeling machine

A cassava peeling machine, that operates based on the principle of impact as tubers spin and comes in contact with the cutting tool during linear movement in the direction of the auger, and these are governed by combining the action of the tuber monitor, auger, and driving force, was developed (Jimoh et al., 2014). The machine was analyzed with different sizes of tubers, and the results show small sizes stay in the peeling unit for too long which increases the mechanical damage. Also, the speed, the peeling efficiency, and mechanical damage increased from 100-140 rpm, 67.53-100%, and 0.51-1.23% respectively. Moreover, at feeding rate of 10kg, 20kg, 30kg, 40kg, and 50kg, the throughput capacity increased from 238.10-454.55 kg/hr, 377.36-740.74 kg/hr, 491.80-967.74 kg/hr, 597.02-1176.47 kg/hr, and 694.44-1351.35 kg/hr respectively. This shows that the performance of the machine improves at 130 rpm speed, and get better at 140 rpm, of which there will be higher mechanical damage if the speed increase further

A combined automated cassava peeler, grater and presser machine (*Fig. 28*) was designed and fabricated by Gumanit & Pugahan (2015) for small scale processing, this design is a batch type. Cassava tubers are fed into a circular peeler that has some perforated materials inside its chamber, the rotary motion of the circular drum moves the cassava tubers in circular motions to cause contact with the perforated tool to make peeling to occur. The peeled wastes get discharged whereas the machine water is pumped to wash the tubers during operation, after which the peeled and washed tubers are discharged to the grating unit. The mean peeling efficiency, fresh losses, and the approximate throughput capacity were recorded to be 75.46% (69.33-81.60% range), 8.801% (4.42-12.78% range), and 60 kg/hr respectively after the performance of the machine was evaluated. The results show that the operating speed is inversely proportional to the peeling efficiency and flesh loss.

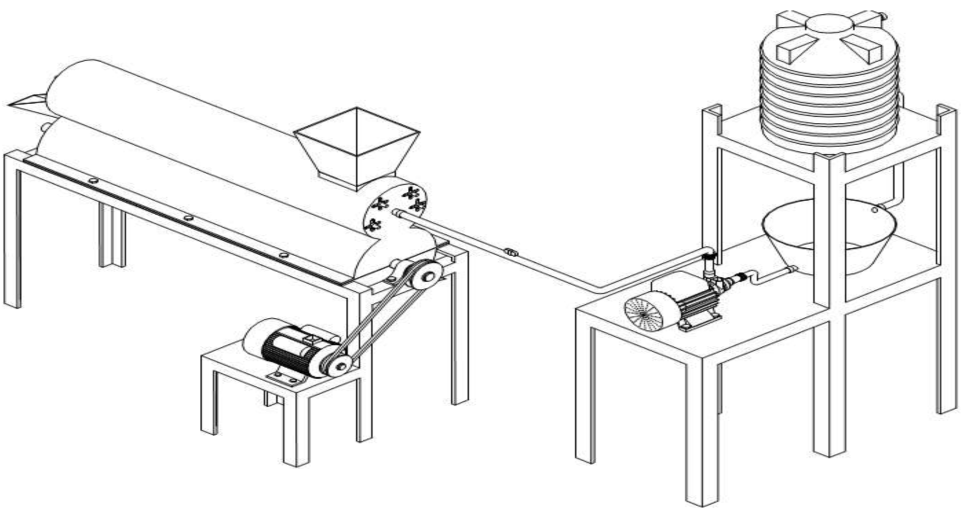


Figure 29: An Isometric view the peeling and washing machine

A motorized vertical cassava peeling and washing machine (*Fig. 29*) that is efficiently and economically viable was designed and fabricated by Ugwu & Ozioko (2015). Cassava tubers, fed into the machine, are been peeled by the rotation of the peeling drum which is been driven by an electric motor. The tubers are been conveyed out of the machine by an auger, and water is also pumped from the tank to wash the tubers at the same time as the peeling process takes place in the peeling drum. This machine has two peeling units; the first unit has a brush shaft that first cleans the tubers, and the second unit has the peeling drum that does the actual peeling. The highest peeling efficiency of 72% is achieved at 420 rpm whereas the lowest efficiency of 55% is achieved at 380 rpm. Henceforth, increasing or decreasing the speed of the machine from 420 rpm decreases its efficiency.

Ajibola & Babarinde (2016) developed a labor less motorized machine for rural areas to peels 20 kg batch of cassava tubers with an average length of 150 mm for rural areas, the machine was tested with soaked and unsoaked cassava tubers of length 100-150 mm, the peeling chamber has 0.264 m^3 capacity while 9.7 kW (13 hp) power is needed to operate it. The tubers portions that come in contact with the peeling drum (barrel), which rotates continuously, are rapidly bruised off. After testing and evaluating the machine, it was verified to has an average peeling efficiency of 80.1% (75-87.5% range) at maximum tuber length of 150 mm and 70 mm diameter, and the machine operating efficiency is 79% (using input and output power). The machine is modified by Samuel & Emmanuel (2019) of which similar design features are incorporated in this modification. The peeling chamber is increased to 0.978 m^3, and the operating power is reduced to 42.28 W (1 hp) at a motor speed of 3000 rpm. The machine has 80% operational efficiency under 30 minutes operating time at an output power of 52.85 W, hence, this modified peeling machine conserves more energy and has high operational efficiency compared to the previous design.

Aji et al. (2016) developed an electrically operated peeling and slicing machine (*Fig. 30*) for small scale industries and for farmers in rural areas. Power is transmitted to the peeling unit shaft, the peeling drum is mounted eccentrically on the shaft. Cassava tubers are manually fed into the machine through the hopper, the abrasion action of the peeling drum effects the peeling process by removing the cortex of the tubers, and after which, the peeled tubers are been channeled into the slicing unit by gravity. The peeling efficiency, flesh losses, and the throughput capacity of the machine were evaluated to be 66.2%, 8.52% and 403.2 kg/hr respectively. The performance test shows that the machine peeled and chipped 7 kg of cassava tuber in one minute.

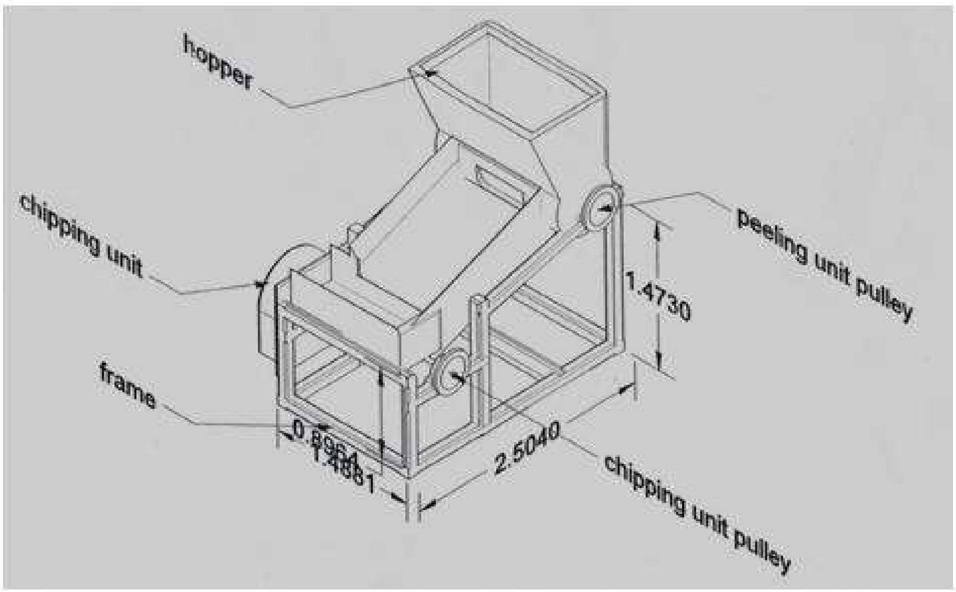


Fig. 30: An isometric view of the electrically operated peeling and slicing machine

An automated machine (*Fig. 32*) for cleaning, peeling, and washing cassava tubers was developed at FUTA, by Ogunlowo et al. (2016). Cassava tubers are manually fed into the machine through the hopper, peeling takes place in the peeling drum through the shear force exerted on the tubers by the cutting blades as the auger conveys the tubers out of the machine through the chute linearly and the peeling drum rotates simultaneously. During testing and evaluation of the machine, the cassava tubers were kept for one to three days, the peeling results ranged from 69-83%, 55-75% and 86-95% for first, second and third peeling respectively under rotational speed range of 40-60 rpm at 5 rpm increment.

Pius & Nwigbo (2017) designed and fabricated a cassava peeling machine (*Fig. 31*) that is capable of handling different diametric sizes of cassava tubers which is driven by an electric motor. Cassava tubers, when getting to the peeling unit through the hopper, align themselves vertically. The knife cylinder (peeling cylinder) and the abrasive cylinder rotate on a counter-motion which causes the peeling process as the tubers travel through the peeling zone to the outlet for discharge. A spring-loaded mechanism, positioned at a certain distance above the peeling and the abrasive drum, exerts required pressure on the tubers for effective peeling. The machine has peeling efficiency ranged from 59-75% when tested with 53.2-58.21 mm diameter of cassava tubers at 100 rpm speed (797.2 W power required). This machine. combines both knife and abrasive peeling mechanism, of which the combined mechanism couldn't give the best-desired output compared to the previous designs.

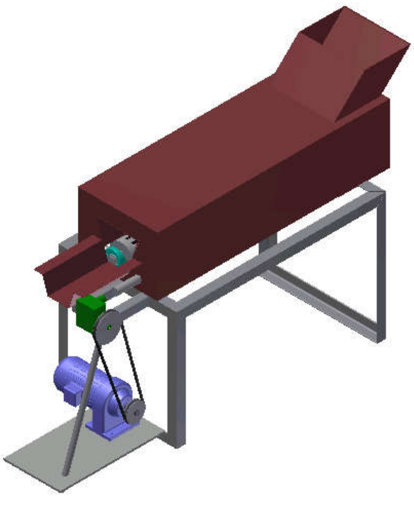


Fig. 31: A model of the cassava peeling machine

Fig. 32: The cassava Peeling and washing machine

Chilakpu (2017) modified the work of Oluwole & Adio (2013) and Le (2012), by powering the machine (*Fig. 33*) with an electric motor of which a reduced gear was used to step down the 1450 rpm to 150 rpm speed of the peeling drum as recommended by Le (2012). The drum volume is increased in this design, and also a hopper is incorporated with a shuttering mechanism by the side of the drum that also serves a metering device. The throughput capacity, the peeling efficiency, and the average efficiency were recorded to be 700-1000 kg/hr, about 97%, and 8% respectively after the performance evaluation. The performance of this machine is higher than the other works.

Fig. 33: The modified cassava peeler

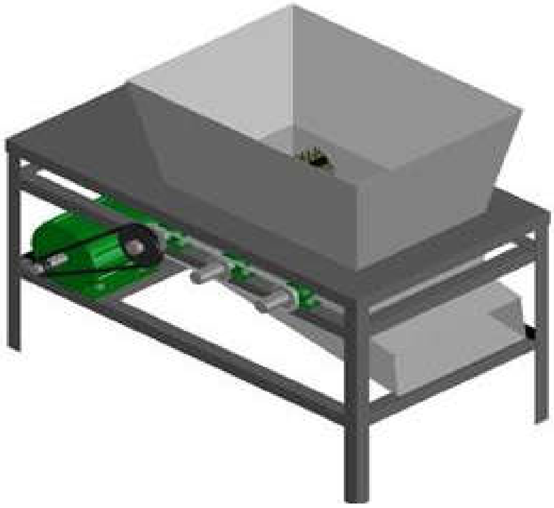


Fig. 34: A model of an improved cassava peeler

Ebomwomyi et al. (2017) developed an improved cassava peeling machine (*Fig. 34*) with a minimal loss of useful flesh, that is powered by an electric motor. The machine consists of three wired-brush shafts that are arranged parallel to each other as well as linearly to the alignment of the machine. Cassava tubers are hand-fed into the machine through the hopper, positioned above the three shafts, and the rotation of the three shafts causes abrasion on the tuber to peels them off. The peeling efficiency, flesh losses, and broken cassava tubers of the machine were calculated to be 85%, 13.13% (compared to manual peeling with 15%), and 5% respectively.

In 2017, Rikzx (2017) embarked on a project to design and fabricate a combined cassava peeling and grating machine (*Fig. 35*). Cassava tubers are been fed into a rectangular container, peeling unit, which has three peeler blades (like a long slanting strip which horizontal and parallel to each other) at the bottom. The peeler blades, fixed on a cylindrical metal, are connected to a rotating shaft, and they peel off the tubers as they come in contact with them. Flat strip blades are employed in the peeling unit to prevent or minimize tuber loss; whiles peeling, water pumps from a tank and sprinkles on the tuber to wash it. Peeled cassava moves to the grating chamber for further processing. The project is still in progress, hence, the machine has not been fabricated yet.

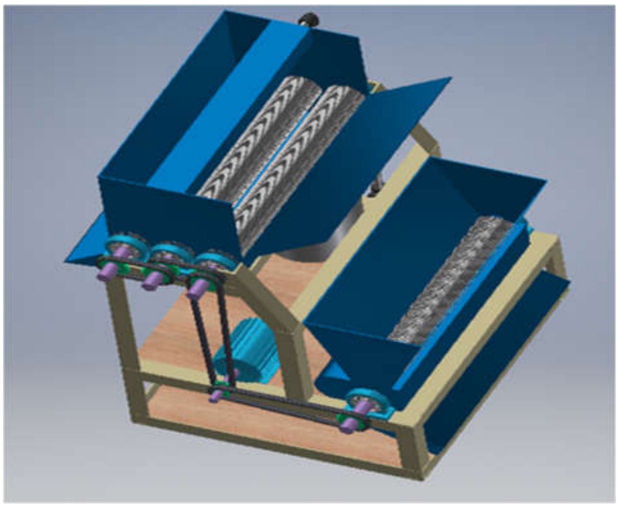
 

Fig. 35: A model of the cassava Peeler and Grater   Fig. 36: The Fomena cassava peeler

An association of farmers at Fomena in the Adansi north district, Ashanti-Ghana, designed a mechanized cassava peeler (*Fig. 36*) that typically uses the manual concept and mechanism of peeling. The machine has a long cutting blade which is fixed at the top-end of one side of the machine, cassava tuber is manual slide over the cutting blade till all sections of the tuber are peeled off. Though it involves a lot of manual work compared to the previous designs, yet after the performance evaluation on the machine by Priscilla (2017), 65% of the people got injured when using knives whiles no injury was recorded for the Fomena peeler. Throughput capacity and flesh losses ranged from 2.72-27.36 kg/hr and 10.35-22.95% respectively for the machine, and that of the knife was from 64.1-67.83 kg/hr and 3.85-8.17% respectively. Henceforth, the performance of the machine is seen to be very low compared to the manual knife peeling.

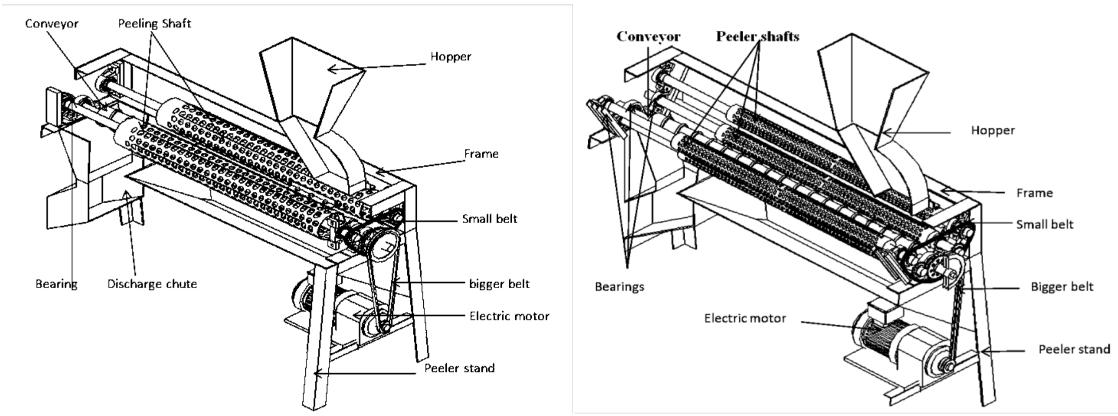
Two cassava peeling machines (Type-1 and Type-2) were developed at the Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria (Nathan & Udosen, 2017). The two machines have the same design and operational features except for the length of their spikes. For each machine, the peeling tool and the peeling chamber of the machines are mounted on frames, the peeling tool has spikes (nails) of specified length mounted on a rotating cylindrical drum. A screw conveyor runs through the peeling unit to the chute, the machines are powered by two separate 750-hp petrol engine. The lengths of the peeling spikes of Type-1 and Type-2 machines are 26 mm and 20 mm respectively.

Different speeds (80,90, 100, and 110 rpm), and graded-weight of cassava tubers (0.81, 0.72, 0.64, 0.55, and 0.50g) were used to comparatively analyze the performance of the two machines. At 80 rpm operational speed, the recordings of evaluated properties for Type-1 and Type-2 are as follows: mass of cassava peels (16% and 15.66%), mass of unpeeled cassava (0.7% and 3.26%), mass of cassava flesh losses (0.7% and 3.26%), mass of peeled cassava (85% and 78%), Mechanical damage (0.0084 kg and 0.040 kg), and Peeling efficiency (88% and 82%) respectively, and throughput capacity (1041 kg/hr and 1149 kg/hr) at 110 rpm respectively. The evaluated results show that the Type-1 peeler is better than the Type-2, hence, long peeling spikes enhance the efficient peeling.

(a) **(b)**

Fig. 37: (a) Type 1 peeler (b) Type-2 peeler (Nathan & Udosen, 2017)

Nathan et al. (2017) comparatively analyzed two types of cassava peeling machines (Type-3 and Type-4) which were being developed at the Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria. Design and development, and all the materials used for the two machines are the same except for the number of the peeling shaft (peeling tool). For each machine, the peeling tool, abrasive metal sheet welded and folded round cylindrical drum, and the peeling chamber is mounted on a supporting frame, the machines are separately powered by a 5-hp electric motor. The number of rotating shafts (abrasive peeling tools) for both Type-3 and Type-4 machines is two and four respectively.



(a) **(b)**

Fig. 38: (a) Type-3 peeler (b) Type-4 peeler (Nathan et al., 2017)

With graded-weight of cassava tubers (0.72, 0.74, 0.76, 0.78 and 0.80 kg), and at different operating speeds (80, 90, 100, and 110 rpm), the performance of the two machines was comparatively analyzed, and the evaluation results show weight of cassava peels (16% and 18%), weight of cassava flesh loss (2.06% and 2.16%), peeling efficiency (85% and 90%), mass of cassava flesh losses (2.06% and 2.16%), mechanical damage (0.046 kg/kg and 0.065 kg/kg), throughput capacity (1141 kg/hr and 1262 kg/hr), weight of peeled cassava (80% and 86%), weight of unpeeled cassava (0.85% and 0.75%) for Type-3 and Type-4 machines respectively at 80 rpm operational speed. With regards to properties evaluated, except for the percentage flesh loss and mechanical damage, the performance of Type-4 peeler was generally better than Type-3 peeler.

A waterjet-assisted cassava peeler (*Fig. 39*) is developed by Raymond et al. (2018). Cassava tuber is manually rolled against the cutting blade of the machine, as the blade cut through the tuber, considerable pressure is exerted from the waterjet between the flesh and the peel to enhance effective peeling. The main special feature of this design is the waterjet system that has a water distribution system including the nozzle and the control valve. A flat and a circular nozzle were used in the technical evaluation of the machine, 37.13 kg/hr highest throughput capacity (for 50-60 mm tuber diameter), and 100% peeling efficiency were recorded with no flesh losses; also, the round nozzle gave higher peeling capacity than the flat nozzle and the manual peeling

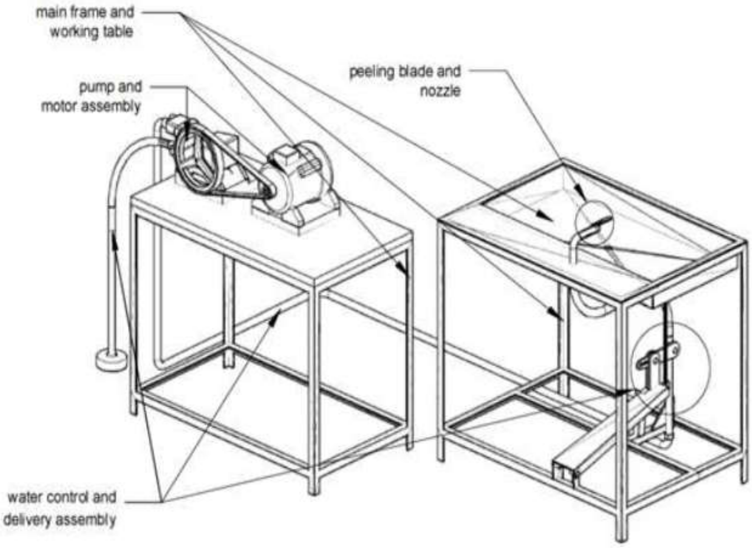


Fig. 39: An isometric view of the waterjet cassava peeler

Alhassan et al. (2018) developed a cassava peeling machine (*Fig. 41*) using the abrasive mechanism powered by a 3-hp electric motor, which is similar to the work of Le (2012), which is powered by pedaling. The performance evaluation of this machine was based on the resident time of the tubers in the peeling drum as well as the effect of drum fill on its performance. At reduced speed, the highest and the minimum peeling efficiency, throughput capacity, and flesh losses were calculated to be 74% and 12.7%, 6.2 kg/hr and 31 kg/hr, and 5% and 12% respectively at 20-30 minutes resident time, 58 rpm manual drum rotational (slider-crank mechanism), and at 10-50% drum fill. It was also observed that low speed increases the machine efficiency, hence, flesh loss and machine capacity are directly proportional to the resident time and percentage drum fill, whereas the peeling efficiency is not.

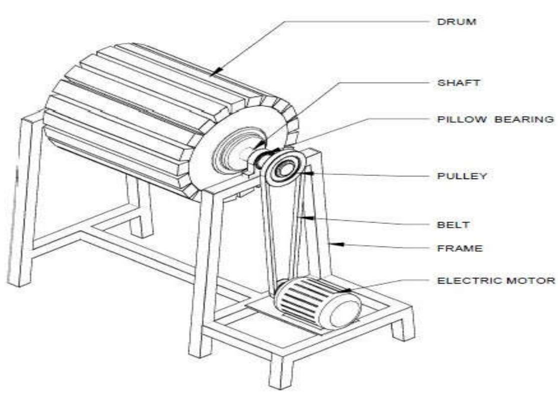


Fig. 40: The rotary cassava peeling machine **Fig 41.: Isometric view of the cassava peeler**

Adekunle et al. (2018) borrowed the peeling concept of Ohwovoriole et al. (1988) to design and fabricate a modified cylindrical rotary-cutter type cassava peeling machine (*Fig. 40*). The main rotor and the planetary rotors (cylindrical cutters) act as the peeling tools and they exert cutting actions on the tubers and also help rotate the tubers to expose their surface to be peeled. After testing with average diameters 33.15mm, 42.09 mm and 52.15 mm at 400 rpm machine speed, the peeling efficiencies, throughput capacity, and flesh losses were (76.92, 82.35, and 83.34%), (103.86, 106.45, and 108.57 kg/hr), (8.89, 9.82, and 11.57%) respectively. As the batch volume and tuber diameters increase, the machine efficiency, output, and tuber losses also increase.

Pariyed et al. (2019) designed and constructed a cassava tuber peeler unit which was tested at a knife rotation speed of 70, 80 and 90 rpm, with three types of peeling knives and two levels of spring stiffness of knife peeling (8.21 N/m and 17.19 N/m). The evaluation results show 90 rpm speed of the knife peeling to be 17.19 N/m spring stiffness and using the second knife peeling type gave the most suitable conditions of 90.3% peeling efficiency, 3.63% flesh losses and throughput capacity of 10.43 seconds/tuber. However, the knife peeling unit is specifically restricted at 30-60 mm diameter and 200 mm length of cassava tuber.

(a) Type-1 (b) Type-2 (c) Type-3

Fig. 42: Types of knife-peeling tools for the studies (Pariyed et al., 2019)

Adeniyi et al. (2019) developed a cassava processing machine (*Fig. 43*) that performs two operations concurrently (peeling and washing). The machine has a peeling drum whose inner surface is abrasive (ceramic mixture) that acts as the peeling medium during its operation. Peeling is accomplished by the rotary motion of the peeling drum, causing the tuber to come in contact with the underlying layer cast with the ceramic mixture, and the continuous shear force among the tubers as water is simultaneously sprung on it. The machine is power by a 10-hp electric motor at 900 rpm speed. During the performance test of the machine, the highest peeling efficiency, throughput capacity, and mechanical damage were recorded to be 68.97%, 223.2 kg/hr, and 22.38% respectively for 15.5kg weight of cassava tuber. Moreover, the lowest peeling efficiency, throughput capacity, and mechanical damage were recorded to be 63.64%, 104.4 kg/hr, and 37.5 % respectively for 3.5kg weight of cassava tuber. Henceforth, the machine performance increases as the weight of the tubers increase.

Fig. 43: The cassava peeler and washer **Fig. 44: A mechanized muti-peeler (Seirraleo, 2018)**

According to Seirraleo News (2018), FINIC developed a mechanized cassava peeling machine (*Fig. 44*) that is capable of peeling other crops like onion, ginger, yam, and potato with any modification. This design looks like the work of Adeniyi et al. (2019). It automatically washes the tubers fed into the machine during peeling through a water supply system is connected to it. It has a peeling efficiency of 97%, 1800 kg/hr machine capacity, and 31.5% tuber losses, it is comparatively better and 60 times faster than hand peeling

Alli & Abolarin (2019) designed the cassava attrition peeling machine (*Fig. 45*) which is a modified version of the design made by Ohwovoriole et al. (1988) which has a single belt coated with abrasives. The tubers enter the machines through the hopper and get transported through the peeling unit, which has rotating brushes and auger. The peeling brushes are uniformly fixed throughout the curved surfaces of two rotating shafts, and the shear force exerted on the tubers by the brushes causes tubers to peel off. The machine is powered by a 1-hp electric motor at 250 rpm maximum speed. The maximum peeling efficiency was calculated to be 80.9% at maximum moisture content of 70%, and throughput capacity at 47.9 kg/hr maximum speed when tested with 4.5 kg and 5 kg weight of cassava tubers at different time intervals.

Fig. 45: The Cassava attrition peeling machine **Fig. 46: The portable cassava peeler**

Locally-sourced materials were used to design a portable cassava peeling machine (*Fig. 46*) by Okoronkwo et al. (2019). This work is similar to the work of Adeniyi et al. (2019), zinc abrasive materials are lined on the inner surface of the peeling drum instead of the ceramic mixture underlaid in the drum. The rotary motion of the peeler disc driven by the rotating shaft, powered by a 1-hp electric motor, exerts a centrifugal force on the tubers, which are manually fed into the machine, to spin and move from the center, and get in contact with the abrasive material to peel them off. 561.6 kg/hr throughput capacity at 784 rpm speed of the machine was recorded, as well as an average peeling efficiency of 91.72%. Comparatively, the performance of this machine surpasses that of Adeniyi et al. (2019), but while an increase in weight of cassava tubers increases the performance of the latter, it is recommended not to feed this machine excessively because of increase in flesh losses. Also, the machine was tested with 0.2 kg to 0.4 kg of cassava tubers while the latter was tested with 4.5kg and 5 kg weight of tubers. This implies, feeding the two machines beyond their feeding capacities will result in poor performance.

Bakare et al. (2011) investigated the optimum conditions of lye (NaOH) pre-treatment on cassava tubers using Response Surface Methodology (RSM). The model suggests that peeling efficiency is directly proportional to the lye concentration and temperature. Optimum conditions of 81.46-92.34ºC lye temperature, lye concentration of 9.02-9.81%, and immersion time of 5.72-5.76 minutes gave that maximum efficiency. It was also observed that the actual peeling was recorded at 9.7% lye concentration, 86ºC lye temperature, and 5 minutes immersion time with 11% mass of peels. Tsekwi & Ngoddy (2019) suggested that temperature ≥60ºC should be avoided as much as possible to prevent gelatinization of the starch for the lye peeling process; the activation energy for hydrolysis breakdown process is directly proportional to lye concentration and temperature in the range of specific variables.

Oyedele et al. (2019) advanced on the work of Bakare et al. (2011) to design and fabricate a wet mechanical brushing unit for lye pre-treated cassava roots. This seems to be a combination of the mechanical and chemical methods of peeling cassava roots. Cassava tubers are first dipped into a concentrated lye solution, heated to a specific temperature within a stipulated time range; the tubers after pre-treatment are washed thoroughly with water before fed into the machine. The spring-loaded machine exerts a compressive force on the tubers to enhance effective peeling in the brushing unit. Performance evaluation shows 20% lye concentration heated at 60ºC and 20 minutes immersion time to be the optimum results for the pre-treatment, of which 66.67-70% peeling efficiency was recorded.

The effect of pre-thaw pre-treatment on the peeling process of cassava tubers was investigated by Ziba et al. (2019). Cassava tubers are first pre-treated by freezing it at -18ºC for 24 hours and then treated in a water-bath at a specific temperature and incubation time. The tubers, after the freeze-thaw pre-treatment, are put into a machine (*Fig. 47*) that has five rotating cylinders covered with abrasive brushes. The machine is powered by an electric motor which causes the cylinders to rotate, at a specified speed, to effect peeling. Performance evaluation shows that the optimum peeling conditions of the machine are at 1000 rpm rotational speed, 3.4 minutes peeling time, 59ºC thawing temperature and 90 seconds incubation time. The peeled surface and the peel losses are 99.5% and 19% respectively; hence, the free-thaw pre-treatment improves cassava peeling, by softening and loosening the peels, and increases the peeled surface area. Moreover, there are changes in the nutritional properties of the tubers, and the starch texture and gelatinization are being influenced by this method. The peel loss is positively affected if the peeling time, brush speed, and incubation time increase, and negatively affect if the thawing temperature increases.

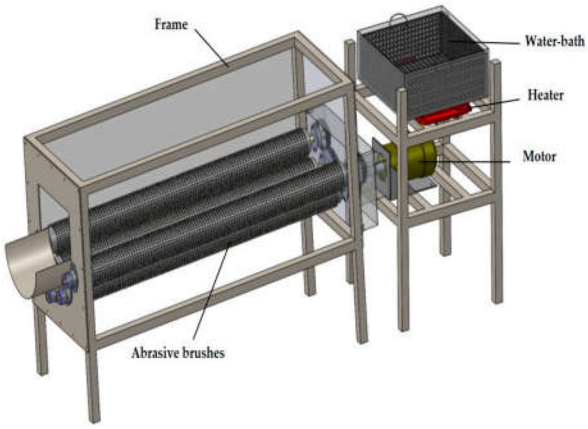


Fig. 47: The prototype cassava peeler **Fig. 48: A Multi-tuber peeling Machine**

Barati et al. (2019) investigated the effect of enzyme treatment on the cassava peeling efficiency, of which the results show that it can improve the peeling process by increasing the peeling yield and reducing the peeling time under optimum conditions. It was recorded that 4.5 pH, 49^{o}C heating temperature, 3.9 hrs incubation time, and 1.25 mL enzyme dose per 1 g of cassava peels were the optimum conditions for the hydrolysis process. The glucose content is positively influenced by decreasing the temperature and pH; increasing the incubation time and enzyme dose. This method softens and hydrolyzes the cell wall components of the peels enough for peeling, hence, peeling time reduces.

The work was advanced by Barati et al. (2020) by mechanically peeling off the cassava tubers after enzymatic treatment. Cassava tubers are first pre-treated with an enzyme solution at a specific incubation time after which the tubers are peeled using a prototype peeling machine at 850 rpm operating speed within a specific peeling time. After performance evaluation with small, medium and large sizes of tubers, the peeling efficiency was recorded to be 82.03%, 80.90%, and 89.52% respectively. The optimum operating conditions were recorded based on the enzyme dose, the incubation time, and the peeling time: 0.8 mL/g, 4 hrs, and 3 mins respectively for small tuber sizes; 0.5 mL/g, 2.9 hrs, and 3.5 mins respectively for medium tuber sizes; and 1.3 mL/g, 2.8 hrs, and a 3.5 mins respectively for large cassava tubers. Also, results after evaluations show that tuber size had an effect on the peeled surface area but had no influence on flesh losses.

Fadeyibi & Ajao (2020) designed a batch loading multi-tuber peeling machine (*Fig. 48*) with a capacity of 600 kg/hr. The machine is made up of a revolving drum made of wire gauze, semi cone-like ends, that rotates to give smooth scratching and scraping of the tuber skin; the machine is powered by a low-speed 3-hp electric motor. The machine was designed to operate at 350-750 rpm speed range in 5-12 minutes time range, and the performance evaluation results show 20-22% flesh losses and 41.4-63.8% efficiency of the machine with respect to increasing speed for cassava tubers. The performance of this machine is relatively lower than the previous ones.

3.1 CASSAVA PEELING MODELS

Olukunle & Akinnuli (2013) investigated the theory of an automated cassava peeling system that is based on the principle of continuous tuber feeding system and peel removal through the shear force action created by the opposing motions of the peeling tools. A mathematical model was deduced after considering the machine and operational parameters such as peeling brush speed, mass of tuber in the chamber per unit time, speed of conveyor, diameter of the peeling rotor, efficiency of tuber, peeling mechanism, etc. and crop parameters such as crop variety, moisture content, maturity of crop, static component of tuber shear strength, peel thickness, dynamic component of tuber shear strength and day after Harvest, etc. the mathematical model predicted 88.73% peeling efficiency with certainty. The results also show that the peeling retention and the peeling efficiency are significantly influenced by conveyor to brush speed ratio, peel thickness, and moisture content of the tubers.

Adetan et. al. (2006) developed a mathematical model that accurately predicts the peeling of efficiency of the machine developed by Adetan et al. (2005) to be 95.46%, the model relates the peeling efficiency to the applied force, tuber average diameter, root-conveying belt speed, and the tuber length. Jimoh et al. (2014) used an already developed cassava peeling machine to develop a mathematical model to predict the peeling performance in different locations. The model predicts 96.20% peeling efficiency, and the result shows that the peeling performance of the machine improves at 130 rpm.

Jimoh et al. (2016) investigated the use of dimensional analysis to establish a model to predict the relationship between functional properties, and machine and crop parameters. The machine used was developed by Jimoh et al. (2014) at FUTA, Nigeria tested with an improved cassava variety. A comparative analysis was done using two kinds of peeling tools, smooth-edge and serrated-edge cutting edges, under different operating speeds. The results show optimum operating speed and feeding rate to be 130 rpm and 20-30 kg respectively for smooth-edge, and 160 rpm and 30 kg respectively for serrated-edge. The Smooth-edge and serrated-edge had (84.97%-94.60%) and

(81.24%-91.36%) peeling efficiency respectively, (1.57%-11.19%) and (6.36%-8.41%) mechanical damage respectively, (5.41%-15.03%), and (8.64%-19.34%) peel retention respectively, (387.10-1046.50 kg/hr) and (248.28-625.00 kg/hr) throughput capacity respectively. The model predicted a linear relationship between the machine speed versus the peeling time and ratio of the velocity of the conveyor.

Table 1: Cassava Peeling models developed to enhance machine performance

Author(s)	Model(s)	Performance Prediction	Contribution(s)
Adetan et al. (2006)	$C = -0.5122 + 109.32 \{\frac{I_n l_1}{l d_a}[F_P d_a]^{1/3}(0.8 - 0.12V)\}$	95.46% peeling efficiency	Used peel-flesh separation via compression and knife-peeling to model the theory of mechanical peeling machine.
Olukunle & Akinnuli (2013)	$M_{ce} = \Pi r_1^2 L\rho(\Pi r_2 + 1)C_v * (La/Lt)$ $Pe = \frac{K BvMc(0.977 + 0.0365(t - 1.098))}{c_v \pi r_1^2 L\rho(\pi r_2 + 1)}$	88.56-88.73% peeling efficiency	Investigated the theory of an automated cassava peeling system, and built a mathematical model that was deduced after considering the machine design and operational and crop parameters.
Jimoh et al. (2016)	Modeled machine efficiency, throughput capacity, mechanical damage, and peel retention using the principle of dimensional homogeneity.	Established a linear relationship between the ratio of	Investigated the use of dimensional analysis to establish a model to predict the relationship between

		velocity and peeling time versus machine speed.	functional properties, and machine and crop parameters using the 2014 peeling model developed at FUTA.

4.0 SUMMARY OF REVIEWED CASSAVA PEELING MACHINES

Some researchers have given recommendations for future areas of focus: Egbeocha et al. (2016) said that greater attention should be given to the abrasive peeler in future, Nathan et al. (2018) recommended that water should be employed in the abrasive design to clean the abrasive surface, the abrasive peeler mechanism is the best (Abdulkadir, 2012). Henceforth, current researchers and cassava peeler manufacturers are focusing on the abrasive mechanism, yet the problem of grating effects and mechanical damages of the abrasive method is still unresolved. Hence, FAO & IFAD (2005) recommended that "engineers and breeders should join forces and figure out how to mechanize the peeling task by developing cassava roots that are uniform in shape and size and having skins that meet certain specifications". This recommendation can't totally be ruled out though, but it will take us over years to come out with a cassava variety which will yield with uniform physical properties and can be grown across the globe, and also considering the fact that climatic conditions, like drought, affect the physical properties of the cassava tubers as well as the current quest for immediate cassava peeling mechanism in the global market to enhance food security.

4.1 Development of the peeling machines

From the reviewed works, it can be observed that several works have been done to develop an efficient mechanical peeling machine in diverse ways dating from the 1970s till now. Different designs with unique features and functionalities have been developed by several people with the involvement of many institutions, some the machines have these features:

- ***Peeling tool***: This is the part that directly contacts the cassava tubers to exert the required peeling force to peel off the tubers. We have the abrasive the peeling tools (brush, wire gauze, and ceramic materials), cutting-edge peeling tool (knife and cutting blades), combination of both abrasive and cutting-edge tools, and the lathe principle.

- ***Functionalities***: The designs have been advanced to add one or more functions like washing, chopping, pressing, cleaning, and grating to the peeling machine. Other machines also have the capabilities of peeling crops like potatoes, yams, onions, and garlic in addition to cassava. These features of the modern developments make the peeling machines more multi-purposeful and reduce cost on buying other components separately, of which some cassava peeler manufacturers have factored these ideas in their designs.
- ***Peeling Assistant***: Due to the adhesion between the peel and the starchy-flesh of the tuber, it is recommended to process it a few days after harvest. Henceforth, cassava tubers are sometimes soaked in water before commencing the peeling process, of which modern development has introduced lye solution (NaOH) solution, freeze-thaw, and Enzymatic pre-treatment before mechanical peeling. This softens and loosens the peel from the flesh enhance peeling performance. A waterjet-pressure system is introduced to assist the mechanical peeling.
- ***Power Source***: Most of the early designs were manually operated or powered, but petrol, diesel, and electric motors have been also added to reduce/eliminate the use of human energy during the process. These motors have specific power ratings and running speed, of which speed reducers have been introduced in some of the designs to achieve the required operating speed.
- ***Conveyor system***: Screw conveyors have been used in most of the peeling machines, they are been designed to have their own operating speed, mostly low speed, to increase the resident time and to transport the tubers through the machine during the peeling process.
- ***Other features***: Most of the machines are supported on frames, hand-fed/self-fed through the hopper, chains or sprockets to transmit motions, and the chute as an exit point for the peeled cassava tubers.

Two or more of these special features have been combined in several ways to enhance the development of an efficient cassava peeling machine.

Table 2: Summary of multi-functional Cassava peeling machines

Authors(s)	Machine Operations	Contribution(s)
Gumanit & Pugahan (2015)	Peeling, grating, and pressing.	Developed a multi-purpose automated machine for small scale processing.
Ugwu & Ozioko (2015)	Peeling and Washing.	Designed an efficient and economical motorized vertical cassava peeling machine.
Ogunlowo et al. (2016)	Cleaning, peeling, and washing.	Developed a manually-fed automated system for cleaning, peeling, and washing cassava tubers.
Rikzx (2017)	Peeling and grating.	Embarked on a project to design and fabricate a combined cassava processing machine. The project is still in progress, hence, the machine has not been fabricated yet.
Seirraleo News (2018)	Without any modification, it peels potato, yam, onions, garlic, and ginger, and cassava tubers.	FINIC developed a mechanized cassava peeling machine that is able to peel some specific crops.
Adeniyi et al. (2019)	Peeling and washing.	Developed a cassava processing machine that performs two operations concurrently. Uses ceramic mixture as abrasion.

Fadeyibi & Ajao (2020)	Peeling cassava, yam, cocoyam and potato tubers.	Designed a batch loading multi-tuber peeling machine.

4.2 The Lathe Mechanism

Manual operation is very high in the lathe mechanism, the operator has control over the contact between the peeling tool and the tubers, efficiencies and throughput capacities are almost the same as previous mechanisms with minimal flesh losses just that its operation is tedious and requires many operational skills.

Table 3: Development summary of the Lathe principle machine

Authors(s)	**Year**	**Contribution(s)**
Abdulkadir	2012	Developed hand-fed cassava peeling machine that has a rotating drum with punched hole-spikes
Ebunilo et al.	2013	Developed a cassava peeling that uses the lathe principle in its operation.
Ebomwomyi et al.	2017	Developed cassava peeler with 3 rotating wire brushes fixed in a metallic frame similar to Abdulkadir (2012) design.

4.3 Abrasive Peeling mechanism

The abrasive peeling system is the most used mechanism throughout the development due to the easy availability of design materials, easy operation, and high average performance. The peeling unit/chamber is mostly designed like a drum, the abrasive materials are either rolled/fixed around a rotating shaft or lined on the inner surface of a rotating drum, augers/screw conveyors are sometimes used along with the peeling tools. Brush speed and size of tubers greatly affect this mechanism, for those without conveyors, brush speed is mostly low (≤150 rpm), this reduces flesh losses as well as increases peeling efficiencies and the throughput capacities. For those with conveyors, high brush speed (>1000 rpm) is combined with slow auger speed (≤150 rpm) to enhance peeling performance, the throughput capacities are averagely lower than the latter but similar peeling efficiency. Also, the peeling retention time is constant and flesh losses are reduced with the help of conveyors while peeling retention time is based on when the machine will be stopped and flesh losses are controlled only at a reduced brush rotating speed; tubers are mostly grated at high speed. Grouped/sized tubers also enhance good performance, especially when operated at the required speed.

The number of abrasive tools, types of abrasive materials, brush speeds, and conveyor speeds are the major challenges in the abrasive mechanism. Choosing effective tools and parameters enhances peeling and machine performance.

Fixed outer-drum peeling machine: High brush speed was used for mechanisms with fixed outer drums, peeling performance increase at an increasing brush speed, and flesh losses were minimal compared to the abrasive mechanism. Sized tubers work better with this design as well.

Table 4: Summary of the abrasive peeler development

Authors(s)	Year	Contribution(s)
Nwokedi	1983	Developed cassava peeler of an egg-shaped cylindrical drum with wire gauze linings, with water placed below.
Odigboh	1985 1988	Developed continuous batch-abrasive peeling machines, that's the model I, II, and III peeling machines.
Akintunde et al.	2005	Design an abrasive peeler of two metallic drums which rotates oppositely to peel off already soaked cassava tubers.
Olawale	2005	Developed the hand-fed single and the double-gang cassava peelers which uses the auger-brush arrangement to impact rotary motion and peeling action on tubers.
Olukunle et al.	2006	Improved on the hand-feed by designing a self-fed cassava peeling machine of longer brush length.
Olawale	2007	Developed a cassava peeler for cottage industries.
Le	2012	Developed the pedal cassava peeler of a cylindrical drum made by bars of wire brushes powered manually.
Olukunle & Akinnuli	2013	Developed abrasive cassava peeling machine that uses forward linear velocity and shear stress on the tubers,

		dropped into the unit, to turn and peel. A model was also designed to predict peeling the efficiency of the machine.
Oluwole & Adio	2013	developed a batch cassava peeling machine that uses an abrasive mechanism. The machine has a stationary abrasive drum and a rotating inner drum.
Olawale & Oluwatoyin	2013	Developed an automated peeling machine for large scale industries that is capable of peeling off both cassava and cocoyam tubers.
Gumanit & Pugahan	2015	Developed an automated combined cassava peeler, grater, and presser machine for small scale processing.
Ugwu & Ozioko	2015	Developed a motorized vertical cassava peeling and washing machine that is efficient and economical.
Ajibola & Babarinde	2016	Developed a labor less motorized machine for rural areas to peels 20 kg batch of cassava tubers.
Aji et al.	2016	Developed an electrically operated peeling and slicing machine for small scale industries and for farmers in rural areas.
Okorie	2016	Modified the peeling machine developed by Oluwole & Adio (2013).
Nathan & Udosen	2017	Comparatively analyzed the performance of the two machines which use nailed-spikes as their peeling tools (Type1 & Type2).
Nathan et al.	2017	Comparatively analyzed the performance of the two machines which use abrasive metal sheets welded and folded round cylindrical drums as their peeling tools (Type-3 & Type-4).
Pius & Nwigbo	2017	Designed and fabricated cassava peeling which is capable of handling different diametric sizes of cassava tubers. It has a spring-loaded mechanism that exerts required pressure on the tuber for effective peeling.

Chilakpu	2017	Modified the designs by Oluwole & Adio (2013) and Le (2012) by powering the machine with an electric motor.
Alhassan et al.	2018	Developed a cassava peeling machine using the abrasive mechanism powered by a 3-hp electric motor, which is similar to the work of Le (2012).
Seirraleo News	2018	FINIC developed a mechanized cassava peeling machine that is capable of peeling other crops.
Alli & Abolarin	2019	Designed the abrasive-cassava attrition peeling machine which is a modified version of the design made by Ohwovoriole et al. (1988)
Samuel & Emmanuel	2019	Modified Ajibola & Babarinde (2016) by increasing the peeling chamber and reducing the operating power.
Adeniyi et al.	2019	Developed a cassava peeler that has a peeling drum whose inner surface is abrasive (ceramic mixture), that acts as the peeling medium
Okoronkwo et al.	2019	Developed a cassava peeler using Zinc abrasive materials as the peeling tool.
Fadeyibi & Ajao	2020	Designed a batch loading multi-tuber peeling machine made up of a revolving drum.

4.4 Knife peeling Mechanism

The knife-peeling machines, averagely, has slight performance differences with the abrasive mechanism. Peeling efficiencies and throughput capacities are high at a very low blade/knife-rotating speed (≤90 rpm), the throughput capacity increases when the auger is introduced at low speed (Thayawee, 2005), the efficiency of the machine by Olawale (2007) increased as a result of the combined action of the brush and knife-peeling system; the contact between the tubers and the peeling tool was controlled by the operator, its similar to the lathe principle. Flesh losses and mechanical damages were high compared to the abrasive system because the tubers were mostly sliced and chipped.

Table 5: Development summary of the Knife-peeling machine

Authors(s)	Year	Contribution(s)
Odigboh	1976 1985	As one of the pioneers, he made an appreciable effort to design the continuous batch-knife peeling machines.
Ohwovoriole et al.	1988	Developed a rotary peeler that uses cutting blades, mounted on a frustum-like drum, as its peeling tool.
Adetan et al.	2005 2006	Experimentally designed a mechanical peeler of spring-loaded knives and two cylindrical drums. A mathematical model that accurately predicts the efficiency of the machine was developed.
Thayawee	2005	Improved on the previous design by rolling the cassava roots over fixed blades mechanically.
Jimoh & Olukunle; Olukunle & Akinnuli	2012	Developed a peeling tool as a rotating cylindrical drum with cutting blades, and the performance of the machine was steadily evaluated.
Aniedi et al.	2012	Developed a machine that applies efficient impact factors on the tuber to remove the cortex at a range of moisture in the tubers without significant loss of the starchy flesh.
Jimoh et al.	2014	Developed a cassava peeler that operates based on the principle of impact as tubers spin and comes in contact with the cutting tool.
Ogunlowo et al.	2016	Developed an automated system for cleaning, peeling, and washing cassava tubers.
Priscilla	2017	Evaluated the performance of the Fomena Cassava peeling machine that involves a lot of manual work.

Adekunle et al.	2018	Borrowed the peeling concept of Ohwovoriole et al. (1988) to design and fabricate a modified cylindrical rotary-cutter type cassava peeling machine.
Raymond et al.	2018	Developed a waterjet-assisted cassava peeler.
Pariyed et al.	2019	Developed a cassava knife-peeling machine with two levels of spring stiffness.

4.5 The Rotary peelers

The rotary peelers mostly use cutting edges/blades as their peeling tool, this system seems to have low efficiency, and their design is very complicated. Their design and operations are similar to that of the knife-edge peelers and hand peeling method, just that they have spring-loaded systems which press the tubers against the cutting blades for efficient peeling, and the rotary motions of the blades cause the cut and roll action on the tubers to peel off. They operate with virtually no/fewer flesh losses under high speed, they have relatively low average peeling efficiencies and low throughput capacities as compared to the abrasive mechanism and almost the same performance as the knife-edge peelers. They give high peeling performance under low speed (≤100 rpm) mostly for large size of tubers.

4.6 Pre-treatment method

Pre-treating the tubers before mechanical peeling enhanced the machine performance, increased in the moisture content of the tubers enhanced peeling by reducing the adhesion between the peel and the starchy-flesh through different ways (treatments), which gave little work to the machines, and they worked better even at high operating speed. As the peeling efficiency and the throughput increase in this mechanism, tuber losses are high due to the concentration of chemicals used, pre-treatment time, and heating temperature.

Table 6: Development summary of pre-treatment method

Authors(s)	**Treatment**	**Contribution(s)**
Ebegbulem et al. (2013)	NaOH and HCl solution	Tubers are pre-treated with a chemical solution and then fed into a rotary brushing machine for peeling.

Oyedele et al. (2019)	Lye (NaOH)	Designed and fabricated a wet mechanical brushing unit for lye pre-treated cassava root.
Ziba et al. (2019)	Free-thaw	Developed a cassava peeling mechanism whereby tubers are pre-treated before feeding them into an abrasive peeling machine.
Barati et al. (2019, 2020)	Enzyme	Used enzyme treatment to maximize cassava tuber peeling, with a reduction of peeling time. Advanced the work by mechanically peeling off the cassava tuber after enzyme treatment.

The extra cost of pre-treatment increases the cost of the peeling process (Barati et al., 2020). Generally, Starchy-flesh of the tubers are sometimes cooked at high temperatures, experience dark color formation, nutrient losses, and many effects which are harmful to human health

4.7 Peeling Performance

The performance of the cassava peeling machines is mostly accessed based on its peeling efficiencies, throughput capacities, and flesh losses which are largely affected by several factors such as the physicomechanical and machine properties as discussed in chapter 3 of this work. The following were deduced from the studies with regards to the performance evaluation of the works reviewed:

- Peeling efficiency: Machine efficiency is the percentage ratio of the input power to the output power (Samuel & Emmanuel, 2019). Moreover, the peeling efficiency is estimated in two ways:
  - The percentage thickness of the tuber peeled by the machine to the ideal thickness to bee peeled by the machine (Abdulkadir, 2012).
  - The percentage weight of peels removed by machine to the weight of the peels removed manually (Oyedele et al., 2019).
- Throughput Capacity: It is the ratio of the peeled mass of tubers to the time taken in peeling (kg/hr).
- Flesh loss: It is the percentage ratio of the weight of flesh removed by the machine to the total flesh weight of the tubers.

The second definition is mostly used for peeling efficiency. They are the most considered performance ratings of the cassava peeling machines, globally. From the works reviewed, it could be seen that achieving 100% peeling efficiency is indeed a difficult task amidst all the several ways and factors considered in the designs. The machines are categorized according to their operating principles, and their performance is summarized as shown in table 9.

Among the abrasive peeling machines reviewed, the FINIC has the highest average throughput capacity (1800 kg/hr) and high peeling efficiency of 97% with high flesh losses of 31.5%; this makes the work of Chilakpu (2017) more outstanding with a peeling efficiency of about 97% with 700-1000 kg/hr throughput capacity and low flesh losses of 8%. Increased in the machine volume increased the throughput capacity of the Henan Doing Machine, hence, though it has high peeling capacity, the machine Chilakpu (2017) still surpasses its performance averagely.

The machine developed by Jimoh et al. (2014) has the highest peeling performance among the knife-peeling machines. At 140 rpm speed, it recorded 100% peeling efficiency, 1351.35 kg/hr throughput capacity, 0% peel retention, and 1.23% mechanical damage as well as minimal flesh losses. Besides the minimal flesh losses of the lathe principle peelers and the stationary peelers, their peeling efficiency and throughput capacity are relatively lower than the other mechanisms.

The pre-treatment mechanisms have high throughput capacity, and high average peeling efficiency; the flesh losses are also higher resulting in an increase in food losses.

Table 7: Performance summary of the peeling machines reviewed

Machine type	Author(s)	Speed (rpm)/ Required Power	% Peeling efficiency	Capacity (kg/hr)	% Tuber loss
Abrasive Peeling Machi	Nwokedi (1983)	-	45-80	15-2400	-
	Odigboh (1985, 1988)	40	-	≈180-300	-
	Olawale (2005)	500-1,500 (brush) 120-450 (auger)		302.4	-

Akintunde et al. (2005)	0.36 hp (motor)	81.2-85.4	35-60	3.87-7.10
Olukunle et al. (2006)	1000-1400 (brush) 50-150 (auger)	82-92	≤1000	-
Olawale (2007)	1000-1400	45-80	-	-
An Ni Le (2012)	Manual	$\bar{x} = 95$	60-100	5
Olukunle & Akinnuli (2013)	500-3000 (brush) 150 (conveyor)	83.80-88.50	-	-
Olawale & Oluwatoyin (2013)	1200 (brush) 150 (auger)	75.5-79.5	95	-
Gumanit & Pugahan (2015)	1.25 hp (motor)	69.33-81.60	60	4.42-12.78
Ugwu & Ozioko (2015)	380-420	55 – 72		
Ajibola & Babarinde (2016)	9.7 kW (13 hp)	75-87.5	-	-
Aji et al. (2016)		$\bar{x} = 66.2$	403.2	8.52
Pius & Nwigbo (2017)	100 (797.2 W)	59-75	-	-
Chilakpu (2017)	150	$\bar{x} \approx 97$	700-1000	8
Nathan & Udosen (2017)	80-110	82 & 88	1041 & 1149	0.7 & 3.26
Nathan et al. (2017)	80-110	85 & 90	1141 & 1262	2.06 & 2.16
Alhassan et al. (2018)	Manual/ 3 hp (motor)	12.7-74	6.2-31	5-12

	Seirraleo News (2018)		97	1800	31.5
	Samuel & Emmanuel (2019)	42.28-52.85 W	80	-	-
	Alli & Abolarin (2019)	≤250	≤80.9	47.9	-
	Adeniyi et al. (2019)	900	63.64-68.97	104.4-223.2	22.38-37.5
	Okoronkwo et al. (2019)	784	$\bar{x} = 91.27$	561.6	-
	Fadeyibi & Ajao (2020)	350-750	41.4-63.8	600	20-22
Knife-edge peeling machines	Odigboh (1976)	88 & 200	75-95%	154.5-204	-
	Ohwovoriole *et al.* (1988)	manual	92	-	None
	Thayawee (2005)	0.22 m/s (conveyor) 4.5 m/s (blades)	75	224	-
	Adetan et al. (2005)	0.20-2.29 m/s (conveyor)	52.4-75.8	-	-
	Jimoh & Olukunle, (2012); Olukunle & Akinnuli (2012)	100-600	50-75	76-442	12-44

	Aniedi et al. (2012)	60 rpm (blades)	≈98	-	-
	Jimoh et al. (2014)	100-140	67.53-100	238.10-1351.35	-
	Ogunlowo et al. (2016)	40-60	55-95	-	-
	Priscilla (2017)	Manual	-	2.72-27.36	10.35-22.95
	Raymond et al. (2018)	Manual	100	12.66-37.13	None
	Adekunle et al. (2018)	400	76.92-83.34	103.86-108.57	8.89-11.57
	Pariyed et al. (2019)	70-90	≤90.3		3.63
Lathe machine principle peelers	Abdulkadir (2012)	-	58.5–77.5	240-300	-
	Ebunilo et al. (2013)	180	>70	-	minimal
	Ebomwomyi et al. (2017)	-	85	-	13.13
Stationary outer-drum peeling-machines	Oluwole & Adio (2013)	364-394	45.1-87.8	-	2.16-7.87
	Okorie (2016)	364-394	60.22-70.45	-	5.09-5.95
Pre-treatments + mechanical peeling	Ebegbulem et al. (2013)	-	-	1836	-
	Oyedele et al. (2019)	-	66.67-70	-	-
			≈99.5	-	19

	Ziba et al. (2019)	1000 (machine)	82.03-89.52	-	-
	Barati et al. (2019; Barati et al. (2020)	850 (machine)			

4.8 Factors affecting cassava peeling

The performance of cassava peeling machines is highly influenced by auger speed, brush speed and tubers moisture content (Alli & Abolarin, 2019; Olawale & Oluwatoyin, 2013). The irregular shape of the tubers, non-uniformity of the cortex thickness, and inadequate technical data on design parameters affect the peeling efficiency (Aniedi et al., 2012). The diameter of the tubers influences the peeling time of the mechanical peeling machine while the length does not (Jimoh et al., 2014). The diameter and the length of the cassava tuber directly affect the penetration pressure with knife-peeling. The rolling resistance against the peeling tool, coefficient of static friction, shear stress, angle of repose, peeling cutting force and Poisson's ratio are mechanical properties of cassava tuber which affect the peeling process, as well as the peeling tool material type used (Nwachukwu & Simonyan, 2015; Ohwovoriole et al., 1988).

Moreover, for cassava peeling machines which use roller-like peeling tools, the mechanical peeling of cassava tuber is been affected by the clearance distance between the rollers, angular speed, and the direction of the rollers (Sagragao & Tan, 2008); also, those with blade-cutting peeling tools are affected by the blade thickness, number of blades, and blade spacings (Ohwovoriole et al., 1988). Ilori & Adetan (2013) investigated the peel penetration pressure of two cassava varieties and found out that the peel penetration forces obtained for both varieties were observed to be similar with the same blade thickness, but the peel penetration pressure is directly proportional to the blade thickness. Moreover, the compressive cracking force required to break the cassava tuber is inversely proportional to the tuber diameter and directly proportional to the peel thickness and tuber length (Olutosin et al., 2017).

Ademosun et al. (2012) investigated the effect of physical and mechanical properties of cassava tubers on mechanical peeling, and the results show that moisture content, tuber surface taper, weight of peel, peel penetration force, size of the tuber, tuber diameter, peel shearing stress, and peel thickness affect the quality performance of a mechanical peeling machine. Inadequate technical data on the properties of the cassava tubers affects the design of an efficient peeling machine. Table 1 shows a summary of some properties affecting the mechanical method of peeling.

Table 8: Some physicomechanical tuber and Machine properties affecting cassava peeling

Tuber Physical Properties	Tuber Mechanical Properties	Machine Properties
• Moisture content • Diameter • Length • Peel thickness • Proportional weight of peel • Angle of repose • Tuber surface taper • Roundness	• Peel shearing stress • The rolling resistance against the peeling tool • Penetration pressure/force • Poisson's ratio • Rupture stress • Coefficient of friction] • Compressive force	• Auger/conveyor speed • Brush speed • Blade thickness • Number of blades • Blades spacings • Peeling tool material type • Peeling time • Clearance distance between rollers

4.9 Some properties considered in some designs

These are some properties considered in design some of the peeling machines reviewed:

- ***Tuber dimension***: Generally, the peeling machines performed better on tubers grouped according to small, medium, and large sizes. Tuber length and diameter are affected by factors such as variety and growth conditions. Most of the peeling machines work poorly on small sized-tubers compared to medium and large sizes which gave better and higher machine performances. The sizes are mostly graded according to the tuber length and diameter, and the values of these parameters were classified differently by different researchers. 100-250 mm, 150-280 mm, and 175-310 mm length were recorded for small, medium, and larges sizes of tubers respectively with their respective diameters of 31.35-45.55 mm, 40.75-70.29 mm, and 68.27-91.67 mm (Ogunlowo et al., 2016); 650 mm is the maximum cut section of cassava tubers (Ebunilo et al., 2013); Tubers ≤40 mm in length normally requires hand trimming after mechanical peeling (Odigboh, 1976), and tuber diameters below 60 mm give lower throughput capacity (Olawale, 2007). Moreover, 70-90 mm and 30-60 mm tuber length and diameter gave high peeling efficiency and throughput capacity with minimal flesh losses (Okoronkwo et al., 2019); and 52-70.5 mm diameter gave an average peeling efficiency above 80% (Ajibola & Babarinde, 2016). Also, 260-300 mm tuber length resulted in 44% mechanical damage at high speed, while 100-140 mm length gave very low mechanical damage and retention time (Olukunle & Akinnuli, 2012). Henceforth, the exact value range of length and diameter is not specific, rather the type and mechanism of the machine, including speed, determine the criteria for the tuber sizings/groupings.

- ***Blade thickness***: Cutting tools are limited to peel thickness (Ebunilo et al., 2013); (2.20-4.72 mm), (1.50-2.00 mm), (0.1-5.0 mm), and (1.22-4.12 mm) were the peel thickness recorded by Olutosin et al. (2017), Adekunle et al. (2018), Olukunle & Akinnuli (2013), and Ademosun et al. (2012) respectively, which were influenced by the tuber variety and size. Peeling/shear stress is needed to exert force to cut through the peel; 0.65-9.25N/mm^2 and 2.0-3.65 N/mm^2 peeling stress were recorded by Ademosun et al. (2012) and Olutosin et al. (2017) respectively; 1.5 mm and 2.0 mm blade thickness were been used in the works of Olutosin et al. (2017) and Ohwovoriole et al. (1988), and 1.7 mm blade thickness by Priscilla (2017). The 2.00 mm blade thickness showed the best result in knife-peeling, which exerts the required peel penetration force, hence, Ohwovoriole et al. (1988) recommended that 2.0 mm blade thickness with a 5 mm blade spacing is the most effective for efficient peeling. Henceforth, regardless of the peel thickness (influenced by tuber variety and size), efficient peeling is achievable by choosing an effective blade thickness with the right blade spacing and speed.
- ***Shear Strength***: The shear stress or strength of cassava tubers is directly proportional to tuber moisture content, that is the percentage water quantity of water contained in the tubers; high moisture content lowers the cutting resistance, penetrometer resistance, and compressive strength of the tubers (Kolawole et al., 2010). The higher the moisture content

the higher the peeling efficiency, MC of 45-70% gave 57.04-88.73% peeling efficiency at 150:3000 (rpm) of conveyor to brush speed ratio (Olukunle & Akinnuli, 2013); the highest peeling efficiency was recorded at 50 rpm brush speed and 70% MC of tubers by Alli & Abolarin (2019). Increasing the number of days after harvest before processing lower MC which increases the adhesion between the peel and the flesh (Jimoh & Olukunle, 2012). According to Kolawole (2012), peel penetration force of 5.4N in 5.3 seconds was required to cut through the peels of equal sizes of tubers at 70% MC, while 9.2N in 9.7 seconds was required to cut through same sizes of tubers at 50% MC, hence, bulk cassava handling processes involving cutting should be done when it is fresh, that is with ≥70% MC (Adeniyi et al., 2019). According to Oriola & Raji (2015), in general, cassava tubers have low strenth properties and they increase as the moisture content increases.

- ***Drum fill***: Though batch peeling of tubers increases the peeling efficiency and the throughput capacity, it increases flesh losses and mechanical damages and through breakages, henceforth, Le (2012) recommended that the drum fill should be reduced. To increase the feeding rate, the peeling unit capacity should be increased to enhance optimum drum fill.
- ***Post-harvest time to peel off cassava tuber***: The force of adhesion between the tuber peel and the flesh is very minimal when freshly harvested, hence, it is very economical to commence the peeling process when it is freshly harvested to reduce mechanical damages (Jimoh et al., 2016). After evaluation of resistance of cassava tuber deformation, Kolawole (2012) recorded that the penetration force for 70% moisture content wet basis is 5.4 N and that of 50% moisture content wet basis is 9.2 N. Also, 5.3 seconds cutting time was recorded for the equal size tuber with moisture content wet basis of 70%, and 9.7 seconds was recorded for 50% moisture content on wet basis. Henceforth, the post-harvest time to peel off cassava tuber is when it is fresh, and the moisture content (wet basis) is high.

4.10 Strengths and weakness of the peeling machines

The machines are grouped according to their operating and design principles, and table 11 shows the strengths and weaknesses of the category of peelers.

Table 9: Strengths and weaknesses of the categories of the peeling machines reviewed

Machine type	Author(s)	Advantages	Disadvantages
Continuous process cassava peeler	Odigboh (1976, 1985) Odigboh (1988)	Low power cost, the manual technique is mostly required. Peeling time is not required.	Tedious since human energy is required. High tuber losses.
Rotary peeler	Ohwovoriole et al. (1988) Adekunle et al. (2018)	Cheap materials used. Little or no tuber loss.	Required manual operation and more skills.
Abrasive drum/brush peeler.	Nwokedi (1983) Akintunde et al. (2005) Olawale et al. (2006) An Ni Le (2012) Olawale & Oluwatoyin (2013) Ajibola & Babarinde (2016) Aji et al. (2016) Pius & Nwigbo (2017) Chilakpu (2017) Ebomwomyi et al. (2017) Nathan & Udosen (2017) Nathan et al. (2017) Alhassan et al. (2018) Samuel & Emmanuel (2019) Alli & Abolarin (2019) Adeniyi et al. (2019) Okoronkwo et al. (2019)	Very simple to operate. Easy to design or model. Mostly give high peeling efficiency.	Low speed, hence, much peeling time, and more energy required. High mechanical damage

	Fadeyibi & Ajao (2020) Ugwu & Ozioko (2015)		
Single and double gang peeler	Olawale (2005)	Easy to operate	Low machine performance with a high undesired output.
Double action self-fed peeler	Olukunle et al. (2010)	Less peeling time, and very efficient	Peeling retention is high, and may require manual peeling. Requires more operational skill due to its complex mechanisms.
Knife-edge automated peeler	Adetan et al. (2005) Thayawee (2005) Olawale (2007) Jimoh & Olukunle, (2012); Olukunle & Akinnuli (2012) Jimoh et al. (2014) Ogunlowo et al. (2016) Priscilla (2017) Adekunle et al. (2018) Raymond et al. (2018) Pariyed et al. (2019)	Mostly gives desired results, and requires less power.	Difficult to handle small tuber sizes. Sometimes chips the tubers, hence, causing high losses.
Lathe principle peeling machine	Abdulkadir (2012) Ebunilo et al. (2013) Ebomwomyi et al. (2017)	Very efficient and easy to operate.	Requires more human effort. High mechanical damage.

An automated peeler	Jimoh & Olukunl (2012); Olukunle & Akinnuli (2012) Aniedi et al. (2012) Olukunle & Akinnuli (2013) Gumanit & Pugahan (2015)	Less/no human effort required. Relative cheap maintenance.	Requires high operational skills. Less efficient for small tuber sizes.
Stationary outer drum peeling machine	Oluwole & Adio (2013) Okorie (2016)	Less peeling time, and very effective to operate.	High tuber losses especially via grating effect.
Pre-treatments + mechanical peeling	Ebegbulem et al. (2013) Oyedele et al. (2019) Ziba et al. (2019) Barati et al. (2019; Barati et al. (2020)	Less abrasion/peeling force required, hence, less power.	It is time-consuming, and food poison might set in since it has to be dipped into some harmful solutions for some time. It exposes the cassava to thermal stresses (lower and higher temperatures during pre-treatment)

5.0 CONCLUSION

It can be concluded from the review that:

- Many governmental and private agencies or institutions have contributed to the development of the peeling machines.
- The machine development has progressed to handle batch cassava tubers at a time, and this is to increase the processing rate of the tuber to boost the crop marketability, globally.

- The machines developed so far still have significant tuber damages and flesh losses; the abrasive peelers mostly grate the flesh and the knife peelers chip off the tubers during peeling.
- An electric motor has replaced the manual source of operating power in most machines.
- Increasing the resident time of tubers in the peeling unit increases peeling efficiency.
- Increasing the brush speed (even above 500 rpm) increases the peeling efficiency, the throughput capacity, mechanical damages, flesh losses, and vice versa.
- The optimum rotational speed of the blades of knife-peeling machines is less than that of the abrasive peeling machines (<200 rpm), and they operate better within 50-150 rpm speed.
- Augers/conveyors run very slow relative to the peeling tool, this is to increase the resident time of the tubers.
- Chemical pre-treatment softens and loosens cassava peels from the starchy-flesh, but affects the nutritional components, cooks the tubers, and also result in food poison.
- The optimum conditions for chemical pre-treatment mechanisms are the solution concentration, heating temperature, immersion time, and pH.
- The peeling efficiencies and the throughput capacities of chemically pre-treated cassava tubers are very high, averagely about 80% and above 1000 kg/hr respectively.
- Increasing the drum fill increases the mechanical damage. Hence, to increase the feeding rate, the volume of the peeling chamber needs to be increased to reduce the drum fill.
- Models have been built to predict the peeling efficiency of some cassava peeling machines, as well as establishing relationships between the machine parameters.
- Most reviewed cassava peeling machines don't produce the desired result with regards to the state of the peeled cassava tubers compared to hand peeling.
- Most of the peeling machines still need further improvement to achieve 100% desirable results.
- The peeling process should be commenced as soon as the cassava is freshly harvested, at about 70% MC and at least 40% MC.
- Most reviewed machines are capable of performing one or more tasks in addition to cassava peeling.

- Drum-like peeling units were used in most reviewed machines, and this enhances easy rotation of the peeling unit to cause turn peel action on the tubers.
- Most reviewed peeling machines perform better on cassava tubers grouped into small, medium, and large sizes at a specific length and diameter.
- Increasing blade thickness from 1.5-2.0 mm and brush length increases the peeling efficiency.
- To design an efficient and effective cassava peeling machine, some physicomechanical properties of the tubers and some mechanical properties of the machine need to be critically considered.
- The abrasive peeling machines have higher throughput capacities, mostly above 500 kg/hr, with high flesh losses, and average peeling efficiency of about 85%.
- The knife-peeling machines have minimal flesh losses but have high mechanical damages and low throughput capacities, mostly below 500kg/hr, and about 90%. average peeling efficiency.
- The lathe-principled machine has low average peeling efficiency, and throughput capacities below 300 kg/hr, with minimal tuber losses.
- The Henan Doing Machine has the highest throughput capacity of 3628.7 kg/hr because of the high-design capacity of the machine.
- The manually-operated peeling machine developed by Alhassan et al. (2018) has a lower performance with high tuber losses, hence, reducing/eliminating manual operations increases the performance.
- As at when this review was contacted, a cassava peeling machine that has 100% peeling efficiency and 0% tuber losses, and is capable of producing a desirable result was not developed yet, hence, the search for a 100% efficient peeling machine still continues.
- Developing a mechanical cassava peeler with a 100% level of performance is far from possible unless an artificial intelligence and biosensing system is been introduced in the design concept.

6.0 RECOMMENDATIONS

It is recommended that:

- The physicomechanical properties of the cassava tubers should be considered in the development of efficient cassava peeling machines.
- Artificial intelligence and biosensing technologies should be employed in the design concept of future peeling machines.
- The knife-peeling mechanism should be giving much attention to future research works.
- The machine operational parameter should be considered in future developments.
- Peeling of cassava tubers as soon as they are harvested or high moisture content should be maintained.
- Other processing functions like grating, milling, etc. should be added to the peeler designs to reduce cost during postharvest handling.
- Much attention should be given to the commercial peeling machines to boost cassava production, especially for consumption purposes.
- Considering to maximize the machine performance and to achieve the desired results in the future, the manual and the mechanical mechanisms should be combined.

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Dedication

This work is dedicated to my mother and all my family members.

Conflicts of Interest

There are no conflicts to declare.