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Development and performance evaluation of an abrasive multi-roller cassava peeling machine.

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Abstract
An abrasive multi-roller cassava peeling machine comprising a feed section, peeling chamber, abrasive rollers, tuber discharge chute and waste peel chute was designed, fabricated and evaluated for performance. The machine development was based on engineering standards and specification while considering crop properties of cassava tubers. The machine and operational factors considered included abrasive property of peeling surface, peeling time and speed of the machine. The peeling process was by abrasive principle. The machine was tested for performance in throughput and peeling efficiency with commonly used cassava varieties NR 8082, 8083, 8208, 09/0581 and UMUCAS 38 at moisture content of 63.33, 64.50, 65.40, 63.50, and 84.33% respectively. The performance evaluation results at a roller speed of 360 rpm showed peeling efficiency of 91%, throughput capacity of 2.17kg/min, and average proportion by weight of peel of 0.9%. It further revealed that moisture content favored peeling. The machine eliminated the drudgery, loss of time and tuber flesh encountered in manual peeling with better product quality when compared with already existing machines. At cost of ₦282,650, the machine is affordable, simple to operate, maintain, and therefore, suitable for small and medium scale processing.

Keywords: Abrasive multi-rollers, cassava variety, peeling machine, efficiency, throughput.

1. Introduction

Cassava (*manihot esculentacrantz*) is a tuberous starchy root crop of the family Euphorbiaceae (Kochlar, 1981). It is a popular crop grown worldwide and it's known for its large deposits of carbohydrates, drought tolerance and thriving well on marginal soil. There is an ever increasing demand globally for the different products of cassava such as chips, pellets, starch, garri, fufu, etc. of which peeling of the tubers is necessary. Peeling is the first and a critical unit operation performed after the cassava tubers have been harvested owing to its role in the detoxification of the tubers (Opara, 1999). The high demand for cassava globally as constituent of human food, raw materials and as source of foreign exchange for producing countries calls for total mechanization of its processes.

There are several unit operations in cassava processing that include; grating, boiling/parboiling, drying, milling, sieving and toasting. The extrusion process has been successfully mechanized (Ezekwe, 1976). Cassava peeling has remained a bottleneck globally for the design engineer. Different efforts in this field have resulted in the production of several prototypes characterized by low efficiency and low quality performance (Egbeocha *et al*., 2016)

Several mechanisms and methods in cassava peeling have been adopted. These include; steam, manual, chemical and mechanical methods with their advantages and disadvantages. Some of the efforts in the mechanical field include; spring loaded cassava peeling machine by Adetan *et al.* (2005) with efficiency of 98.8 % and 15 % broken tubers; the PRODA model of cassava peeling machine made with peeling balls and recording peeling efficiency of 30 % and much loss of the root flesh; UNN model of a batch cassava peeling made with abrasive materials loaded in a peeling drum resulted in a throughput capacity of 180 kg/hr and loss of cassava tuber flesh; UNIBEN model of a cassava peeler designed at the mechanical engineering department of the university of Benin with a single tool point and fed tuber after tuber to its chuck recorded a peeling efficiency of about 25 %; Cassava peeler designed and fabricated at Tamil Nudu Agricultural university, Alade had throughput capacity, peeling efficiency and peel retention of 549 kg/hr, 50.33 % and 0.572 respectively.

Howeler *et al.,* (2004), in their research work observed that most cassava farmers/growers were small farm holders of between 0.5-5 ha farm land. As a result of this, there is need for a portable, affordable and efficient peeling machine for the cottage industries to meet their processing needs. A multi-roller abrasive cassava peeling machine was therefore developed and evaluated at the Mechanical Engineering Department, Michael Okpara University of Agriculture, Umudike, Nigeria. Among the purpose was to develop a design data base for the peeling machine; form a relationship between the cassava tubers (varieties), machine and machine operational parameters, thereby, establishing machine operational parameters for effective peeling of the different sizes and shapes of cassava tubers.

2. Materials and Method

2.1. Materials

The materials used in this study included mild steel angle iron, mild steel plate, mild steel flat bar, mild steel shafts, sprockets, bolts and nuts, bearings, V-belts, couplings, circuit breaker, electric motor, mild steel pulleys for fabrication of the peeling machine. Five varieties of cassava tubers accessed from National Root Crop Research (NRCR), Umudike, Nigeria.

2.2. Design Consideration:

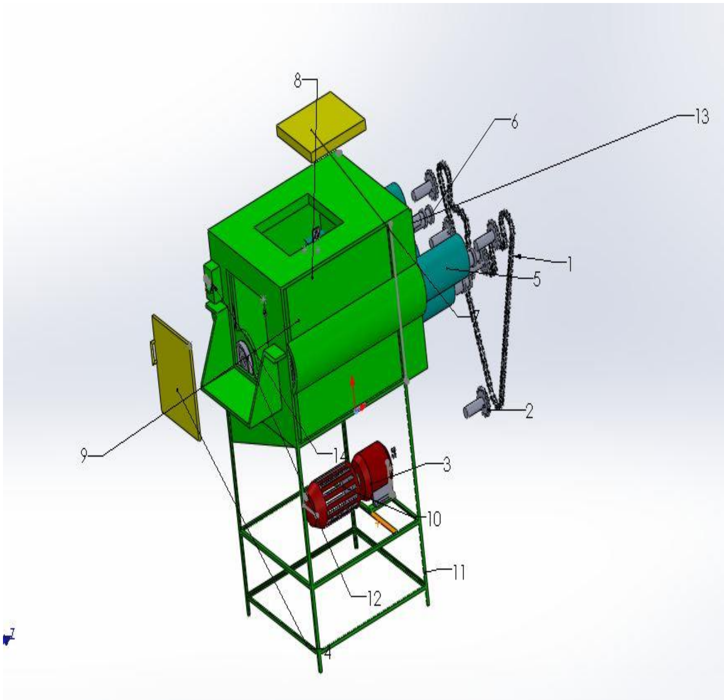
The machine was designed based on the following considerations so as to obtain high efficiency at acceptable throughput, portability and reliability:

(i) The capacity should be higher compared to manual operation.
(ii) Flexibility of the parts and components of the machine and convenient servicing.
(iii) Versatility of the machine to peel tubers of different sizes, shapes and varieties.
(iv) Reliability, durability and rigidity of the materials for the machine components.
(v) Cost and availability of the materials.
(vi) Reduce loss of time and drudgery encountered in manual method.
(vii) Arrangement of the transmission components so as to transmit efficient power.

2.3. Machine Component/Description:

The machine comprises the following components: electric motor and gearbox, sprocket and chain drive, shafts, bearing, feed section, peeled tuber discharge chute, waste peel discharge chute, peeling rollers with abrasive surface made of emery cloth, support frame as shown in Figs. 1 and 2 and Plate 1. Each of the component has function(s) to perform for the efficient performance of the cassava peeling machine.

The machine was powered by the electric motor with an incorporated gearbox serving as a speed reducer. With five shafts (each supported on a pair of bearings) arranged in u-shape configuration, mechanical energy was transmitted from electric motor and gearbox through the sprockets and chain drive system to the set of peeling rollers equipped with abrasive surfaces (emery cloth) to peel the cassava tubers. The rotational motion of the rollers with its abrasive surface effects the peeling of the tubers. A feed section was designed to serve as a portal through which the cassava tubers are introduced into the peeling chamber where the tubers undergo peeling action from the set of concave shape arranged abrasive rollers in constant rotation through the shaft. The peeled tubers fall through the detachable discharge Chute at the end of the machine. The rollers were assembled to a 5 mm clearance in between to allow for waste peel/flake discharge**.** A peel discharge chute was situated below the peeling chamber as a slanted casing through which the flake is let out of the peeling chamber. The whole assembly was mounted on mild steel angular bar support frame robustly designed to withstand torsional and vibrational energy occasioned by the operation of the machine.



Legend

1. Chain
2. Driver sprocket
3. Gearbox
4. Outlet chute opener
5. Abrasive surface (Emery cloth)
6. Idler sprocket
7. Feed section opener
8. Peeling chamber casing
9. Peeling chamber
10. Electric motor
11. Main frame
12. Peeling rollers
13. Peeling roller driven sprocket
14. Electric switch

Figure 1: Isometric view of the multi-roller cassava peeling machine.

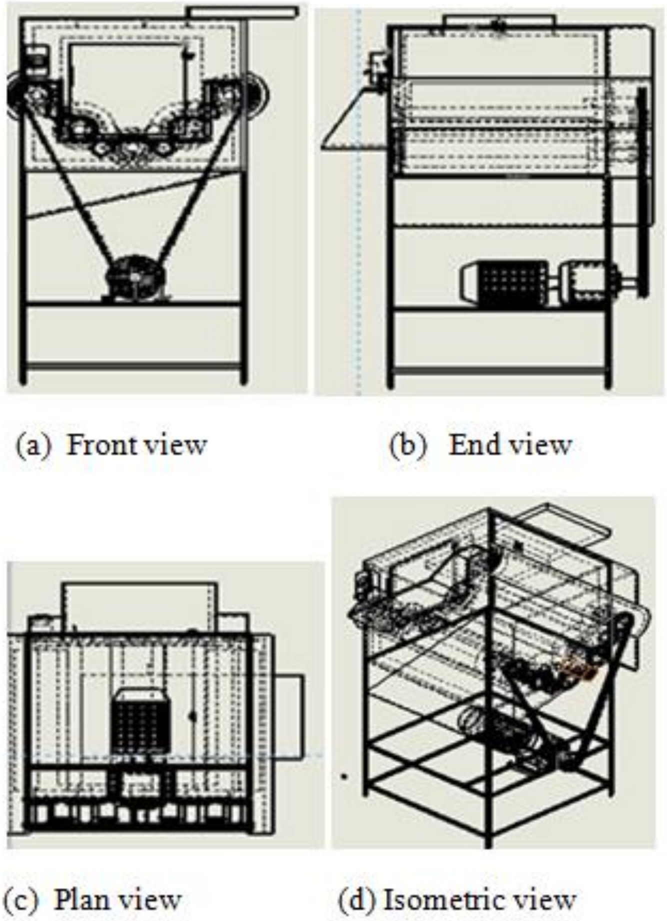


Figure 2: Orthographic view of the machine.

Plate1: Pictorial view of the constructed multi-roller cassava peeling machine.

2.4. Design Analysis

The transmission of the rotational motion of the electric motor to effect the needed revolutions of the peeling rollers was achieved by the use of chain drive. The parameters of the shaft of the electric motor and its sprocket were selected as follows:.

Electric motor speed, N = 1440 rpm;

Number of teeth of the sprocket on the electric motor shaft, $T_1 = 15$;

Desired number of teeth on peeling rollers sprockets, $T_2 = T_3 = T_4 = T_5 = T_6 = 15$.

To achieve the desired speed of the peeling rollers, an integral gearbox of transmission ratio 4:1 was integrated with the electric motor.

The Design power (P_D) of the chain drive was determined as given by Khurmi and Gupta (2012):

$$P_D = P_R \times S_F \quad (1)$$

where P_R = rated power of motor,

$$S_F = S_1 \times S_2 \times S_3 \quad (2)$$

where

Service factors S_1, S_2, and S_3 represent constant loading, periodic lubrication and continuous service respectively (Bur and Cheathman, 2002; Sharma and Aggarwal, 2009; Khurmi and Gupta, 2012)

For a complex chain drive involving five (5) driven sprockets of the peeling rollers and the sprocket of the electric motor-gearbox, the entire length of chain was sectioned into five (5) sections: L_1, L_2, L_3, L_4, and L_5. First section was formed by the driving sprocket and the first (lowest) driven sprocket with centre to centre distance x_1 = 300mm while the sections connecting the driven sprockets have centre to centre distances of x_2, x_3, x_4, x_5 = 130mm.

The length of the chain as sectioned was determined with the formula suggested by Sharma and Aggarwal (2009) and Khurmi and Gupta (2012):

$$L_1 = K_1 \times p \quad (3)$$

$$L_2 = K_2 \times p \quad (4)$$

where;

K_1 = chain link formed by the driver sprocket and the first driven sprocket:

K_2 = chain link between driven sprockets 2 and 3

$$K_1 = \frac{T_1 + T_2}{2} + \frac{2\,x_1}{p} + \left(\frac{T_2 - T_1}{2\pi}\right)^2 x \, \frac{p}{x_1} \quad \text{(Khurmi and Gupta, 2012)} \quad (5)$$

x_1 = centre distance of the first chain section.

$$K_2 = \frac{T_2 + T_3}{2} + \frac{2\ x_2}{p} + \left(\frac{T_3 - T_2}{2\pi}\right)^2\ x\ \frac{p}{x_2}$$ (Khurmi and Gupta, 2012) (6)

$x_2 = x_3 = x_4 = x_5$ = centre distance of the driven sprockets

K_2, K_3, K_4, K_5 = chain link between the driven sprockets.

$L_2 = L_3 = L_4 = L_5$

While the entire length L, of the chain was gotten as

$$L = L_1 + 4L_2 \quad (7)$$

To transmit the design power as calculated from Equation (1), a chain type No 10 with two stands, pitch p, roller diameter d, minimum width of roller w, of 15.875mm, 10.16mm, and 9.65mm respectively was selected (Khurmi and Gupta, 2012).

The pitch circle diameter, d_1 and average speed of the chain which is the chain pitch line velocity, V on the sprockets were determined using equation (8) (Sharma and Aggarwal, 2009) and equation (9) (Khurmi and Gupta, 2012).as 76.36 mm and 14.39 m/s respectively

$$d_1 = p\ x\ \text{cosec}\ x\left(\frac{180}{T}\right) \quad (8)$$

$$V = \frac{\pi\ x\ d_1\ x\ N}{60} \quad (9)$$

where; T = number of teeth of the sprockets, (15)
N = speed of the sprockets, (360 rpm)

The angle of articulation, θ/2 through which the links swing as they enter contacts with the sprockets teeth was determined as 12^0 using equation (10) (Khurmi and Gupta, 2012);

$$\theta = \frac{360}{T} \quad (10)$$

The shaft diameters, D, of the peeling rollers of this machine were determined using maximum stress relations given by Burr and Cheathan (2002); and Khurmi and Gupta (2012) in equation (11):

$$D = \left[\frac{16}{\pi\,\tau}\left(\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right)\right]^{\frac{1}{3}} \quad (11)$$

where; τ = Allowable shear stress for steel shaft with provision for key ways, (42 N/mm^2)

M_t = Maximum Twisting Moment on the shafts, (N-mm)

M_b = Maximum Bending Moment on the shafts, (N-mm)

K_b = Combined shock and fatigue factor for bending, (2)

K_t = Combined shock fatigue factor for twisting, (1.5)

The actual power, p required for the operation of this machine is the power required to drive the shaft of the speed reducer which then drive the shafts in the peeling rollers. The power in watts required to drive this machine was determined using equation (12).

$$P = \frac{2\pi NT}{60} \quad (12)$$

where; P = Power to drive the machine in watts
N = Output speed of the speed reducer and peeling rollers

T = Twisting moment on the output shaft of the speed reducer, 29.58 N-m

Taking care of 10% possible loss due to friction (Nwankwojike *et al*., 2012), the power required to drive the multi-roller abrasive peeling machine was computed from equation (12) as 1.100Kw (1.474 HP). Therefore, (2 HP) electric motor which can be powered using a 3 phase electric power supply was selected for this cassava peeling machine.

2.5. Evaluation procedure

The machine was evaluated for performance in terms of throughput capacity, T_C, proportion of weight of peel, P, and peeling efficiency, μ. The throughput was measured in terms of mass of tubers per batch of peel per unit time. The peeling chamber was filled with different batch sizes of 5kg, 10kg, 15kg, and 20kg of different varieties of cassava (NR 8082, 8083, 8208, 09/0581 and UMUCAS 38) which their moisture contents at harvest were determined.

The time of peel, mass of peeled tuber, mass of waste peel were duly noted during the test. The throughput capacity, T_C, proportion of weight of peel, P, and peeling efficiency, μ were obtained from the expression given by Olukunle & Akinnuli, (2012) and Olukunle & Jimoh (2012):

$$T_C = \frac{M_C}{t} \quad (13)$$

$$P = \frac{M_{PC}}{M_C} \quad (14)$$

$$\mu = \frac{M_{PC}}{M_{PR} + M_{PC}} \quad \text{(Aggarwal, 1987)} \quad (15)$$

where M_C = mass of cassava (kg), t = time taken in Seconds, M_{PC} = mass of peeled cassava (kg), M_{PR} = mass of peel retained (kg).

3. Results and Discussion

The machine design technical parameters as determined from Equations (1)-(12) were presented in Table 1. From the result, the power requirement of the machine was 1.464kw hence 2Hp electric motor with speed of 1440 rpm was used to power the machine. This power was transmitted to the shafts bearing the peeling rollers that peel the cassava tubers with an abrasive surface (emery cloth). The peeling rollers rotate at a speed of 360 rpm.

Table 1: The machine design technical parameters

Technical/Calculated Parameters	Symbol	Value	Unit
Chain Length	L	2.8	m
Angle of Articulation	θ/2	12^0	Radians
Design power of the chain	P_D	2.475	Kw
Average Speed of chain	V	14.39	m/s
Power required	P	2	Hp
Shaft speed	N_2	360	rpm
Diameter of peeling roller shafts	D	0.46	m
Maximum mass of cassava tubers per batch of peel	M	24	Kg
Maximum bending moment on the peeling roller shafts	M_b	1.61, 0.89, 0.23	Nm
Effective volume of peeling chamber	V_{PC}	0.072	m^3

Tables 2 and 3 present the machine performance results while Table 2 showed measured crop parameters, Table 3 showed the evaluated performance indicators determined from Equations (13)- (15). From the results as recorded, it was observable that the machine attained peeling efficiency of up to 91% at corresponding minimum average flesh loss of 0.195kg for umucas 38 variety with highest moisture content (84.33 %). This is an indication that moisture content favoured the developed multi-roller abrasive peeling machine.

Table 2: Varieties and parameters for performance evaluation

Type (Moisture Content)	Time of peel, t (min)	Weight of tuber before peeling Mc (kg)	Mass of peel, Mp (kg)	Weight of peeled tuber Mpc (kg)	Weight of peel removed by hand Mpr	Tuber loss M_F (kg)
NR 8208 (65.40%)	2	5	0.6	4.35	0.60	0.05
	4.01	10	1.29	8.50	1.29	0.21
	7.32	15	1.58	13.16	1.58	0.26
	10.10	20	2.59	17.10	2.59	0.31
NR 09/0581 (63.50%)	1.98	5	0.82	4.10	0.82	0.08
	3.92	10	1.62	8.20	1.62	0.18
	7.25	15	1.98	12.80	1.98	0.22
	10.00	20	2.21	17.50	2.21	0.29
UMUCAS 38 (84.33%)	2.10	5	0.70	4.21	0.70	0.09
	4.12	10	0.82	9.00	0.82	0.18
	7.10	15	1.63	13.15	1.63	0.22
	9.53	20	2.35	17.36	2.35	0.29
NR 8083 (64.50%)	2.01	5	0.60	4.34	0.60	0.60
	3.96	10	1.30	8.49	1.30	0.21
	7.28	15	1.57	13.12	1.57	0.31
	10.04	20	2.58	17.00	2.58	0.42
NR 8082 (63,33%)	2.05	5	0.86	4.02	0.86	0.12
	4.02	10	1.57	8.22	1.57	0.21
	7.94	15	1.80	12.74	1.80	0.41
	9.92	20	2.17	17.46	2.17	0.37

Table 3: Results of the performance evaluation of the multi-roller cassava peeling machine

Type	Mc	Proportion by weight P (kg)	Mechanical damage (λ)	Peel retention (PR)	Peeling efficiency (µ)	Throughput Capacity Tc (min)
NR	5	0.87	0.04	0.03	0.87	2.17
8208	10	0.85	0.05	0.04	0.86	2.11
	15	0.87	0.05	0.05	0.89	1.79
	20	0.85	0.04	0.03	0.86	1.69
NR	5	0.82	0.06	0.04	0.83	2.07
09/0581	10	0.82	0.05	0.04	0.83	2.09
	15	0.85	0.06	0.05	0.86	1.76
	20	0.87	0.04	0.03	0.88	1.75
	5	0.84	0.05	0.04	0.85	2.00
UMUCAS	10	0.90	0.06	0.05	0.91	2.18
38	15	0.87	0.04	0.03	0.88	1.80
	20	0.86	0.07	0.06	0.88	1.82
NR	5	0.86	0.04	0.03	0.87	2.15
8083	10	0.84	0.04	0.03	0.86	2.14
	15	0.87	0.05	0.04	0.89	1.80
	20	0.85	0.05	0.04	0.86	1.69
NR	5	0.80	0.09	0.07	0.82	1.96
8082	10	0.82	0.05	0.04	0.83	2.04
	15	0.84	0.09	0.07	0.87	1.60
	20	0.87	0.05	0.04	0.88	1.76

The cost evaluation is presented in Table 4.

Table 4; Bill of Engineering Measurement and Evaluation (BEME) 31st March, 2018

S/N	Component Part	Material used	Quantity	Rate	Amount (₦)
1	Electric motor	2 HP 3-phase	1	-	40000
2	Frame	Mild steel angle iron 2x2	3	2500	7500
		Mild steel angle iron 1x1	2	1000	2000
3	Bearing	Mild steel	10	800	8000
4	Bolts and nuts	Mild steel	16	80	1280
5	Plate	Mild steel 2mm	1	-	15200
		Mild steel 10mm	1	-	30000
6	Hinges	Mild steel	2	150	300
7	Pulley	Mild steel	4	900	3600
8	Sprockets	Carbonised mild steel	6	1500	9000
9	Rollers	Hardened mild steel	5	6520	32600
10	Shaft	Hardened mild steel	5	2530	12650
11	Chain	Medium carbon	1	5200	5200
12	Paint	Red oxide, green	-	-	11000
13	Transportation	-	-	-	15000
14	Labour	-	-	-	60000
15	Miscellaneous	-	-	-	29320
16	Total	-	-	-	282650

From the bill of engineering measurements and evaluation, the total cost of fabricating the machine is Two Hundred and Eighty Two Thousand, Six Hundred and Fifty naira only (₦282,650.00)., This machine is affordable to small and medium scale processors as justified by the capacity, performance and prevailing economic realities.

4. Conclusion and Recommendation

The need for pre-operation such as cutting of the cassava tuber with depressed sections, tuber stumps, and washing of the tubers before peeling in order to have an effective operation poses a great limitation. However, an improvement can be made so as to eliminate the time expended in preoperational activities. The developed cassava peeler recorded high peeling efficiency of 91% and throughput of 2.71kg/min for variety having highest moisture content (84.33%), hence revealing that the machine performs better with freshly harvested tubers (with high moisture content).The cassava peeler produced is a prototype therefore can only contain about 24kg of cassava at a time. However it can be improved upon by scaling up the peeling chamber capacity for industrial purposes. Further research could be carried out on the production of a more advanced machine where pre-operational treatment will be eliminated to enhance efficiency and productivity.

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