Design, Fabrication and Performance Evaluation of a Sweet Potato (*Ipomoea Batatas*) Peeling Machine

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Abstract
Peeling of tubers in Nigeria is normally done by hand which is tedious and time consuming. Therefore, this research work is aimed at designing, fabricating and carrying out performance evaluation of a sweet potato peeling machine, taking into consideration some physical and mechanical properties of the tubers. The machine was evaluated based on the following parameters: speed of the machine, throughput capacity, and peeling efficiency of the machine at speeds of 875 *rpm*, 933 *rpm* and 1000 *rpm*. At the three speeds, the machine has peeling efficiencies of 76 %, 78 %, and 81 % with an average throughput capacity of 82.87 kg/h as against manual of 0.22 kg/h. The machine performed optimally at the speed of 936 rpm with an efficiency of 78.33% and the percentage peeling weight proportion of 21.67 %. The developed potato peeling machine is 40 % more efficient than the hand method.

Keywords: Sweet potato, spherecity, peeling, compressive strength, abrasive action

Introduction

Sweet potato (*Ipomoea batatas*) is a dicotyledonous plant that belongs to the family *Convolvulaceae*. Sweet potato has a large, starchy, sweet-tasting, tuberous roots. The young leaves and shoots are sporadically eaten as greens. The plant is an herbaceous perennial vine, bearing alternate heart-shaped or palatably lobed leaves and medium-sized sympetalous flowers (Janssens, 2001). The edible tuberous root is long and tapered, with a smooth skin whose colour ranges between yellow, orange, red, brown, purple, and beige. Its flesh ranges from beige through white, red, pink, violet, yellow, orange, and purple. Sweet potato varieties with white or pale yellow flesh are less sweet and moist than those with red, pink or orange flesh. Some others are used locally, but many are poisonous. Some cultivars of *Ipomoea batatas* are grown as ornamental plants; the name "tuberous morning glory" may be used in a horticultural context (Scott, 2000; Udealor *et al*., 1996; Leon, 1977).

The plant grows best at a standard temperature of 24 °C, surplus sunshine and warm nights. Annual rainfalls of 750 - 1,000 mm are considered most appropriate, with a minimum of 500 mm (20 in) in the growing season (Kwatia, 1986).

Depending on the cultivar and conditions, tuberous roots mature in two to nine months. With care, early-maturing cultivars can be grown as an annual summer crop in temperate areas. They are mostly propagated by stem or root cuttings or by adventitious roots called "slips" that grow out from the tuberous roots during storage. True seeds are used only for breeding (Udealor *et al*., 1996). Sweet potatoes are grown on a variety of soils, but well-drained, light- and medium-textured soils with a pH range of 4.5 - 7.0

are more favourable for the plant. They can be grown in deprived soils with little fertilizer. In the tropics, the crop can be maintained in the ground and harvested as necessary for market or home utilisation. In temperate regions, sweet potatoes are most frequently developed on larger farms and are harvested before first frosts (Njoku, 2007).

The extremely perishable nature of potato tubers poses a serious difficulty to storage; the deterioration is caused by microbial infections and physiological factors like loss of moisture. Also, processing is to improve sweetness of the food products (Kwatia, 1986). A method that was found competent in hastening the dry rate and improving the quality of product in peeling and drying the tuber.

The works done so far on the development of biomaterial peeling systems revealed five general methods of peeling: use of abrasive action/mechanical peelings, chemical, heat, and manual. The mechanical peeling can be classified into manual and automatic, using abrasive methods. The abrasive method has been used to peel tubers such as potatoes, ginger and yam (Tomori and Onyeugboh, 2014).

Over the years traditional methods of peeling sweet potato have evolved which is the use of knife in peeling fresh cornels or hand to peel when cooked. Hand peeling of sweet potato take san hour to peel about 33 kg by hand which is time consuming (Tomori and Onyeugboh, 2014). With the use of a mechanical machine the work will be faster, easier and efficient. Presently in Nigeria, there is no known machine for peeling of sweet potato. This work represents the design, fabrication and performance evaluation of a potato peeling machine.

Materials and Methods

Materials

The materials used were selected based on their availability, cost, suitability and viability in service among other considerations. In the design of this sweet potato peeling machine, some properties of sweet potato were also considered such as the physical properties (shape, size, spherecity, surface area, and weight of the sweet potato tuber) and the mechanical properties (compressive strength of sweet potato when placed on the horizontal and vertical directions). Also the hardness of the sweet potato was measured so as to know the required force for peeling the periderm of the sweet potato (ASAE, 2003; Balami *et al.*, 2012).

Methods

The sweet potato peeling machine shown in Figure 1 has a rotating drum which is eccentrically placed on a shaft and powered by 1 hp electric motor. The sweet potatoes were fed through a feed tray into the peeling chamber where the tubers come across the perforated rotating drum enclosed by a metal case. The peeling of the tubers takes place as a result of the abrasion caused by the perforated drum as the potatoes rotate inside the peeling drum. The peeled periderms are collected through the outlet provided.

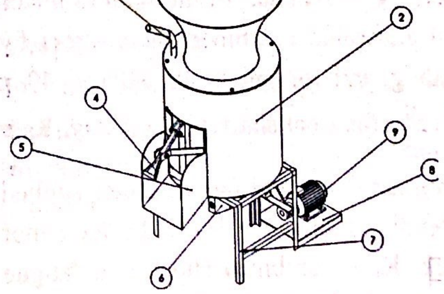

Fig. 1: The Sweet Potato Peeling Machine

Legend: 1-Hopper, 2-Peeling drum casing, 3-Handle, 4-Lever, 5-Tray outlet, 6-Water outlet 7-frame, 8-Eletric motor seat and 9-Electric motor.

Design of the Machine Components

Determination of the volume of the hopper

The volume of the hopper V_p was calculated using the expression given in equation 1 (Tim, 2009; Tomori and Onyeugboh, 2014):

$$V_p = \frac{\pi h}{3}(R^2 + Rr + r^2) \quad (1)$$

Where: V_p = Volume of the hopper in m^3, h = Height of cone, R = Radius of the upper part of circular cone, r = Radius of the lower part of circular cone

Determination of the volume of the peeling drum

The volume of the peeling drum (V_d) was calculated using equation 2 as given by Rajput (2012):

$$V_d = \pi r^2 h \quad (2)$$

Where: V_d = Volume of the peeling drum, r = Radius of the peeling drum, h = Height of the peeling drum

Determination of the diameter of the shaft

The required diameter for a solid shaft having combined bending and torsional loads was calculated using the ASME code (Hall *et al.*, 1980) as given in equation 3:

$$d^3 = \frac{\sqrt{(K_b M_b)^2 + (K_t M_t)^2}}{\pi S_s} 16 \quad (3)$$

where: d = Diameter of the shaft in meter, S_s = allowable combined shear stress for bending and torsion = 40 MPa = 40 x $10^6 \frac{N}{mm^2}$ for steel shaft with keyway, K_b = combined shock and fatigue factor applied to bending moment = 1.5 to 2.0 for minor shock, K_t = combined shock and fatigue factor applied to torsional moment = 1.0 to 1.5 for minor shock, M_b = Bending moment; M_t = Torsional moment

Determination of the torque

The torque was calculated using the expression given in equation 4 (Khurmi and Gupta, 2005):

$$T = \frac{\pi}{16} \tau d^3 \quad (4)$$

where: T = transmitted torque, Nm; τ= shear stress, MPa; d = diameter of the peeling shaft, mm

Determination of the torsional deflection of the peeling shaft

The angular deflection of torsion of solid shaft was determined using the expression in equation 5 (Khurmi and Gupta, 2005):

$$\theta = \frac{32LT}{G\pi D^4} \quad (5)$$

where: L = length of shaft = 0.3 m; T = torque to be transmitted = 5.08 Nm; G = modulus of rigidity for mild steel = 80 GPa = 80 x 10^9 Pa (Khurmi and Gupta, 2005); D = diameter of shaft = 0.02 m

Determination of the angle of wrap

In the open belt configuration, the wrap angle of the belt around each of the three pulleys was determined using the expressions given in equation 7 (Khurmi and Gupta, 2005):

$$\left.\begin{aligned} \theta_A &= \pi - 2\sin^{-1}\frac{R_A + R_{B1}}{C_1} \\ \theta_B &= \pi + 2\sin^{-1}\frac{R_A + R_{B1}}{C_1} \end{aligned}\right\} \quad (7)$$

where: θ_A = wrap angle of pulley A i.e. motor pulley; θ_B = wrap angle of pulley B i.e. machine pulley; R_A = effective radius of pulley A i.e. motor pulley = 50 mm; R_{BI} = effective radius of pulley B i.e. machine pulley = 75 mm; C_1 = distance between centers of pulley A and B = 170 m; π = 180°.

Determination of the belt size

The length of the belts between the electric motor and the peeling drum pulley was obtained using equation 8 (Khurmi and Gupta, 2005):

$$L = 2C_1 + 1.57(D_1 + d) + \frac{(D_1 - d)^2}{4C_1} \quad (8)$$

where: C_1 = center distance between motor and machine pulley = 170 mm; D_1 = outer diameter of large sheave = 150 mm; d = outer diameter of small sheave = 100 mm; C_2 = 190 m; D_2 = 140 m

Determination of the belt tension

The tensions on the belt were determined using the expression in equation 9 (Khurmi and Gupta, 2005):

$$\text{Tension ratio} = \frac{T_1}{T_2} \quad (9)$$

where: $T_1 = \frac{33000\,(1.25 - F_A)xHp}{F_A x V_b}$ - tension on tight side, (N); $T_2 = \frac{41250\,xHp}{F_A x V_b}$ - tension on slack side, (N); Hp = horsepower of driving motor = 1 Hp; F_A = arc of contact correction factor; V_b = belt speed in rpm

But to find the arc of contact correction factor (F_A), the coefficient of arc of contact was determined using the expression given in equation 10:

$$\text{Coefficient of arc of contact} = \frac{D_1 - d}{C} \quad (10)$$

where: D_1 = outer diameter of large sheave = 150 mm; d = outer diameter small sheave = 100 mm; C = center distance = 170 mm

The belt speed was determined using equation 11:

$$\text{Belt speed, } V = \frac{\pi d_m n_m}{12} \quad (11)$$

where: d_m = diameter of motor pulley = 100 mm; n_m = speed of motor = 1400 rpm

Power required to operate the machine

The power required to operate the machine was calculated using equation 8.

$$P_o = T\omega \ (Nm) \quad (12)$$

where: P_o = Power in Kw, T = torque in (Nm), $\omega = \frac{2\pi N}{60}$ - angular speed (rad/s).

N_1 = speed of the pulley, rpm

Peeling drum

This was made of galvanized medium carbon steel sheet, which was punched from one side leaving the spike on the other surface used for the abrasion of the potato periderms. In the selection of the material used, considerations were made based on its resistance to corrosion, weight, and non-toxicity to sweet potato.

Performance Evaluation

The machine was evaluated using 100 kg of the white type sweet potato purchased at Kure Ultra-Modern market, Minna, Nigeria. The purchased sweet potatoes was sorted out, cleaned and divided into 3 groups of 30 kg each. The throughput capacity (T_c), peeling weight proportion (P_w) and peeling efficiency P_{eff} were determined using equations 13, 14 and 15. The time taken for peeling was determined by a stop watch. The machine was tested at three different speeds of 875, 933 and 1000 *rev/min* which were used to peel the sweet potato tuber.

Throughput capacity

The throughput capacity (T_c) was determined using equation 13 as adopted from Olukunle and Akinnuli (2012):

$$T_c = \frac{W_t}{t}\ kg/h \quad (13)$$

where: W_f= mass of Sweet potato fed into the machine (kg); t =average time taken for the sweet potato and its peel to completely leave the machine (h)

Peeling weight proportion

The peeling weight proportion was calculated using equation 14 (Olukunle and Akinnuli, 2012):

$$P_w = \frac{M_{pc}}{M_s} \quad (14)$$

where: M_{pc}=average weight of peelings collected in (kg); M_s=average mass of the sweet potato (kg)

Peeling efficiency of a sweet potato peeling machine

The peeling efficiency of the machine was determined by the expression 15 as given by Agrawal (1987) as:

$$P_{eff} = \frac{M_{po}}{M_{pr}+M_{po}} \times 100 \quad (15)$$

where: M_{po}= total mass of peeled tubers collected through the peel outlet of the machine, *kg; M_{pr}*= total mass of peeled sweet potato, *kg*

Results and Discussion

The technical characteristics of the machine are presented in Table 1.

Table 1: Technical characteristics of the machine

S/No.	Technical characteristics	Values
1	Power required to operate machine	0.75 kW (1 hp electric motor selected)
2	Diameter of peeling drum shaft	20 mm
3	Speed of operation	1400 rpm
4	Volume of peeling drum	0.019 m3
5	Volume of hopper	0.045 m3
6	Angle of wrap	1st Pulley, Q_A = 85.34 rad; Q_B = 274.66 rad 2nd Pulley, Q_A = 128.64 rad; Q_B = 205.68 rad 3rd Pulley, Q_A = 101.67 rad; Q_B = 258.33 rad
7	Length of belts	Belt 1 = 740 mm Belt 2 = 700 mm
8	Arc of contact correction factor	Belt 1, F_A = 0.96 when coef. of arc of contact = 0.3 Belt 2, F_A =0.94 when coef. of arc of contact = 0.4
9	Diameter of camshaft	20 mm
10	Torsional deflection of shaft	0.1°
11	Average Peeling efficiency, %	78.33 %
12	Average machine throughput	82.87 kg/h.
13	Average manual throughput	33 kg/h.
14	Average peeling weight proportion	21.67 %

The results of the performance test are shown in Table 2.

Table 2: Results of performance evaluation of the Machine at the three different Operational Speeds

Parameters	Operational Speeds (rpm)		
	875	933	1000
Throughput Capacity, (kg/h)	77.12	81.08	90.40
Peeling Weight Proportion, (%)	24.00	22.00	19.00
Peeling Efficiency, (%)	76.00	78.00	81.00

Table 1 presents the technical characteristics of the developed machine. The average machine throughput is 82.87 kg as against the average manual throughput of 33 kg. From Table 2 we can notice that at the three operational speeds of the peeling drum of 875 rpm, 933 rpm and 1000 *rpm*, the average throughput capacities were calculated to be 77.12

kg/h, 81.08 kg/h, and 90.40 kg/h respectively, average percentage peeling weight proportions of 24.00 %, 22.00 %, and 19.00 % were recorded while average peeling efficiencies of 76.00 %, 78.00 %, and 81.00 % respectively were also obtained at the three machine speeds. These values were lower than the value in a research carried out by Tomori and Onyeugboh (2014) and Idris (2015) for yam peeling machine with an average efficiency of 95.97 %.

Conclusions

A sweet potato peeling machine was developed and evaluated at three operational speeds (875 rpm, 933 rpm and 1000 rpm). The developed machine has an average peeling efficiencies of 78.33 % and throughput capacities of 82. 87 kg/hrespectively. The developed machine is 40 % more efficient than the hand method.

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