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Design, construction, and performance evaluation of an innovative cassava peeling machine

A.F. Adegoke, M.O. Oke, K.O. Oriola, and L.O. Sanni

Abstract: *Postharvest processing of cassava requires peeling as a unit operation, and it has been well documented that peeling is a major challenge of cassava processing. This study presents a recently developed cassava peeling machine made from locally available engineering materials. The machine has a capacity of 8 tonnes/day with the dual role of peeling and recycling of fruit water used in the peeling process for washing/mild pretreatment. The peeling machine utilizes an abrasive peeling surface inscribed with indented 1.2 mm stainless steel of 770 mm height with 2,450 mm diameter, a concrete based cavity, fruit water recovery tank, water pump, and the transmission system. The configuration resulted in careful removal of the tuber peels achieving > 90 per cent flesh recovery at an average rotational speed of 1,600 rpm < Nt <2,600 rpm. The average peeling efficiency of the machine was 58.6–85.75 per cent depending on the maturity, age, and variety of cassava. The cost of a single unit in Nigeria was estimated at US$1,230.*

Keywords: cassava, fruit water, abrasive peeling

CASSAVA (*MANIHOT ESCULENTA* CRANTZ) is an important dietary source of carbohydrates for approximately 800 million people in Africa, Asia, and Latin America (Sowmyapriya et al., 2017) and it is widely cultivated for its root. The edible part of the fresh root contains 32–35 per cent carbohydrate, 2–3 per cent protein, 75–80 per cent moisture, 0.1 per cent fat, fibre, and 0.70–2.50 per cent ash (Oluwole et al., 2004) as well as other components such as beta carotene, depending on the variety. Nigeria is the largest producer of cassava in the world, with a production level estimated at 57,134,478 tonnes per year (Uthman, 2011; FAOSTAT, 2016). This is a third more than the production in Brazil (the world's second-largest cassava producer) and almost double the production of Indonesia and Thailand. Until recently, cassava was primarily produced for food as it is consumed on a daily basis in different forms and often more than once a day. Its importance as a major cheap source of calorie intake for both humans and livestock in many tropical countries has been widely acknowledged (Diop, 1998). Most cassava produced is processed traditionally in Nigeria into local foods like *gari, lafun, fufu, abacha* and *akpu*, while sweet varieties are boiled and pounded into dough and consumed with vegetable

A.F. Adegoke (saintadekolaadegoke@yahoo.com), Country Technical Expert (Engineering), Cassava Adding Value for Africa Phase II (CAVA II-Nigeria); M.O. Oke (ola4ade@yahoo.com), Professor at the Department of Food Science and Engineering, Ladoke Akintola University of Technology, Nigeria; K.O. Oriola (kazzyoris@yahoo.com), Senior Lecturer at the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Nigeria; L.O. Sanni, Professor/Country Manager at Cassava Adding Value for Africa Phase II (CAVA II-Nigeria)

soup (Oriola and Raji, 2013). It is also made into *kokonte* and *agbelima* in Ghana (Quaye et al., 2009). Egbeocha et al. (2016) reported that the output of the cassava production and its demand are projected to be more than doubled by 2020 as the trend in cassava production shows a steady growth over time and they further reported that improved cassava varieties were grown on about 22 per cent of the 9 million hectares of land that were planted in 20 countries all over the world.

Cassava plays a vital role in world food security because of its capacity to yield under marginal soil conditions and tolerance to drought. It is the most widely cultivated crop in Nigeria by smallholder farmers who depend on seasonal rainfall to grow it. Also, cassava provides a livelihood for over 30 million farmers and countless processors and traders (Kolawole and Agbetoye, 2007).

According to Oriola and Raji (2013), cassava is presently the most important food crop in Nigeria from the point of view of both the area under cultivation and the tonnage produced, due to the fact that it has transformed greatly into a high yielding cash crop and a foreign exchange earner, as well as a crop for world food security and industrialization. The short shelf life of cassava roots is primarily attributed to the postharvest physiological deterioration (PPD), which is triggered as a wound response shortly after harvest (Sánchez et al., 2013). PPD reduces the quality and quantity of starch and renders the cassava roots unmarketable and inedible. PPD is a complex process, and its exact mechanism is still not fully understood (Zainuddin et al., 2018); however, it is known that it involves enzymatic stress responses to wounds and changes in gene expression. Freshly harvested cassava root starts deteriorating almost immediately after harvest and can only last for three days before PPD sets in. This is due to its high moisture content of about 70 per cent (Ngoddy, 1989). The FAO reports losses in cassava of 30 per cent while other reports are lower at 8 per cent in Nigeria (Naziri et al., 2014). The best form of preservation and reduction of postharvest losses is therefore immediate processing after harvest into various shelf-stable products such as *gari*, chips, and pellets. Alternatively, farmers can delay harvest of tubers until it is actually needed, leaving it in the ground for up to two years and beyond. As cassava stores well in-ground and efforts to develop modern storage technologies to store cassava tubers beyond a few days are ongoing, processing of cassava into value-added products becomes the best option.

Processing cassava into finished or semi-finished products often involves all or some of the following operations, depending on the desired end-products: peeling, washing, grating/chipping, dewatering/fermentation, pulverizing, sieving, pelletizing, and drying/frying. Most of these operations are still being done manually, and they are generally labour intensive, arduous in nature, time consuming, and unsuitable for large-scale production (Adetan et al., 2003; Quaye et al., 2009). This is due to their low output capacity among other negative attributes, although some levels of success have been recorded in the areas of grating and dewatering (Davies et al., 2008; Adetunji and Quadri, 2011). However, it has been well documented that cassava peeling is the major challenge of cassava processing in Nigeria (Nwokedi, 1984; Olukunle, 2005; Olukunle et al., 2006, Oriola and Raji, 2013; Egbeocha et al., 2016).

Of all the cassava processing steps, peeling appears to be the most time-consuming. Jekayinfa and Olajide (2007) reported that a total of 44.88 hours is used to process 1 tonne of raw cassava tubers to *gari*; the peeling process alone account for 25 hours, that is, over 55 per cent of the time is spent on peeling alone. Peeling involves peeling off the cassava tuber's outer skin or the removal of the thin layer (usually called the peel) from the tuber. Peeling, therefore, must distinguish between the layers to remove, so that the peeled tuber and the peels can be put to different uses (Egbeocha et al., 2016). The peels of cassava consist of an outer and inner part, the former comprising a layer of cork cells and the phellogen. The cork layer is generally dark in colour and can be removed by washing in water as is done in large factories. The inner part of the peel contains the phellogen and the phloem which separate the peel from the body of the root. The cork layer varies from between 0.5 and 2 per cent of the weight of the whole root, the inner part of the peel accounts for about 8–15 per cent. The proportion of peel in a whole tuber in factory-processed and hand-processed cassava is 5 and 8 per cent, respectively (Aro, 2008).

In order to overcome peeling constraints, an efficient and innovative cassava peeling machine is needed. This work is an effort to bring to the fore a solution to cassava peeling with an uncomplicated, easy to operate, easy to maintain and cheap peeler which is capable of peeling different sizes of cassava without cutting to size with the dual role of peeling and recycling of fruit water used in the peeling process for washing/mild pretreatment.

Peeling may be done with a sharp knife in small factories by many people shortly after the roots are harvested (FAO, 1983; 1998; Massaquoi et al., 1990; PRCIS, 2006). The roots structure makes it easy for manual peeling to be done, although much depends on the root shape and the skill of the peeler. The roots are cut longitudinally and transversely to a depth corresponding to the thickness of the peel, which can then be easily removed by gently working the knife under the cortex layer. Hand peeling is slow and labour intensive but yields the best results. The output of one person is about 25 kg/hour of peeled roots with a loss of 25–30 per cent of weight in the peels (FAO, 1998). IITA was reported to have produced a knife-like manual tool with a capacity of less than 30 kg/h with minimum tuber loss mostly used by women and children (Egbeocha et al., 2016).

The chemical method of peeling cassava using hot solutions of sodium hydroxide (lye) has been wasteful and ineffective (Igbeka, 1985). The solution had been used to loosen the skin of sweet potatoes to facilitate later peeling by water spray or scrubbing with brushes. The desired effect can be obtained according to Diop (1998) by a careful combination of lye concentration, temperature, and time of immersion and is more appropriate for small commercial operations. Igbeka (1985) stated that this method of peeling may not be appropriate for cassava for the following reasons: concentration of sodium hydroxide may be high while higher temperature, more immersion time, and operational pressure may be required to peel cassava tuber; with high concentration of the caustic soda (NaOH), the tuber may need to be immersed in acid solution to neutralize residual caustic soda. This implies an additional running cost with possible food poisoning; for food or industrial starch production, the method may result in the formation of an objectionable heat ring (dark colour) on the surface of the tuber flesh and the gelatinization of starch (Igbeka, 1985; Oluwole and Adio, 2013; Jimoh et al., 2016). Generally, this method will not be suitable for cassava peeling because the peels are tougher than those of potatoes.

In the steam peeling method, the cassava tubers are subjected to high steam pressure over a short period of time to avoid partial cooking (or eventual cooking). Timing the steam is a major problem with this method. Steaming beyond the time required will lead to cooking the tuber. Also, because of the shape of the cassava tuber, there may be an unequal distribution of heat. By thermal softening the firmness, adhesiveness, and springiness of the tuber are affected (Sajeev et al., 2009). Despite the above demerits, the steaming method has a favourable peeling effect without causing any appreciable loss in the mass of the cassava tubers (Abdullahi et al., 2010).

Mechanical peelers have different types of machine parts that interact directly with cassava skin and then remove it, thereby providing high quality fresh final products. Products from mechanical peelers are environmentally friendly and non-toxic (Shirmohammadi et al., 2012). Shirmohammadi et al. (2012) also reported that mechanical peelers can provide high quality fresh final products, and they typically do not create any harmful effects on the fruit or the environment and they do not create a cooked ring on the surface of the tissue. In addition, mechanical peeling methods complete the peeling process in one step and any further washing or removing skin would not be required. Common prototype peelers have functional systems such as abrasive devices, brushes, drums, rollers, knives, blades, and milling cutters which remove the outer cortex using mechanical means to reduce drudgery and eliminate hazards encountered in manual peeling. The disadvantages of this method include the associated mechanical damage, peeling off of an unacceptable percentage of useful flesh, and reduction in peeling efficiency with increased time of operation; some of the peelers are either too slow or too fast and cost ineffective (IITA, 2006). Jimoh (2014) reported that most abrasive and impact peelers developed in Africa, China, and Brazil are either manually operated, have low peel removal efficiency or high mechanical damage (Adetan et al., 2003; Olukunle, 2005).

According to Egbeocha et al. (2016), the merit of mechanical peeling is that the edible portions of the products are kept clean and harmless. For this reason, many attempts have been made to develop optimized peeling processes. Analysis of tuber movement in a mechanical peeling system to achieve high peeling efficiency was idealized by Jimoh (2014) so as to form the basis for near 100 per cent peel removal as well as whole tuber flesh recovery. The tuber movement in the peeler may be achieved by:

- continuous impact between the tuber and cutting tool;
- linear movement of tubers in the direction of the auger;
- displacement of the tuber by kinetic energy;
- circular motion of the cylindrical barrel at which the cutting blade grips the tuber;
- material flow as a result of continuous feeding in the hopper governed by the combined action of the auger, tuber monitor on each side, and the driving force.

However, cassava tuber loss of up to 42 per cent has been a major disadvantage of mechanized peeling in Nigeria (Olukunle and Jimoh, 2012).

It is worth noting the efforts of some local fabricators in Nigeria who have fabricated peeling machines, though some of their works were not published in journals or academic articles. They include: A and H Technical Metal Works, Iwo, Osun State; BASICON Engineering Company Ltd, Owerri, Imo State; TOSMAT Foods and Agro Products, Soku, Oyo State; AKTEM Technology Incubation Centre, Ilorin, Kwara State; Xtian Tech, Owerri, Imo State; and NOBEX Tech Company Ltd, Idimu, Lagos. These engineering firms have worked with the researchers listed in Table 1.

Table 1 Some authors and their contributions to the design of cassava peelers in Nigeria

S/No	*Machine type*	*Author (s)*	*Merits*	*Demerits*
1	Continuous process cassava peeler	Odigboh (1976) Odigboh (1983a)	No peeling time and power source required as it uses manual techniques.	Tedious, tuber losses are high, and it consumes a lot of human energy.
2	Rotary peeler	Ohwovoriole et al. (1988) Ariavie and Ohwovoriole (2002)	Little or no loss of useful flesh and available cheap materials.	Manually operated, arduous, and requires skills.
3	Abrasive drum/brush peeler	Ezekwe (1976) Odigboh (1983a, b) Nwokedi (1984) Akintunde et al. (2005) Enyabine and Bassey (2013) Ukenna and Okechukwu (2014) Ugwu and Ozioko (2015)	Ease of operation and convenient.	Requires slow speed operation thereby consumes time.
4	Single and double gang peeler	Agbetoye et al. (2006)	Easy and simple to work on.	Lowest output capacity and tubers have to be cut.
5	Double action self -fed peeler	Olukunle et al. (2010)	Good, efficient, and time conserving during operations.	Complex working mechanism, high partial peel retention, and requires hand trimming of tubers and machine skills.
6	Knife-edge automated peeler	Olukunle and Jimoh (2012) Adetan et al. (2005)	Required less power and energy.	Unable to peel small cassava tubers and has a very high tuber loss.
7	Lathe machine principle peeler	Abdulkadir (2012)	Excellent functions in operations and low cost.	Much mechanical damage to the tubers.

(Continued)

Table 1 (Continued)

S/No	*Machine type*	*Author (s)*	*Merits*	*Demerits*
8	An automated peeler	Olukunle and Akinnuli (2013) Jimoh and Olukunle (2012)	Simplicity, utilization, and maintenance are relatively cheap.	Requires technical know-how and cannot fully peel small tubers.
9	Fixed outer peeling drum machine	Oluwole and Adio (2013)	Fast, reliable, and effective in operation. Needs low maintenance.	Tuber losses and grating of cassava tubers are unavoidable.
10	Continuous process cassava peeler	Jimoh (2014)	No peeling time and high throughput, fair peel retention.	Requires technical know-how and cannot fully peel small tubers.
11	Continuous process cassava peeler	Jimoh et al. (2016)	Simple to use, and maintenance is relatively cheap.	Requires technical know-how and cannot fully peel small tubers.

The ideal peeling method possesses the following features: minimizes product losses, peels to the extent dictated by the product, minimizes energy and chemical usage, and minimizes pollution loads and heat ring formation (Radhakrishnaiah Setty et al., 1993). Getting closer to the 'ideal' peeling method was the aim of this work.

Materials and methods

The materials for the construction of the peeling machine were sourced locally at Owode Onirin Engineering Materials Market, Lagos, Nigeria. Freshly harvested wholesome cassava root (TME 419 and TMS 30572) varieties were used for the performance evaluation. The fresh roots were obtained from the Demonstration and Research Farm of the Cassava Adding Value for Africa (CAVA II-Nigeria).

Designed components and parts

The machine is divided into the following parts: the hopper, the peeling unit, the outlet unit, the diesel engine/seat (power part), the peeler seat or hanger, power transmission, and the water pump/sprinkler jet.

Materials and fabrication procedures

The materials used in fabricating the cassava peeler are: mild steel plate, stainless steel shaft, angle iron, bolts and nuts, iron rod, welding electrodes, adjunct materials, and stainless steel plate.

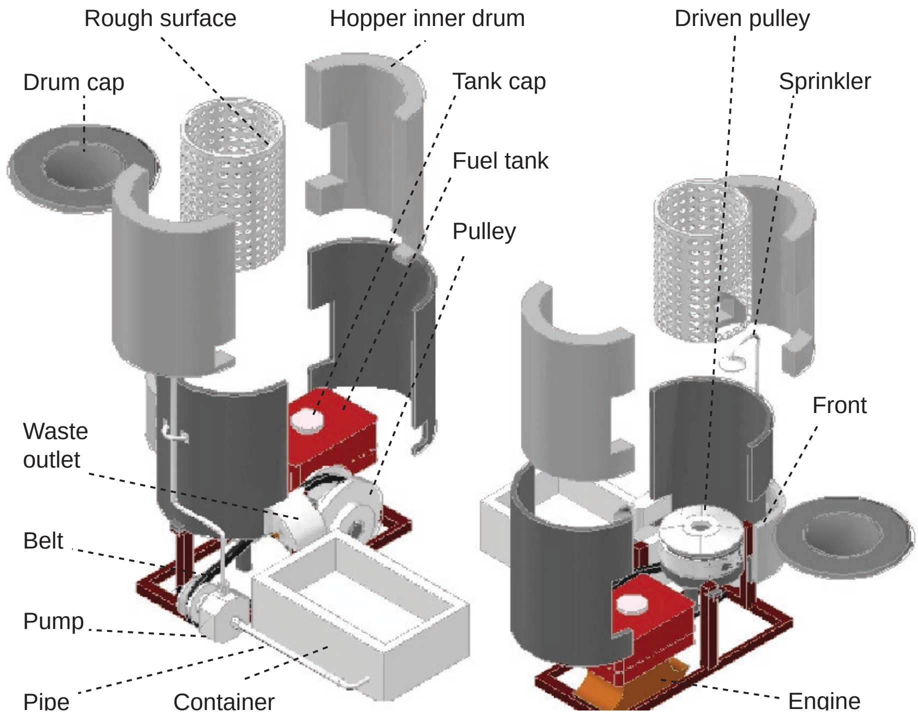

Figure 1 Exploded view of the cassava peeler as developed with component parts

Design considerations and calculations

In order to obtain high efficiency and reliability, the machine was designed based on the following considerations:

1. The equipment is relatively cheap and within the buying capacity of small and medium cassava enterprises with cassava input capacity of 1–10 tonnes of cassava per day. Locally sourced engineering materials were used to bring down the cost of the machine.
2. The equipment is able to peel different varieties, shapes, and sizes of cassava; the peeling chamber was lined with regularly indented stainless steel plate.
3. The equipment should be made with readily available materials.

Design of hopper. The design of the hopper was obtained using Khurmi and Gupta (2005)

$$v = \frac{(AB - ab) \times h}{6} \tag{1}$$

Where: A = length of hopper (mm)
B = width of hopper in feed (mm)
a = length of hopper out feed (mm)
b = width of hopper out feed (mm)
v = volume in cubic mm
h = height of the hopper in mm

Assuming operational capacity of 1,000 kg/h
The bulk density of cassava roots = 500 kg/m³ (Adetan et al., 2006)

$$\text{Density } (\rho) = \frac{mass,\ m}{volume,\ v}$$

$$\text{Volume} = \frac{1000}{500}$$

$$= 2.0 \text{ m}^3$$

Power design. Total power required will be calculated thus:

$$P_T = P_{shaft} + P_{peeling} \tag{2}$$

but shaft and inner drum are welded together, so:

$$P_T = P_{inner\ drum\ with\ shaft}$$

$$P_{inner\ drum\ with\ shaft} = T_{inner\ drum\ with\ shaft} \times V_{inner\ drum\ with\ shaft} \tag{3}$$

$$V_{inner\ drum\ with\ shaft} = \frac{2\pi N}{60}\ m/s$$

$T_{\text{inner drum with shaft}}$ is the torque (Nm)
N is the number of revolutions per minute of inner drum with shaft = 1,400 rpm

$$T_{inner\ drum\ with\ shaft} = mass\ (m) \times acc.\ due\ to\ gravity\ (g) \times radial\ dist.\ (d) \tag{4}$$

Assumed mass of cassava = 10 kg

$$T_{inner\ drum\ with\ shaft} = 10 \times 9.8 \times 0.5$$

$$= 49 \text{ Nm}$$

$$P_{inner\ drum\ with\ shaft} = T_{inner\ drum\ with\ shaft} \times V_{inner\ drum\ with\ shaft}$$

$$V_{inner\ drum\ with\ shaft} = \frac{2\pi N}{60} m/s$$

$$= \frac{49 \times 2 \times 3.142 \times 1400}{60 \times 1000}$$

$$= 7.184 \text{ kw}$$

$$= \frac{Total\ power}{0.746} \text{ hp}$$

$$= 9.63 \text{ hp}$$

Therefore, power factor assumed = 1.25
A motor of 4.95 kW was chosen to drive the inner drum, shaft, and cassava roots.

Belt analysis. The equations that are applicable to belt analysis are:

$$Power = (T_1 - T_2) \tag{5}$$

$$\left(T_1/T_2\right) = e^{f\alpha} \text{ (Belt tension ratio)} \quad (6)$$

The angle of wrap for an open belt is given as (Khurmi and Gupta, 2005):

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \quad (7)$$

Where: P = belt power (W)
V = belt speed (m/s)
T_1 and T_2 are tensions on the tight and slack sides respectively (N)
α_1 = the angle of wrap for driving pulley (rad)
α_2 = the angle of wrap for driven sheave
f = coefficient of friction between belt and sheave
D_1 = outside diameter of driving sheave (mm)
D_2 = outside diameter of driven sheave (mm)
C = centre to centre distance between driving pulley and driven sheave (mm)

Analysis of driven pulley and driving pulley. The diameter of driving pulley selected, D_1 = 500.0 mm.

If the outside diameter of the driven pulley is five times that of the driving pulley, using the ratio (Khurmi and Gupta, 2005):

$$N_1 D_1 = N_2 D_2 \quad (8)$$

$$N_1 = 5N_2$$

$$\frac{N_1}{N_2} = 5$$

But N_1 = 1,400 rpm as seen on 10 Hp (7,460 W) electric motor.

$$N_2 = \frac{1400}{5}$$

N_2 = 280 rpm

From $N_1 D_1 = N_2 D_2$

$$D_2 = \frac{1400 \times 500}{280}$$

D_2 = 2,500 mm

To obtain speed of driving and driven pulley:

$$V_1 = \frac{\pi D_1 N_1}{60}$$

and

$$V_2 = \frac{\pi D_2 N_2}{60}$$

Where, V_1 = 36.66 m/s
N_1 and N_2 are the numbers of revolutions (rad) for the driving pulley and driven pulley, respectively.

Determination of wrap angles. If the centre to centre distance between the driven pulley and driving pulley, C = 1,550 mm (Khurmi and Gupta, 2005):

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \tag{9}$$

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{2500 - 500}{2 \times 550}\right)$$

$\alpha_1 = 96.34$ rad

$$\alpha_1 = \frac{177.94 \times \pi}{180}$$

$\alpha_1 = 1.68$ rad

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)$$

$$\alpha_2 = 180 + 2\sin^{-1}\left(\frac{2500 - 500}{2 \times 550}\right)$$

$\alpha_2 = 263.62$ rad

$$\alpha_2 = \frac{181.29 \times \pi}{180}$$

$$\alpha_2 = 3.61 \text{ rad}$$

Determination of belt tensions. Khurmi and Gupta (2005):

$$P = (T_1 - T_2)V \tag{10}$$

$$P = 10 \text{ hp} = 10 \times 746$$

$$= 7460 \text{ W}$$

$$\text{and } V = 36.66 \text{ m/s}$$

$$7460 = (T_1 - T_2)36.66$$

$$(T_1 - T_2) = \frac{7460}{36.66}$$

$$= 203.49 \text{ N}$$

Using belt ratio for an open belt:

$$\left(T_1 / T_2\right) = e^{f\alpha} \tag{11}$$

For mild steel pulley and rubber belt, $f = 0.30$

$$\frac{T_1}{T_2} = e^{(0.30 \times 2.94)}$$

$$\frac{T_1}{T_2} = 2.54$$

$$T_1 = 2.54T_2$$

From $(T_1 - T_2) = 203.49\,N$

$$2.54T_2 - T_2 = 203.49$$

$$1.54T_2 = 203.49$$

$$T_2 = 132.14\,N$$

$$Using, T_1 = 2.54T_2$$

$$T_1 = 2.54 \times 132.14$$

$$= 336.63 \text{ N}$$

Shaft design. (Hall et al., 1987: 113–23)

$$d^3 = \frac{16}{\pi \times S_u}\left(\sqrt{(K_tM_t)^2} + \sqrt{(K_bM_b)^2}\right) \quad 12$$

Where: d = shaft diameter (mm)

K_t = stress combine shock and fatigue factor for torsion
K_b= stress combine shock and fatigue factor for bending
S_u = ultimate tensile strength of steel is 56 MPa (56×10^6) Pa
K_b = 1.5 (loading gradually constant)
K_t = 1.0 (loading gradually constant)

$$d^3 = \left(\frac{16}{\pi \times 56 \times 10^6}\right)\left(\sqrt{(1.5 \times 193.6)}\right)^2 + \left(\sqrt{(1.0 \times 16.5)}\right)^2$$

$$= \left(\frac{16}{\pi \times 56 \times 10^6}\right)\left(\sqrt{(290.4)}\right)^2 + \left(\sqrt{(16.5)}\right)^2$$

$$= \left(\frac{16}{\pi \times 56 \times 10^6}\right) \times 306.9$$

$$= \frac{4910.4}{\pi \times 56 \times 10^6}$$

$$= \sqrt[3]{2.6453 \times 10^6}$$

$$= 0.030 \text{ m}$$

NB. 30 mm shaft was selected

Determination of polar moment of inertia of the shaft about the axis of rotation (*J*) (Khurmi and Gupta, 2005):

$$(J) = \frac{\pi}{32} \times d^4 \quad (13)$$

$$= \frac{22}{7} \times \frac{1}{32} \times (0.030)^4$$

$$= \frac{22}{224} \times 8.1 \times 10^{-7}$$

$$= 0.09821429 \times 8.1 \times 10^{-7}$$

$$= 8.0 \times 10^{-8} \text{ mm}$$

Determination of twisting moment (τ) (Khurmi and Gupta, 2005):

$$\text{Twisting moment } (\tau) = \frac{P \times 60}{2\pi N}$$

$$P_{inner\ drum\ with\ shaft} = T_{inner\ drum\ with\ shaft} \times V_{inner\ drum\ with\ shaft}$$

$$V_{inner\ drum\ with\ shaft} = \frac{2\pi N}{60} m/s$$

$$= \frac{49 \times 2 \times 3.142 \times 1400}{60 \times 1{,}000}$$

$$= 7.184 \text{ kw}$$

$$= \frac{Total\ power}{0.746} \text{ hp}$$

$$= 9.63 \text{ hp}$$

$$\text{Twisting moment} = \frac{7.184 \times 60}{2 \times 3.142 \times 1{,}000}$$

$$= \frac{431.04}{6283}$$

$$= 0.07 \text{ Nm}$$

Determination of shaft torque and permissible angle of twist:
The torque, M_E is determined as follows:

$$M_E = \frac{(T_1 - T_2)D}{2} \tag{14}$$

$$= \frac{(346.79 - 143.3)\, 0.5}{2}$$

$$= 50.87 \text{ Nm}$$

and the twist caused by this torque on the shaft is given by:

$$\theta = \frac{584 M_E L}{G D^4} \tag{15}$$

Where: D = diameter of the driven pulley (mm)
T_1 = tension on the tight side of the belt (N)
T_2 = tension on the slack side of the belt (N)
M_E = shaft torque
θ = permissible angle of twist (°)
G = rigidity modulus of the shaft (Pa)
L = length of the shaft (mm)

But: Length of the shaft, L = 250 mm = 0.25 m
Diameter of the shaft, D = 0.03 m
$G = 84 \times 10^9$ (constant)
To derive the permissible angle of twist, θ caused by the Torque:

$$\theta = \frac{584 \times 50.87 \times 0.25}{84 \times 10^9 \times 0.03^4}$$

$$\theta = 0.11°/m$$

Note that the maximum permissible angle of twist = 0.3°/m. Therefore, the choice of a 30 mm diameter shaft is good for the design and can transmit the torque without damage.

Capacity of the peeling machine

The capacity of a machine can be expressed as:

$$\text{Capacity} = \frac{\text{Quantity of material processed}}{\text{Time taken}} \quad (16)$$

Olukunle and Akinnuli (2013) expressed the capacity of a peeling machine as:

$$M_{ce} = \left(\frac{\pi\rho r \times rL}{C_1}\right)\left(\frac{L_a}{L_t}\right)C_v \quad (17)$$

Where: M_{ce} = effective machine capacity (tonnes/h),
C_v = conveyor speed (m/s²)
ρ = density of cassava (kg/m³)
r = radius of tuber (m)
L = auger conveyor length (m)
L_t = actual distance covered by the tuber during peeling
L_a = theoretical length covered by tuber (m)

Adopting equations above, the capacity of the peeling machine can be expressed as:

$$C_m = 3.6\left(\frac{M_{at}}{V_c}\right)\left(\frac{L_l}{L_d}\right)L_A \quad (18)$$

Where: C_m = effective capacity of the peeling machine (tonnes/h)
M_{at} = average mass of the cassava (kg)
V_c = conveyor speed (m/s)
L_l = actual distance covered by the tuber during peeling (m)
L_d = theoretical length covered by the tuber (m)
L_A = horizontal length of the auger (m)

The conveying speed is the same as the optimized speed of the drum rotation and as such:

$$V_c = V_{rv} = 0.786 \text{ m/s}$$

M_{at}, L_A and L_d were obtained as 0.53 kg, 2.1 m and 2.74 m, respectively.
By design, $L_l = L_A$ = 2.1 m

As such,

$$\frac{L_l}{L_d} = \frac{2.1}{2.74} = 0.77$$

Computing the values into equation above, we obtain:

$$C_m = 3.6 \times \left(\frac{0.53}{0.786}\right) \times (0.77) \times 2.1$$

$$= 3.91 \text{ tonnes/hour}$$

The effective capacity of the machine is 3.91 tonnes/hour.

The peeling machine parameters such as the peeling efficiency (per cent), mechanical damage (per cent), peel retention (per cent) and throughput capacity (kg/h) were duly obtained using the equations below:

$$\mu = \frac{w_{pr}}{w_{pr} + w_{prh}} \tag{19}$$

$$\lambda = \frac{w_{trp}}{w_{trp} + w_{tc}} \tag{20}$$

$$P = \frac{w_{prh}}{w_{prh} + w_{pr}} \tag{21}$$

$$\eta = \frac{w_{pr} + w_{prh} + w_{trp} + w_{tc}}{t} \tag{22}$$

Where, W_{pr} is the weight of peel removed by the machine, W_{prh} is the weight of peel removed by hand after machine peeling, W_{trp} is the weight of tuber flesh removed along with peel, W_{tc} is the weight of tuber flesh completely peeled, and t is the peeling time (Jimoh et al., 2016).

Mode of operation of the machine

The cassava peeling machine has a variable speed (1,600–2,600 rpm) diesel engine of 4.85 kW maximum power rating, rated power of 4.41 kW. The design of the machine was based on the development and modification of the peeling tool of previous cassava peeling machines. The machine was aimed at achieving a good configuration to achieve 90 per cent cassava tuber flesh recovery irrespective of the size, shape, variety, and orientation of the tuber. The main features of the machine include peeling chamber, abrasive peeling surface or tool, supporting frame, hopper, and the transmission system. High pressure water from a water sprinkler is sprayed on the roots during operation. After running for 20–25 minutes, the recycled water becomes ‘fruit water’.

The combined action of the high pressure water jets and abrasion of the tubers against the walls of the perforated stainless steel sheet wound around the inner chamber of the machine and the roots against each other, remove the cassava skin. A batch of cassava is peeled in 4–6 minutes. For the start, fresh water of pH 7 was used, and as the peeling process continued, the recovered fruit water was used as the water jet in the peeling process. The pH of the cassava fruit water is usually between 3.6 and 4.5; the fruit water has a mild acidity with a positive impact on the peeling process. It gives the peeling tubers a mild chemical pretreatment effect to augment the mechanical peeling process. The roots are propelled by centrifugal force courtesy of the drive system consisting of a belt and pulley arrangement with a speed ratio of 1:4 between the drive and the driven pulley. The peeling chamber was designed to accommodate 30–100 kg of fresh cassava roots in a batch with a discharge gate to offload peeled roots. The base of the peeling machine conjoined with the driven system of the machine has a small clearance that disallows clogging of the peels and stops other extraneous materials from going through, but the clearance is large enough to allow the tuber peels to fall off and find their way to the waste exit point. A guard in the form of a lid was constructed to guard the roots from falling off during operation and with an opening for the water jet or sprinkler. The machine was designed to maintain good engineering practices in the food processing outlets as the machine's water jet sprinklers will clean up the machine before and after every use, with high water economy bearing in mind the water recovery system.

Other design details

In the selection of the gear drive, the following requirements were considered:

- The gear teeth have sufficient strength so that they will not fail under static loading or dynamic loading during normal running conditions.
- The gear teeth have wear characteristics so that their life is satisfactory.
- The use of space and material was economical.
- The alignment of the gears and deflections of the shafts were considered because they affect the performance of the gears.
- The lubrication of the gears was satisfactory.

Results and discussion

The results obtained from Tables 2, 3, and 4 indicate the result of the peeling undertaken with the machine. The weight of peels and flesh are as indicated from different weight samples carried out, and the machine was operated by a man. These were done for reproducibility.

Effect of speed on tuber losses

As the speed of the machine increases, the tuber loss increases. Table 2 shows the speed increases from 1,600 to 2,600 rpm; the tuber losses increased from 5.57 to 9.10 per cent generally for the TME 419 and TMS 30572. Specifically, at the speed of 1,600 rpm, the peeling loss was 7.72–7.83 for TME 419 while at the speed of 2,600 rpm the peeling loss was 8.24–8.67 for the same varieties for 30–50 kg weights of freshly harvested cassava roots. The reason for the general increase in tuber losses as the speed of the machine increases is the increased number of impacts between

Table 2 Peeling variables of the cassava peeler

Variety	*Speed (rev/min) (Engine)*	*Weight of tuber (kg)*	*Weight of peeled tuber (kg)*	*Weight of peel (kg)*	*% Weight of peel (%)*	*% Peeling loss (%)*
TME 419	1,600	30	24.50	5.50	18.30	7.83
TME 419	1,600	50	42.50	7.50	15.00	7.72
TME 419	2,100	30	24.00	6.00	25.00	7.62
TME 419	2,100	50	43.35	6.65	13.30	7.68
TME 419	2,600	30	21.20	8.80	29.30	8.67
TME 419	2,600	50	40.30	9.70	19.40	8.24
TMS 30572	1,600	30	24.18	5.82	19.40	6.93
TMS 30572	1,600	50	42.61	7.39	14.78	5.57
TMS 30572	2,100	30	25.10	4.9	16.33	7.76
TMS 30572	2,100	50	42.00	8.00	16.00	7.70
TMS 30572	2,600	30	20.91	9.09	30.30	9.10
TMS 30572	2,600	50	41.10	8.90	17.80	8.94

Table 3 Regression coefficients of the responses as a function of the independent variables

Parameters	*Weight of tuber*	*Weight of peeled tuber*	*% Weight of peel (%)*	*% Peeling loss (%)*	*Mean peeling efficiency (%)*
Intercept	32.1	7.84	20.54	7.88	71.19
A-Speed	–1.22*	1.29*	3.67*	0.86*	–7.99*
B-weight	9.53*	0.54*	–3.79*	–0.26	4.42*
AB	0.29	–0.36*	–1.81*	0.11	–1.27
R^2	0.99	0.98	0.99	0.68	0.91

Notes: *Significant at $p < 0.05$
Where AB = Interaction effects of speed and weight

Table 4 Peeling efficiency of the cassava peeler

Variety	*Speed (rev/min)*	*Mass of tuber (kg)*	*Mean peeling efficiency (%)*
TME 419	1,600	30	75.50
TME 419	1,600	50	84.00
TME 419	2,100	30	70.00
TME 419	2,100	50	80.50
TME 419	2,600	30	61.50
TME 419	2,600	50	71.50
TMS 30572	1,600	30	71.50
TMS 30572	1,600	50	85.75
TMS 30572	2,100	30	63.40
TMS 30572	2,100	50	68.00
TMS 30572	2,600	30	58.60
TMS 30572	2,600	50	61.20

(a)The peeling machine (b) The mechanically peeled cassava tubers

(c) Discharge of mechanically peeled roots (d) Peels from mechanically peeled roots

Photo 1 Peeling machine, peeled roots, and the peels

cassava tubers with the surface curvature and the irregular shape of the tubers. Similar results were reported by Ezekwe (1976), Odigboh (1983a, b), and Akintunde et al. (2005).

Effect of speed on peel retention

As the speed of the machine increases, peel retention increases. As shown in Tables 2 and 3, as the speed increases from 1,600 to 2,600 rpm, peel retention was at 5.5–9.7 kg for the two cassava varieties. For TME 419 at the speed of 1,600 rpm, the weight of peels was 5.5–7.5 kg for 30 and 50 kg fresh cassava tubers subjected to the peeling process, while at the speed of 2,600 rpm, the weight of the peels was 8.8–9.7 kg. Also, for TMS 30572 at the speed of 1,600 rpm, the weight of peels was 5.82 to 7.39 kg while for TME 30572 at the speed of 2,600 rpm, the weight of peels for 30 and 50 kg samples of freshly harvested cassava was 8.90 to 9.09 kg. The reason for general increase in peel weight was that the increase in speed brings about displacement of the tuber from abrasion during its movement to the exit, thereby reducing the amount of contact during the operation. This observation was reported by Nwokedi (1984), Akintunde et al. (2005), Enyabine and Bassey (2013), Ukenna and Okechukwu (2014), and Ugwu and Ozioko (2015).

(a) Cassava fruit water used in soaking roots (b) Peeled roots after soaking in fruit water

(c) Peeled roots from mechanical peeling (d) Soaking in cassava fruit water

Photo 2 Soaking in fruit water and peeled roots

Effect of speed on peeling efficiency

As the speed of the peeling machine increases for 30 and 50 kg weights of freshly harvested cassava tuber, peeling efficiency reduces. From Table 4, as the speed increases from 1,600 to 2,600 rpm; peeling efficiency reduced from 58.60 to 85.75 per cent. For TME 419 cassava variety at the peeling machine speed of 1,600 rpm, the peeling efficiency was 75.5 to 84.0 per cent for 30 and 50 kg samples of cassava, while at the peeling machine speed of 2,600 rpm, the peeling efficiency was 61.5 to 71.5 per cent. Freshly harvested 30 and 50 kg samples of TMS 30572 cassava tuber subjected to the peeling process had an efficiency of 71.50 to 85.75 per cent at the speed of 1,600 rpm while the same variety at the speed of 2,600 rpm had 58.6 to 61.2 per cent peeling efficiency. The reason for this general reduction in peeling efficiency is because at high speed, the peeling machine engaged in severe abrasion due to spontaneous reaction of the stainless steel wall on the tubers. Akintunde et al. (2005) and Ugwu and Ozioko (2015) reported similar results.

Effect of speed on peeling time

Generally, peeling time reduced as machine speed increased from 1,600 to 2,600 rpm. Increase in the peeling time reported in the peeler is because of the speed of

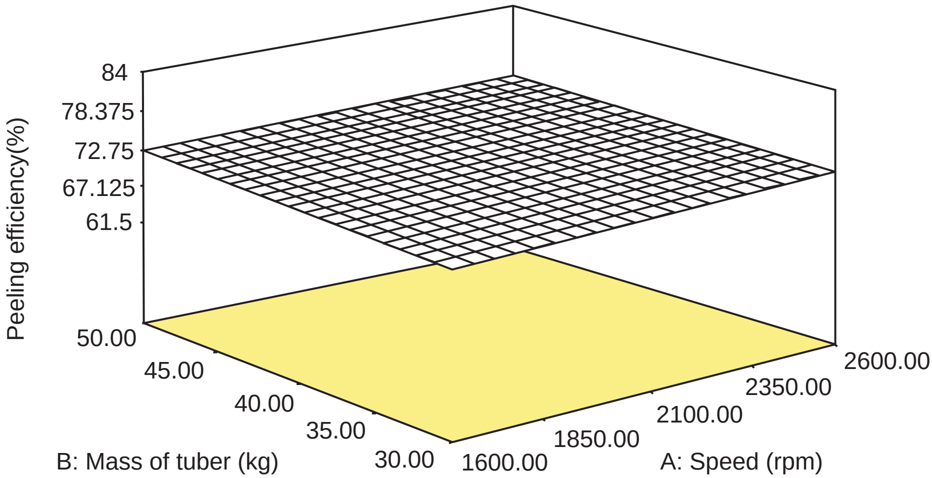

Figure 2 Response surface plot showing the effect of mass of tuber and speed on peeling efficiency for TME 419

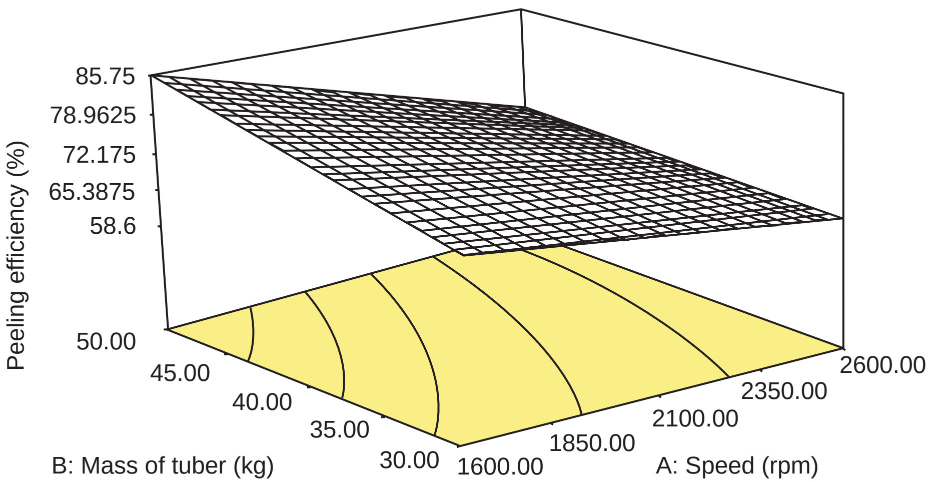

Figure 3 Response surface plot showing the effect of mass of tuber and speed on peeling efficiency for TMS 30572

the rotation. This observation was reported by Nwokedi (1984), Akintunde et al. (2005), Enyabine and Bassey (2013), Ukenna and Okechukwu (2014), and Ugwu and Ozioko (2015).

Conclusions

The configuration of the designed and fabricated machine resulted in the careful removal of the tuber peels achieving > 90 per cent flesh recovery at average rotational speed of 1,600 rpm < Nt < 2,600 rpm. The average peeling efficiency of the machine

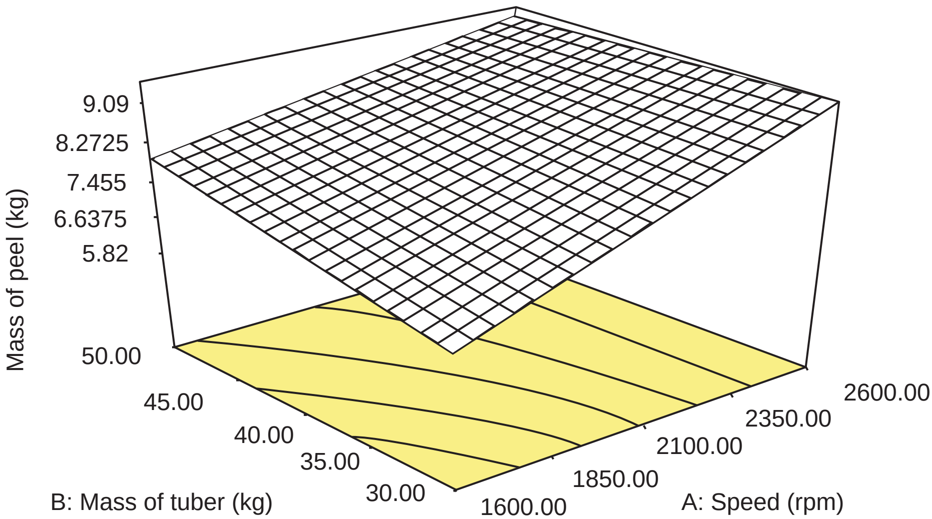

Figure 4 Response surface plot showing the effect of mass of tuber and speed on mass of peel for TMS 30572

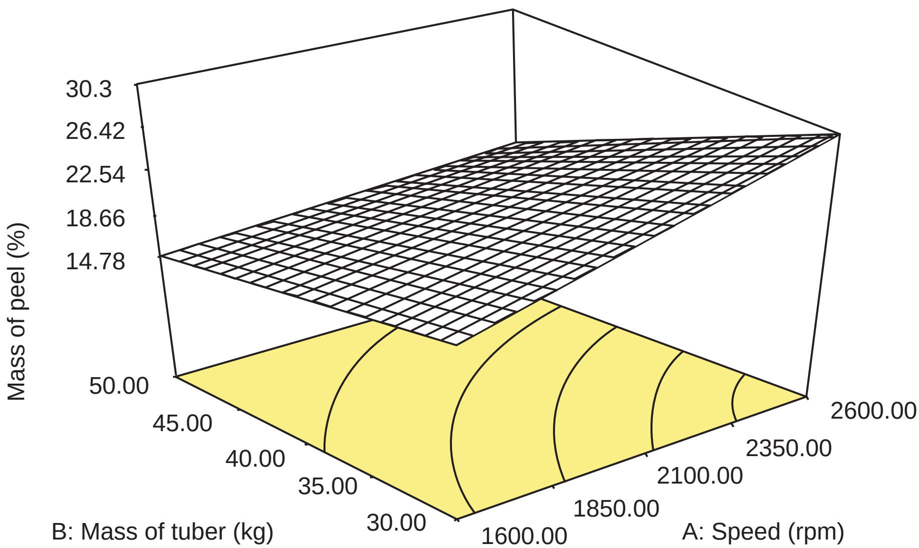

Figure 5 Response surface plot showing the effect of mass of tuber and speed on percentage mass of peel for TMS 30572

was 58.6–85.75 per cent depending on the variety. The machine uses impact rotary motion on the tubers through shear/or abrasion effect required for the peeling process, with an output capacity of 500–583 kg/h. The machine could accommodate 30–100 kg of fresh cassava roots for each loading operation. The throughput

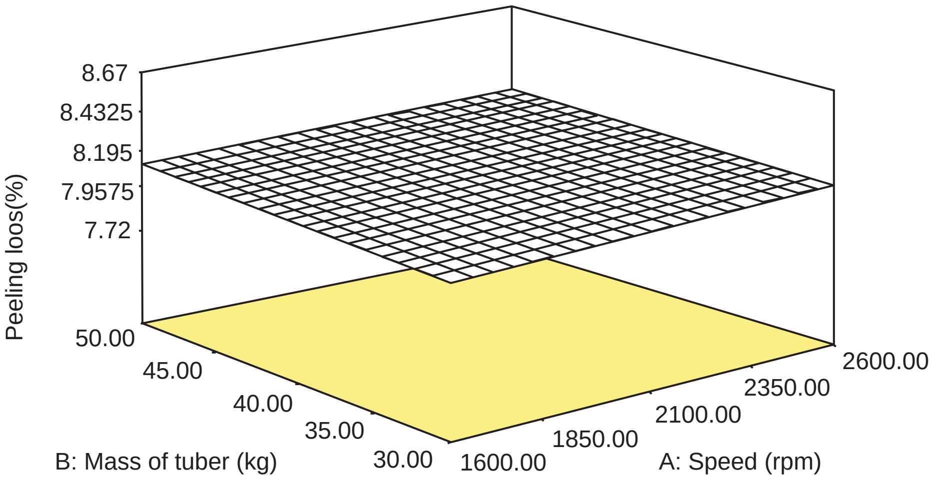

Figure 6 Response surface plot showing the effect of mass of tuber and speed on peeling loss for TME 419

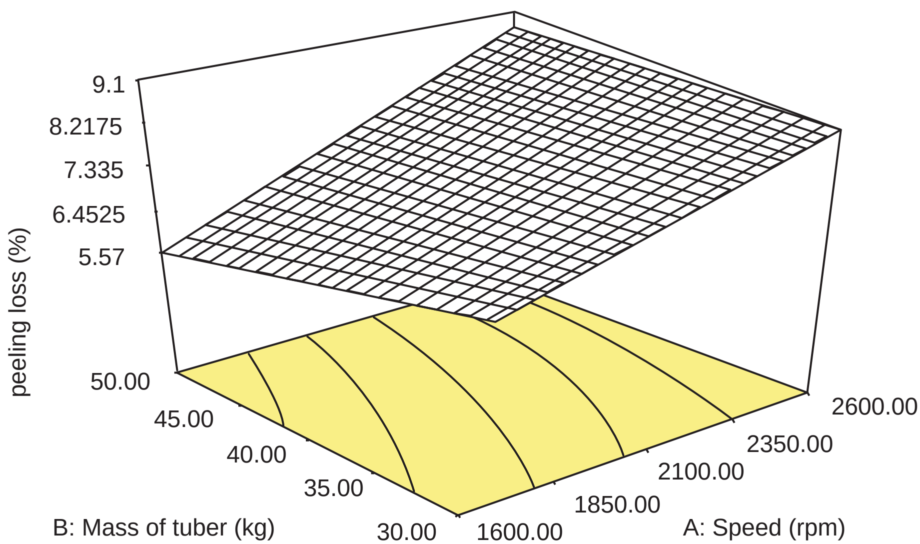

Figure 7 Response surface plot showing the effect of mass of tuber and speed on peeling loss for TMS 30572

capacity was higher than for existing peeling machines. The machine has a capacity of 8 tonnes/day with the dual role of peeling and recycling of fruit water used in the peeling process for washing/mild pretreatment. The machine recycles fruit water from the peeled cassava roots and conserves water consumption. The cost of a single unit was estimated at $1,230.

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