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OPTIMIZATION OF PEELING TIME AND OPERATIONAL SPEED FOR CASSAVA PEELING USING CENTRAL COMPOSITE DESIGN AND RESPONSE SURFACE METHODOLOGY

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ABSTRACT

The effect of two process parameters namely: peeling time and operational speed on the peeling process of cassava during cassava processing were investigated. The optimization of flesh loss from cassava was carried out using the central composite design and response surface methodology. Taking flesh loss as the response of the designed experiment, the data obtained were statistically analysed to get a suitable model for optimization of flesh loss as a function of peeling time and operational speed. The optimization produced 13 feasible solutions whose desirability is close to 1 and the selected (most desirable) condition was found to be: reaction time (3.5 mins) and operational speed (775 rpm) at a minimum flesh loss was found 38.6%. Physical experiment was also done using cassava of average width of 60 mm and height 140 mm at different speeds of operation ranging from 350 to 750 and 1440 rpm within a resident time of 3 minutes. The optimum speed of shaft rotation was found to be 750 rpm with an average minimum flesh loss of 36.31% and average peeling efficiency of 63.68%. The correlation of the results obtained from both the central composite design and physical experiments validates the efficiency of the developed model. Increase in speed and peeling time increases the peeling efficiency, however, further increase beyond the optimum reduces the peeling efficiency of the machine as the machine starts grating the cassava with significant flesh loss.

KEYWORDS: Cassava, Central Composite Design, Flesh Loss, Optimization, Response Surface Methodology.

INTRODUCTION

Cassava (*Manihot esculenta Crantz)* is cultivated mainly in the tropical parts of Africa, Brazil, Malagasy, Indonesia, South India, Philippines, Malaya, Thailand and China (Ajibola, 2000; Adetan *et al.*, 2006). It is very tolerant of drought and heat and thrives well on marginal soils. According to Perez and Villamayor (1984) it is an important dietary staple within the tropical regions of the world. Cassava has become the most important crop in the tropical part of Africa in terms of both the total land area devoted to its production and contributes to human diet which is mostly carbohydrate. As a subsistence crop, cassava is the third most important carbohydrate food source in the tropics after rice and maize, providing more than 60 % of the daily calorific needs of the populations in tropical Africa (Nartey, 1978; Richardson, 2011). Cassava plays an important role in alleviating the African food problems because it thrives and produces stable yields under conditions in which other crops failed (Alexandratos, 1995).

Ajibola (2000) reported that the economic potential of cassava in Nigeria is currently being under-utilized. The author reported that Nigeria is the largest producer of the crop in the world with over 34 million tonnes of fresh tubers being produced annually. Also, Hillocks *et al.* (2002) reported that the total production of cassava in Africa has increased from 35 – 80 million tons between 1965 and 1995. According to Olukunle (2005) Africa now produces cassava than the rest of the world combined with biggest increase from 22 % to 35 % (of African total production) in Nigeria and 4 % to 8 % in Ghana.

It is mostly processed, traditionally, into garri, lafun, fufu, abacha and akpu in Nigeria, and, kokonte and agbelima in Ghana (Quaye *et al.*, 2009). Cassava starch is an ingredient in the manufacture of dyes, drugs, chemicals, carpets and in the coagulation of rubber latex (Odigboh, 1983). The demand for these products is on the increase which provides great opportunities in the area of cassava processing but these opportunities cannot be fully exploited with the use of traditional methods like knives. This is because knives are adjudged as arduous in nature, labour intensive, and time consuming and unsuitable for large scale production (Igbeka, 1984; Adetan *et al.*, 2003). The major problem encountered in cassava peeling arises from the fact that the cassava roots exhibits appreciable differences in weight, size and shape Adetan *et al.* (2006). There are also differences in the properties of the cassava peel which varies in thickness, texture and strength of adhesion to the root flesh. Thus, it is difficult to design a cassava peeling machine that is capable of efficiently peeling all roots due to the wide differences in the properties of roots from various sources. Indeed, the development of a technically and economically acceptable cassava peeling machine is still an issue being faced by the engineers of today. In many occasions, attempts have been made to replace the human labour by the mechanized process of cassava peeling so as to prevent wastage, save time and have the overall best peeling efficiency. The most basic peeling method which is also the first attempt is the use of sharp edged objects like knives in cassava peeling. This method is a primitive, cumbersome and less efficient.

Cassava peeling methods are manual (Abdullahi *et al.,* 2010 and Odigbo 1976), use of chemicals (Igbeka 1984), mechanical methods (Abdulkadir 2012) and steaming method (Oluwole and Adio, 2013). Oluwole and Adio (2013) described the steaming method of peeling cassava as a clean method of peeling and does not cause environmental pollution but not efficient especially for garri and starch production because it leads to the formation of objectionable heat ring in the tuber surface and gelatinization of the starch. There is also the mechanical method of peeling of cassava tuber. This method includes the use of mechanized strategy of peeling, aimed at peeling a large number or a batch at a time. Many mechanisms have been devised for this purpose. This includes the continuous process, abrasive belt conveyors and batch abrasion types among others. These methods of peeling have not been yielding the desired results.

This has necessitated researchers in the engineering field to study the crude and traditional way of removing peels from cassava with a view of designing model machine to remove cassava peels mechanically. From literature, it could be deduced that the analysis detailed design analysis of incorporating machine features of the overall process for cassava peeling via the use of machine has been a missing link and process design issue have not always been sufficiently highlighted. These are areas of interest that could enhance cassava peeling process design, engineering and optimization in cassava processing.

In addition, existing cassava peeling machine is limited to a range of sizes of cassava at a speed of operation, however, in this study, a cost effective, semi-automated cassava peeling machine was developed that can peel various sizes of cassava tubers at different operational speeds.

MATERIALS AND METHOD

The machine was designed based on power required by the machine, tension of belt, load on shaft pulley and belt tension, load on peeling drum, shaft diameter and weight of peeling drum. It consists of a rotating shaft, belt, pulley, machine frame, bearings, peeling drums and a 3 kW variable speed electric motor. A 1.5 mm thick mild steel was used in the fabrication of the peeling drums because it balances ductility and strength and has good wear resistance. The metal sheet was punched and rolled into cylindrical form; the outer peeling drum was punched inward and was fixed to the machine frame while the inner peeling drum was punched outward. The inner peeling drum has length of 510 mm and 120 mm diameter. The speed of the inner diameter was high due to the fact that it is the rotating member and creates the motion for the peeling.

Machine Capacity

The machine is designed to accommodate 8 cut tubers of cassava.
Average length of cut tubers of cassava = 220 mm
Average diameter of cut tubers = 100 mm
The weight of each cut cassava is approximately 1.3 kg
Total load weight = $1.3 \times 8 = 10.4\ kg$
The machine is designed to accommodate cut cassava tubers having a total weight of 10.4 kg
The machine member is subjected to torsion (action of two equal and opposite couple acting in parallel plane which could be torque or twisting moment. The stress induced by the torsion results in torsional shear stress which is zero at the centroidal and maximum at the outer surface. The machine has a shaft fixed at one end and is subjected to torque T at the other end.

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Design of Peeling Drum

According to Eugene and Theodore (1996) and Abdulkadir (2012), mass of the drum m is given by;

$$m = \rho V \quad (1)$$

where;

ρ is the density of the material (kg/m^3) and V the volume of the material (m^3)

but

$$V = (length \times width \times thickness) + (2 \times circumference \times thickness)$$

$$V = \left(L \times \pi D_d \times t_p\right) + \left(2 \times \pi D_d \times t_p\right)$$

$$V = \pi D_d t_p (L + 2) \quad (2)$$

Hence equation becomes

$$m = \rho \times \pi D_d t_p (L + 2) \quad (3)$$

$\rho = 7850\ kg/m^3, \pi = 3.142,\ D_d = 0.0625\ m, L = 0.125\ m, t_p = 0.005\ m$

From equation 8, $m = 16.5\ kg$

Weight of the drum is given by;

$$W = mg` \quad (4)$$

$$W = \pi \rho D_d t_p (L + 2) g \quad (5)$$

$m = 16.5\ kg, g = 9.81\ m/s^2$

From Equation 4, weight of the drum $W = 160\ kg$

It was constructed using 1.5 mm mild metal sheet. The metal sheet was cut to size for the outer cylinder and inner cylinder. The metal sheet used for the outer drum was equally spaced 10 mm horizontal and vertically and the inner drum was marked equally 5 mm. The point of intersections of each line was centre punched. The outer drum was punched inward on the point of intersection of the lines already marked out horizontally and vertically while the inner drum is punched outwards on the lines also marked out to create the abrasive surface required to peel the cassava tubers. The outer drum has an opening on the upper part of the drum which serves as the inlet for the drum (Figures 1 and 2).

Figure 1: Outer Peeling Drum

Figure 2: Inner Peeling Drum

Shaft

Shaft designs consist primarily of the determination of the correct shaft diameter that will ensure satisfactory rigidity and strength when the shaft is transmitting power under different loading conditions (Hall *et al.*, 1961). The design of the machine is such that the shaft receives power from the electric motor via a V-belt.

For rotating shaft, the torsional moment acting on the shaft us given by equation 6

$$M_t = \frac{P \times 1000 \times 60}{2\pi N} \quad (6)$$

$$M_t = \frac{1.5 \times 1000 \times 60}{2 \times 3.142 \times 450}$$

$$M_t = 31.826 Nm$$

The bending moment of the shaft of length 3 m with a central load is given by equation 7

$$M = \frac{wl}{4} \quad (7)$$

Where; w is the central point load in N, l is the length of shaft.

The magnitude of the load is given by equation 8

$$load = m \times a \quad (8)$$

Where; m is the mass of the drum, (6.2 kg) and a is the acceleration due to gravity, (9.81m/s^2).

$W = 6.2 \times 9.8,\ W = 60.822\ N$

$M = \frac{wl}{4}$

$M = \frac{60.882 \times 3}{4}$

$M = 45.6\ Nm$

$M_b = \sqrt{(45.6)^2 + (45.6)^2} \ = 64.488\ Nm$

The shaft is solid having little or no axial loading.

The shaft diameter is given by equation 9;

$$d^3 = \frac{16}{\pi s_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (9)$$

where; M_t is the torsional moment, (31.826 Nm), M_b is the bending moment (64.488 Nm) K_b is the combined shock and fatigue factor applied to bending moment for gradual loading (1.5), K_t is the combined shock and fatigue factor applied to torsional moment for gradual loading (1.0), s_s is the allowable shear stress for shaft without keyway ($55 \times 10^5\ N/m^2$) and d is the shaft diameter, m.

From equation 9

$d^3 = \frac{16}{3.142 \times 55 \times 10^6} \sqrt{(1.5 \times 64.488)^2 + (1.0 \times 31.826)^2}$

$d^3 = 9.2587 \times 10^{-8} \sqrt{9357.079 + 1012.894}$

$d^3 = 9.42841 \times 10^{-6}$

$d = 0.0211\ m$

$d = 21.125\ mm$

$d = 21\ mm$, 25 mm to the nearest standard size.

A 25 mm diameter and 760 mm length high mild steel rod shaft was used so as to ensure satisfactory rigidity and strength when the shaft is transmitting power under different operating and loading conditions.

Machine Frame

The frame is to provide support for other components of the cassava peeler. High mild steel was selected for its fabrication so as to combine its hardness, relative toughness rigidity and good machining characteristics since it will be constantly subjected to direct stresses as well as varying degree of loads from other machine components.

Power Unit

Power transmitted by shaft in watt is given by equation 10

$$P = \frac{2\pi N}{60} \times T \qquad (10)$$

$$\omega = \frac{2\pi N}{60} \qquad (11)$$

Substituting equation 11 into 10

$$P = T \times \omega \qquad (12)$$

where; P is the power rating of the electric motor (kW), T is the torque transmitted in (Nm), ω is the angular speed (rad/sec) and N is the number of revolutions per minute.

Torque T is given by equation 13

$$T = m \times a \times r \qquad (13)$$

where; m is the mass of the inner drum (16.5 kg), a is the acceleration due to gravity (9.81 m/s^2) and r is the radial distance (0.25 m)

From equation 13, torque T is calculated as $40.466\ Nm$. The number of revolution per minute is 450

From equation 1, the power requirement for the electric motor is 1.48 kW. Using a factor of safety of 2, the power requirement is calculated as 2.96 kW. Hence, 3 kW electric motor will produce sufficient motion for the belt and shaft. The power unit consist of V-belt which is used to transmit power from the electric motor to the shaft using pulley. The driver pulley is 70 mm in diameter and the driven pulley is 200 mm in diameter. Electric Motor is a device powered by electric current to produce continuous motion. It rotates at a maximum speed of 1440 rpm and attached to it is the pulley which in turn drives the shaft. The power of the electric motor is rated as 3 kW and it is such that it is a variable speed electric motor from which different stir speed can be selected. It has a maximum frequency of 3000 Hz. The speed of the electric motor is varied by using the running capacitor to vary the speed. There were three capacitors used in running the machine; 50 µf, 30 µf and 12.5 µf. Each of these capacitors has their own speed making the 50 µf having the highest speed. The capacitor acts as the speed regulator but also store electrical charges. When the capacitor is powered, the starting capacitor accepts the charge and starts running the

electric motor. As the motor runs, the running capacitor begins operation, maintaining the speed that the starting capacitor sends while the centrifugal switch cuts of the starting capacitor
The integration of various machine component is shown in Figure 3.

Figure 3: The Developed Cassava Peeling Machine

PHYSICAL EXPERIMENT

Physical experiment was also done at Afe Babalola University, Ado Ekiti, Nigeria with the developed cassava peeling machine using cassava of average width of 60 mm and height 140 mm at different speeds of operation ranging from 350 to 750 and 1440 rpm within a resident time of 3 minutes. The results obtained from the performance evaluation of the machine is given in Tables 1, 2 and 3.
Percentage weight of peel (%)

$$\%\ weights\ of\ peels = \frac{weight\ of\ peels}{weight\ of\ unpeeled\ tubers} \times \frac{100}{1} \quad (14)$$

Peeling efficiency (P.E %)

$$P.E = \frac{weight\ of\ peel\ removed\ by\ machine}{total\ weight\ of\ peels} \times \frac{100}{1} \quad (15)$$

$$= \frac{percentage\ weight\ of\ peels - weight\ of\ peels\ removed\ manually}{total\ weight\ of\ peels} \times \frac{100}{1}$$

Total weight of peels = % weight of peels x weight of unpeeled tubers
Percentage flesh loss of tubers (% F. L.)

$$F.L = \frac{weight\ of\ flesh\ removed\ by\ machine}{total\ flesh\ weight\ of\ tubers} \times \frac{100}{1} \quad (16)$$

OPTIMIZATION OF PROCESS VARIABLE

Optimization of process variables was carried out with Design-Expert® (version 7) software for experiment design using a four-level-two factor central composite design model and response surface methodology to study the effect of independent variables such as peeling time (minutes) and operational speed (rpm) on the flesh loss. Using the central composite design and response surface methodology, the flesh loss was taken as the response of the designed experiment while varying the input process parameter; peeling time within the range of 2-5 mins and operation speed within 350 -1440 rpm (Table 1).

Table 1: Numeric Factors and Levels

s/n	Factor	Name	Unit	-1 Level	+1 Level	-alpha	+alpha
1.	A	Peeling time	Minutes	2	5	1.71619	5.28381
2.	B	Operational speed	rpm	350	1440	246.882	1543.12

The input process parameters in Table 1 generated 13 experimental runs (Table 2).

Average Classification Error

The average classification error was used to determine the degree of agreement between the actual and predicted values from the central composite design. The root mean square error for the actual and the predicted value of the flesh loss is given by equation 17

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$$E_{r.m.s} = \sqrt{\frac{\sum_{i=n}^{n}(Actual-Predicted)^2}{n}} \quad (17)$$

The root mean square value for the flesh loss is given by equation 18

$$A_{r.m.s} = \sqrt{\frac{\sum_{i=n}^{n}(Actual)^2}{n}} \quad (18)$$

The ratio of the two values given in equations 17 and 18 gives the average classification error given in equation 19.

$$E_C = \frac{E_{r.m.s}}{A_{r.m.s}} \quad (19)$$

RESULTS

The peeling analysis at a speed of 350 rpm is presented in Table 2. This include flesh loss, percentage flesh loss and peeling efficiency.

Table 2: Cassava Peeling Analysis at 350 rpm

Parameters	Tuber 1	Tuber 2	Tuber 3	Tuber 4	Tuber 5
Height (mm)	140	110	121	163	180
Width (mm)	60	50	48	70	70
Weight (g)	428.77	368.00	415.43	437.42	538.34
Weight after peeling (g)	353.76	290.05	340.45	352.42	453.37
Weight of peels and flesh (g)	75.01	77.5	74.98	85.00	84.97
Weight of peels (g)	44.91	50.55	42.17	54.65	50.02
Flesh loss (g)	30.01	26.95	32.81	30.35	34.95
Flesh loss (%)	40.0	34.77	43.75	35.7	41.13
Efficiency of peeling (%)	59.8	65.22	56.24	64.29	58.86

The peeling analysis at a speed of 750 rpm is presented in Table 3.

Table 3: Cassava Peeling Analysis at 750 rpm

Parameters	Tuber 1	Tuber 2	Tuber 3	Tuber 4	Tuber 5
Height (mm)	140	110	121	163	180
Width (mm)	60	50	48	70	70
Weight (g)	426.77	368.00	415.43	437.42	538.34
Weight after peeling (g)	361.69	302.95	350.37	372.388	498.02
Weight of peels and flesh (g)	65.07	65.04	65.06	65.03	65.00
Weight of peels (g)	42.95	40.00	42.23	41.62	40.3
Flesh loss (g)	22.12	25.04	22.83	23.41	24.70
Flesh loss (%)	33.99	38.49	35.09	35.99	38.00
Efficiency of peeling (%)	66	61.5	64.9	64.0	62

The peeling analysis at a speed of 1440 rpm is presented in Table 4.

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Table 4: Cassava Peeling Analysis at 1440 rpm

Parameters	Tuber 1	Tuber 2	Tuber 3	Tuber 4	Tuber 5
Height (mm)	140.00	110.00	121.00	163.00	180.00
Width (mm)	60.00	50.00	48.00	70.00	70.00
Weight (g)	428.77	368.00	415.43	437.42	538.34
Weight after peeling (g)	363.77	302.3	350.44	372.38	449.27
Weight of peels and flesh (g)	65.0	65.70	64.98	65.03	64.86
Weight of peels (g)	39.00	35.80	36.00	38.50	37.07
Flesh loss (g)	26.00	29.9	28.98	26.53	27.79
Flesh loss (%)	40.00	45.50	44.59	40.79	42.84
Efficiency of peeling (%)	60.00	55.00	55.40	59.20	57.00

Figure 4 shows the effect of operational speed on cassava during the peeling process. Increase in operational speed increases the peeling efficiency up to the optimum, beyond which there is significant flesh loss due to the fact that the machine starts chopping off the cassava flesh.

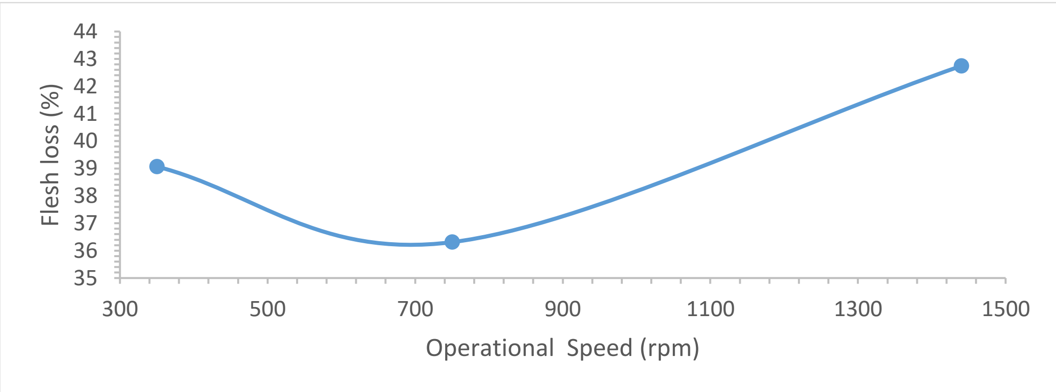

Figure 4: Flesh Loss at Different Operational Speed

Figure 5 shows the effect of operational speed on the peeling efficiency. Increase in speed increases the peeling efficiency up to the optimum, beyond which the peeling efficiency due to flesh loss.

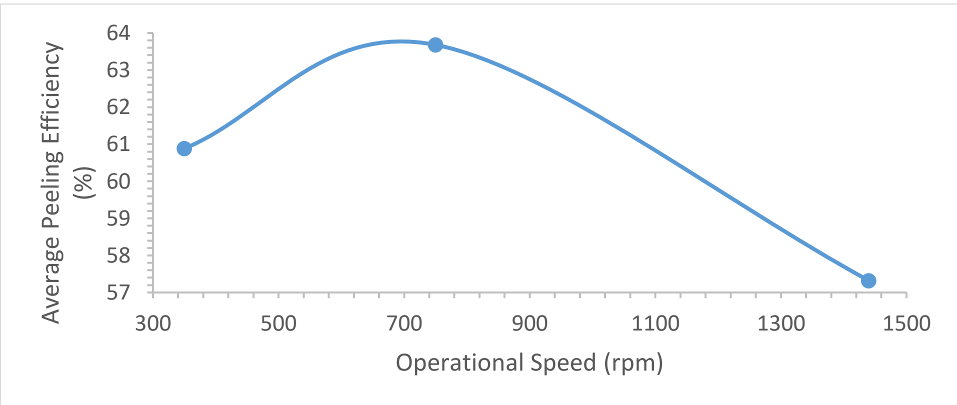

Figure 5: Peeling Efficiency at Different Operational Speed

Figure 6 is a 3D Response Surface plot of the interaction effect of peeling time and operational speed on cassava during the peeling process. From Figure 6, there is significant flesh loss with increase in time beyond 3 mins and increase in operational speed beyond 775 rpm. This may be due to the grating effect of the machine when the

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optimum time and speed is exceeded.

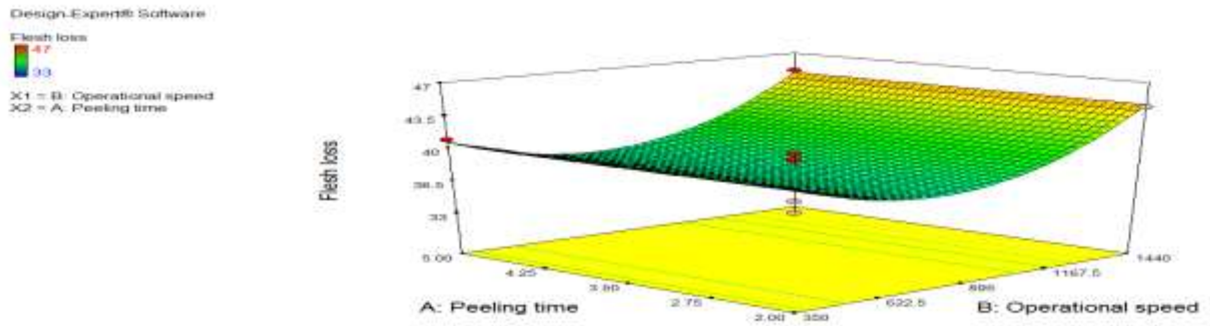

Figure 6: Interaction of Peeling time and Operational speed

Figure 7 is a 3D response surface plot of the desirable conditions for optimum peeling efficiency. They are; peeling time (3.09 mins) and operational speed (773.59 rpm).

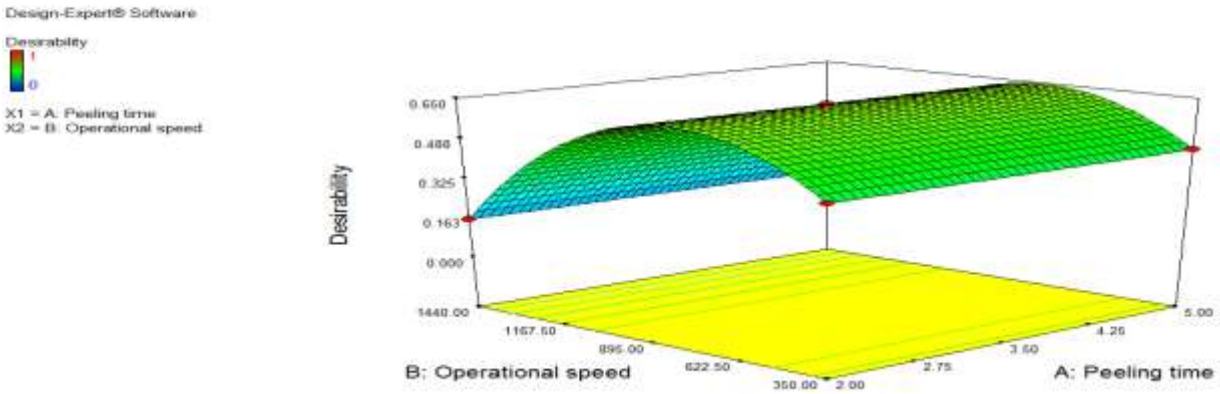

Figure 7: Desirability of Peeling time and Operational speed

Table 5 shows the feasible combination of peeling time and operational speed. Using the combination of process parameters in Table 5, 13 experiments were carried with the developed cassava peeling machine and the percentage flesh loss was determined from equation 16. The values obtained from experiment for flesh loss for each combination of process parameter is shown in Table 5. This was statistically analysed with Design Expert software to get a predictive model for flesh loss (%) as a function of the independent variables (Equation 20).

Table 5: Process Parameters and Flesh loss

S/N	**Standard deviation**	**Block**	**A: Peeling** time **(mins)**	**B: Stir speed (rpm)**	**Flesh loss (%) from Experiment**
1	7	1	3.50	246.88	43
2	2	1	5.00	350.00	41
3	10	1	3.50	895.00	33
4	4	1	5.00	1440.00	45
5	13	1	3.50	895.00	37
6	12	1	3.50	895.00	39.5
7	11	1	3.50	895.00	39.5
8	6	1	5.28	895.00	40
9	1	1	2.00	350.00	39.5
10	5	1	1.72	895.00	40
11	3	1	2.00	1440.00	44.5
12	8	1	3.50	1543.12	47
13	9	1	3.50	895.00	38.8

The predictive model for the determination of flesh loss is given by equation 20

$$Flesh\ loss = 38.21 + 2.01 \times B + 4.54 \times B^2 \quad (20)$$

where; B is the stir speed (rpm).

The validation of the predictive model from the central composite design was done using arbitrary values within the range of the process parameters given in Table 5. The percentage flesh loss from experimental response and the predictive model was found to be in agreement (Table 6)

Table 6: Experiment and Predicted Flesh Loss Using Central Composite Design

S/N	A: Peeling time (mins)	B: Stir speed (rpm)	Flesh loss (%) from experimental response	Flesh loss (%) from predicted response
1	5.00	230.08	49	48.02
2	4.00	650.00	47.5	49
3	4.50	805.00	40	43
4	3.00	1200.00	47.7	45.6
5	3.50	775.00	39	38.6
6	4.50	800.00	40.5	42.06
7	2.50	900.00	42.5	39.9
8	3.28	850.00	42	40.10
9	2.00	350.00	48.5	47.00
10	4.72	895.00	46	44.90
11	2.50	1000.00	48.5	49.98
12	3.00	1500	47.2	48.67
13	3.00	895.00	47.03	49.00

Figure 8 shows the actual values of percentage flesh loss for 13 experimental runs and predicted values from the central composite design (CCD). The predicted values have good correlation with the experimental values, hence validating the efficiency of the developed model.

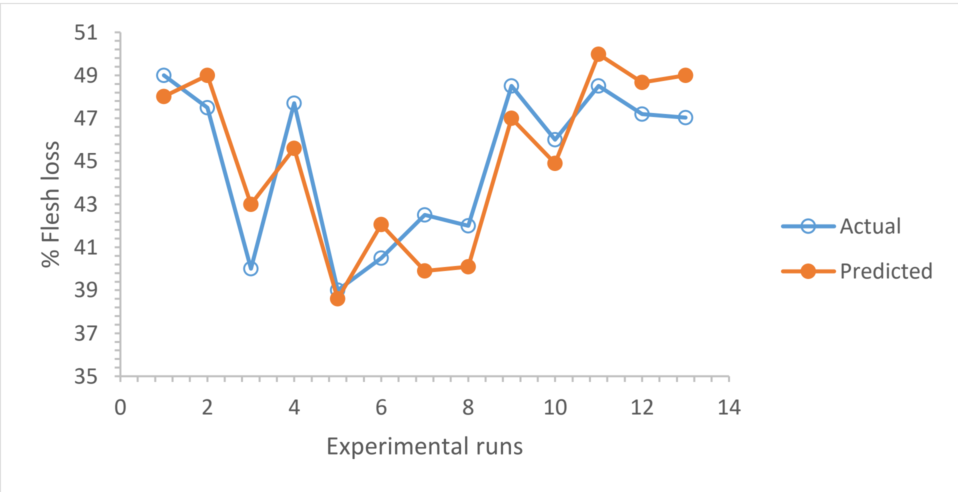

Figure 8: Actual and Predicted Values of % Flesh Loss from Experiment and CCD

DISCUSSION OF RESULTS

Five cut tubers were used for the physical experiment with different sizes ranging from 110-180 mm (height) to 48-70 mm (width) and 360-550 mm (weight). The rotational speed of operation also varies from 350 to 750 and 1440 rpm at a resident time of 3 minutes. From the analysis of the results obtained for a speed of 350 rpm, the average flesh loss was 39.07% with an average peeling efficiency of 60.882% (Table 2). At 750 rpm, the average flesh loss was 36.31% with an average peeling efficiency of 63.68% (Table 3). Increase in speed of operation to 1440 rpm results in average flesh loss of 42.744% with an average peeling efficiency of 57.32% (Table 4). From Figure 4, at operational speeds of 350 and 750 rpm there is reduction flesh loss but increase in operational speed up to 1440 rpm results in significant loss of flesh (42. 74%) as the machine starts grating parts of the cassava. Hence, operational speed of 750 rpm is considered the optimum for the physical experiment. Using the central composite design, the optimum process parameters were found to be; peeling time (3.5 mins), operational speed (775.0 rpm) with a flesh loss of 38.6% (Table 6). The root mean square error for the actual and predicted values was calculated as 4.829 from equation 17, while the root mean square value for the experimental values was found to be 329.31 from equation 18. The average classification error was also calculated as 0.0146 from equation 19. The value of the average classification error is negligible thus indicating high degree of correlation between the experimental values and predicted values using the central composite design.

CONCLUSION

Increase in peeling time increases the peeling efficiency, further increase in peeling time beyond the optimum may grate the cassava with significant flesh loss thereby reducing the peeling efficiency. From the analysis of the results obtained, there is high degree of correlation between the results obtained from the physical experiment and the central composite design, thus validation the efficiency and the predictive capability of the developed model.

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