PERFORMANCE EVALUATION OF A PERFORATED CYLINDER TYPE CASSAVA PEELING MACHINE

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ABSTRACT

Peeling of cassava tuber at all levels is still largely carried out manually; however, this study assessed the performance of a perforated cylinder type cassava peeling machine and developed an empirical model to predict the performance of the machine. The data of physical and mechanical properties of five varieties of cassava tubers grown in Niger State were used in the design of the machine. The machine was evaluated using cassava variety - TSM 82/00661 obtained from Kure – Ultra modern market, Minna, Niger State. The performance of the machine was based on the peeling efficiency and tuber flesh loss using machine speed range of 370, 570 and 770 rpm, applied load of 5, 8, 11, 14 and 17 N. The peeling efficiency increased with increase in speed and load applied on tuber irrespective of the category of tuber diameter used. The highest peeling efficiency of 69.93 % was obtained at speed of 770 rpm, load of 17 N and tuber diameters 11 - 40 mm, 41 - 70 mm and 71 - 100 mm. The percentage of tuber flesh loss was 3.01 – 4.05 %. The developed models are adequate and valid between the predicted and the observed values. The experimental variables (speed and load) fit into the models generated with higher coefficients of determination (R^2 = 81.87 %, R^2_{adj} = 75.77 %, R^2_{pred} = 69.16 %).

Keywords: *Cassava, machine speed, applied load, peeling efficiency, tuber flesh loss, and perforated peeling mechanism*

INTRODUCTION

Cassava (Manihotesculenta) is a tropical plant which has a fibrous root system. Some of these roots develop into root tubers by the process of secondary thickening. These roots develop radially around the base of the plant forming five to ten tubers per plant. These are the main economically useful parts of the plant (Ajibola, 2000). Cassava is a popular, important food energy and commercial crop in tropical countries. There are numerous varieties of cassava in the world today and these are usually differentiated from one another by their botanical characteristic and level of hydrocyanic acid which causes toxicity in the root. This toxicity vary from place to place, for instances, a bitter variety may become sweet or vice versa. This is as a result of environmental factors such as soil type, soil moisture, soil fertility, tillage practice and vegetation of the farm (Grace, 2004). Olukunle and Oguntude (2007) further reported that soil factors would also influence shape and size of the tuber which constitutes major bottleneck in cassava peeling.

Cassava has nutritive and commercial benefits which make it attractive especially to the local farmers. First, it is rich in carbohydrates and could be enriched with other food compositions such as protein. Secondly, it is always available in all seasons, making it preferable to other more seasonal crops such as grains, peas, beans etc for food security. Compared to other crops, cassava is more tolerant to low soil fertility, and more resistance to pest and diseases. More importantly too, it thrives very well on soil so depleted by repeated cultivation that has becomes unsuitable for other crops. It also tolerates environmental stresses such as short period of drought, strong and desiccating winds (Osundahunsi, 2005).

Cassava yield varies from as low as 5 tonnes to more than 60 tonnes per hectare (CBN Newsletter, 1995; RMRDC, 2004). World production of cassava root was estimated to be 184 million tonnes (FAO, 1991). Majority of production is in Africa where 99.1 million tons are grown. Fifty-one and a half (51.5) million tons were grown in Asia and 33.2 million tons in Latin America and the Caribbean. Nigeria is the world's largest producer of cassava. However, based on the statistics from the Food and Agricultural Organization (FAO) of the United Nations, Thailand is the largest exporting country of dried cassava with a total of 77% of world export in 2005. The second

largest exporting country is Vietnam, with 13.6% followed by Indonesia (5.8%) and Costa Rica (2.1%). Worldwide cassava production increased by 12.5% between 1988 and 1990 (RMRDC, 2004).
All the unit operations involved in cassava processing such as grating, drying, milling, pressing, sieving, frying and extrusion have been mechanized successfully; however, peeling remains the only unmechanized process which has constituted a serious global challenge in food industries. On the average about 20 to 25 kg of roots can be peeled in an hour. It is reported that 30 kg of fresh weight is lost during the manual peeling because woody tips are removed. The process is slow and labour-intensive, averaging 25 kg per man-hour, but it gives the best result. It is worthy to note that the major problem in cassava peeling arises from the fact that cassava roots exhibit appreciable differences in weight, size and shape (Alade, 2005). There are also differences in the properties of the cassava peel, which varies in thickness, texture and strength of adhesion to the flesh (Agbetoye, 2003). Another major constraint of cassava is that the roots deteriorate rapidly (IITA, 1990). Cassava tubers have a shelf life of 24 - 48 hours after harvest (Akintunde *et al.*, 2010). Fresh roots must be processed within 2 to 3 days from harvest to avoid deteriorating.
Thus because of the difficulties associated with cassava peeling, there is the need to develop a perforated cassava peeling machine to develop models to predict the performance of the machine.

MATERIALS AND METHODS

Material selection

The materials used for the construction of the machine were chosen on the basis of their availability, suitability, economy and viability in service among other considerations (ASAE, 2003; Gupta and Das, 1997; Sahay and Singh, 1994; Mohsenin, 1986; Khurmi and Gupta, 2007). Each component of the machine was designed following standard engineering principles (Balami *et al.,* 2012). The materials used in evaluating the machine was the cassava variety - TSM 82/00661 obtained from Kure – Ultra modern market, Minna, Niger State, Nigeria. The machine was powered by a 1 hp electric motor.

Principles of operation

The developed cassava peeling machine (Fig. 1) basically consists of the perforated peeling cylinder type which is operated by a 1hp electric motor through the pulleys by which the speed was varied. The variation in speed was achieved by varying the pulley on the driven shaft. The concept of this peeling system involves feeding the tubers in the feed tray at predetermined sizes and shapes after sorting out the cassava tubers. The perforations provided on the cylinder give rotary and linear motion on the tuber. As the tuber enters into the peeling chamber, it receives a rotary motion as a result of the rotation of the peeling cylinder which is tilted at 35° to the horizontal. The shear force created between the peeling cylinder and the metallic press which give support to the applied load in turn peels the cassava tuber. After that the peeled cassava tuber glides easily out through the outlet chute due to the 35° inclination of the shaft of the peeling cylinder. The peel removed is separated from the desired products into the waste section of the machine.

Figure 1: The developed Cassava Peeling Machine

Performance Evaluation of the Machine

The test was conducted using cassava variety - TSM 82/00661 obtained from Kure – Ultra modern market, Minna, Niger State, Nigeria at an average moisture content of 65 % (wet basis).

Determination of Peeling Efficiency of the Machine

The peeling efficiency *(PE)* of the machine was determined using the expression given in equation 1 (Khurmi and Gupta, 2005).

$$PE = \frac{Q_c}{Q_t} \times 100\% \qquad (1)$$

Where:

Q_c– Mass of unpeeled skin remaining on the tuber after going through the peeling process, g;
Q_t = Mass of peeled skin of the tuber after going through the peeling process, g

Determination of percentage of tuber flesh loss

The percentage of tuber flesh loss ($\%T_{f.loss}$) was determined using equation 4 (Khurmi and Gupta, 2005).

$$\%T_{f.loss} = \frac{M_{pfm} - \mathrm{M}_{ph}}{M_{pt}} \text{ x } 100\% \qquad (4)$$

Where:

M_{pfm} – mass of peel and flesh, g; M_{ph} – mass of peel removed, g; M_{pt} – mass of peeled tuber, g

Experimental Design

A two variable factorial design was used to conduct the experiment for the determination of peeling efficiency and percentage of tuber flesh loss. The parameters considered are the speed of peeling mechanism (370, 570 and 770 rpm) and applied force (5, 8, 11, 14 and 17 N).

Model Development

The assumptions made in Model Development are: cassava tubers are fairly cylindrical (this is feasible where tubers are cut into sizes in order to eliminate pronounced bends); cylinder length is 0.8 m; the applied loads are in two categories, namely 5 - 11 N and 11 - 17 N, tuber weight is between 0.5 kg to 2.0 kg, tuber diameter between 11 to 100 mm and the tubers come into the peeling chamber one at a time.

The statistical method employed is factorial design, having 6 levels of the applied load and 3 levels of the operation speed of the cassava peeling machine. The data obtained were analysed using MATLAB tools.

Quadratic model equation was finally employed after unsatisfactory use of the linear model for predicting the efficiency of the cassava peeling machine as expressed in equation 5.

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_{12} x_1 x_2 + \alpha_{11} x_1^2 + \alpha_{22} x_2^2 + \alpha_{211} x_2 x_1^2 + \alpha_{122} x_1 x_2^2 + \alpha_{1122} x_1^2 x_2^2 \qquad (5)$$

And since $y = \alpha_{211} x_2 x_1^2 + \alpha_{122} x_1 x_2^2 + \alpha_{1122} x_1^2 x_2^2$ terms are insignificant, the equation (5) was reduced to equation (6) as follows:

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_{12} x_1 x_2 + \alpha_{11} x_1^2 + \alpha_{22} x_2^2 \qquad (6)$$

Where: y = peeling efficiency of the machine (%), x_1 = speed of the machine operation (rpm), x_1 = load applied on the cassava tuber (N), α – a constant

Model Validity and Adequacy Tests

The mean of the replicated data, the individual regression coefficients and the t-values for the individual regression coefficients were evaluated by using statistical software MATLAB R 2011b. Based on the calculated regression coefficients, the model for the perforated cylinder type and diameters (11-40 mm, 41-70 mm and 71-100 mm) were developed. However, the statistical significance of each of these regression coefficients was assessed by constructing confidence interval and testing of hypothesis, using the T-test protocol, about individual regression coefficient (Spiegel and Stephen, 2008; Shangodoyin and Agunbiade, 1999).

Also the regression sum of squares (ANOVA), for individual regression coefficient (including the expunged ones) were evaluated (Owen and Jones, 1994). The adequacy of the fitted model was evaluated by testing hypothesis (F-test) on the individual regression coefficient (Dougherty, 2002; Attwood and Dyer, 1995).

RESULTS AND DISCUSSION

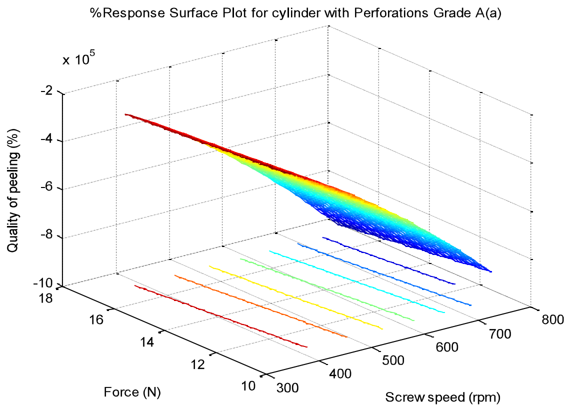
Effect of Operational Speed and Load on Peeling Efficiency

The effects of the speed of operation and applied load on the peeling efficiency of the perforated type cassava peeling machine are shown in Tables 1and 2.The peeling efficiency increased with the individual effect of speed but decreased with the applied load when above 17 N. The increase of peeling efficiency with the associated increase in speed is not unconnected with higher peeling rate of the machine at higher speed, irrespective of the applied load. The combination of speed and load, however, behaves differently as the peeling efficiency tends to increase at some instance and decrease at some instance too. The efficiency of the cassava peeling machine is an important parameter which helps in deciding the performance of the machine operation. Lower peeling efficiency implies that most of the cassava roots processed by the machine are lost in the process, and only very meagre amount of the product is usable, and this is unacceptable in machine design (Adetan*et al.,* 2005).

Effects of Operating Parameters on the percentage of tuber flesh loss

The variations of applied load and speed of operation of the cassava peeling machine on the percentage of tuber flesh loss of the different tuber root diameters, namely 11 - 40 mm, 41 - 70 mm and 71 - 100 mm are shown in form of surface response plot Figures 1 -3. From the figures 1 – 4, it can be seen that the percentage tuber flesh loss increases with increase in machine speed and load applied. It can therefore be concluded that the effect of peeling on tuber flesh loss is dependent on force applied on tuber, speed of operation of the machine, and time the tuber spent inside the machine before it is discharged from the outlet of peeling unit.

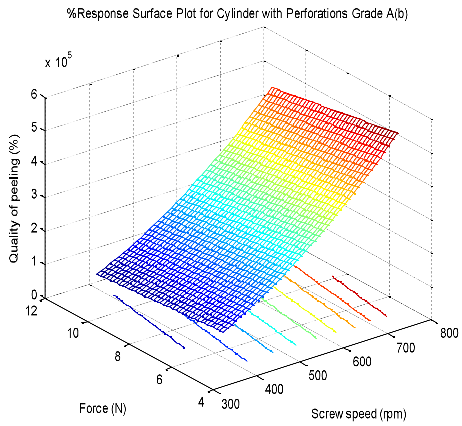
(a)



D = 11–40 mm

X_1 = 570 rpm

(b)

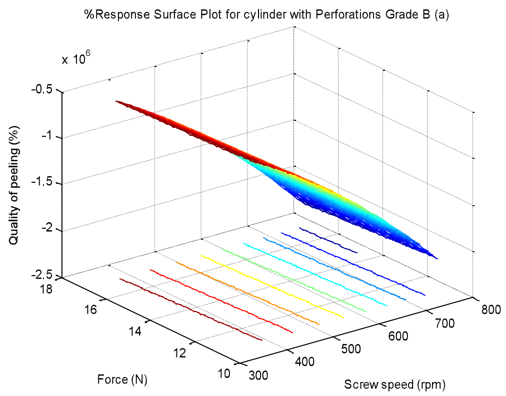


D = 11–40 mm

X_1 = 770 rpm

Figure 1: Variation of Force and Machine Speed on Percentage of tuber flesh loss (11 – 40 mm diameter) a) Load (5 - 11 N) b) Load (11 - 17 N) [D = diameter of tuber, X_1 = speed of operation, X_2 = force applied, FL = % of peel removed]

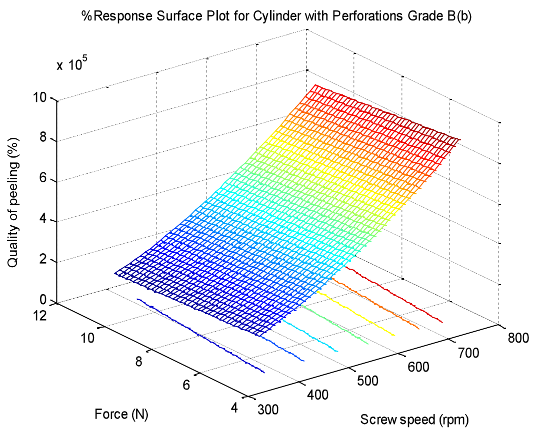
(a)



D = 41–70 mm

X_1 = 570 rpm

(b)

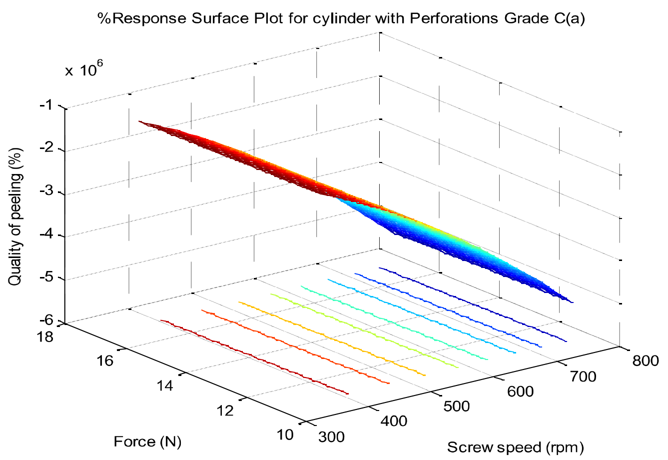


D = 41–70 mm

X_1 = 770 rpm

Figure 2: Variation of Force and Machine Speed on Percentage of tuber flesh loss (41 – 70 mm diameter) a) Load (5 - 11 N) b) Load (11 - 17 N) [D = diameter of tuber, X_1 = speed of operation, X_2 = force applied, FL = % of peel removed]

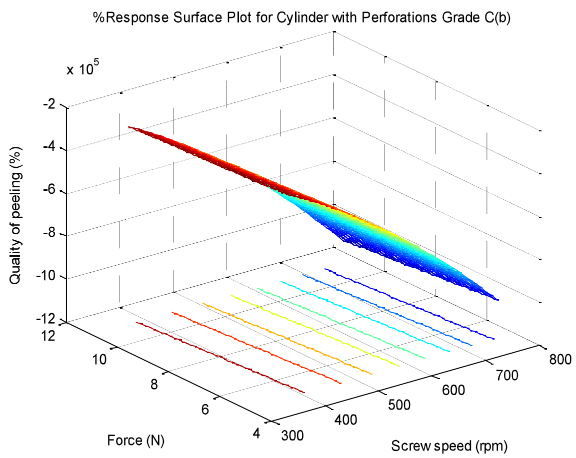
(a)



D = 71–100 mm

X_1 = 770 rpm

(b)



D = 71–100 mm

X_1 = 770 rpm

Figure 3: Variation of Force and Machine Speed on Percentage of tuber flesh loss (71 – 100 mm diameter); a) Load (5 - 11 N) b) Load (11 - 17 N) [D = diameter of tuber, X_1 = speed of operation, X_2 = force applied, FL = % of peel removed]

Model Validation of the Peeling Efficiencies of the Machine

The validation of the models developed for predicting the peeling efficiencies of the machine are shown in Figures 4.

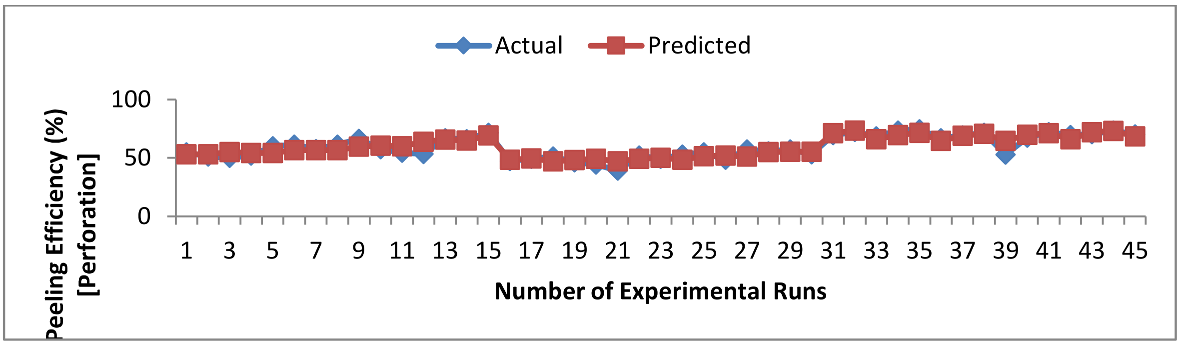


Figure 4: Validation of the Model for Predicting the Peeling Efficiency of the Machine

Model Equations for Predicting Peeling Efficiency of the Machine

The model equations for predicting the peeling efficiency of the cassava peeling machine were developed by assuming that the peeling efficiency varied as a function of the speed and the applied load on the cassava tubers subject to the 370 < speed< 770 rpm and 5 < load < 17 N as constraints. Equation 7 shows the fitted models. Also, the analysis of variance of the model for peeling efficiency prediction is shown in Table 2.

Peeling efficiency:

$$PE\ (\%) \quad = 137.49 - 0.349S + 0.534F - 0.0025SF + 0.00034S^2 + 0.0706F^2 \begin{cases} R^2 = 81.83\% \\ {R_{adj}}^2 = 75.77\% \\ {R_{pre}}^2 = 69.16\% \end{cases}$$

(7)

Where, S = operating speed of the machine (rpm), F = applied load on the tubers (N), $PE\ (\%)$ - the peeling efficiency.

Table 2 shows the analysis of variance of the quadratic model developed. The Model F-value of 13.51 implies the model is significant. There is only a 0.01% chance that a "Model F Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicating model terms are significant. In this case S, F, SF, S^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), but model reduction may improve the model.

Model Equations for Predicting the Percentage of tuber flesh loss

The model equations for predicting the percentage of tuber flesh loss, were operated under two separate load categories (5 – 11 and 11 – 19) and were fitted in Equations (8 - 13) and results obtained were used in plotting Figures 5 - 7.

Percentage tuber flesh loss (11 – 40 mm diameter)

Machine Operation under 5 – 11 N load category

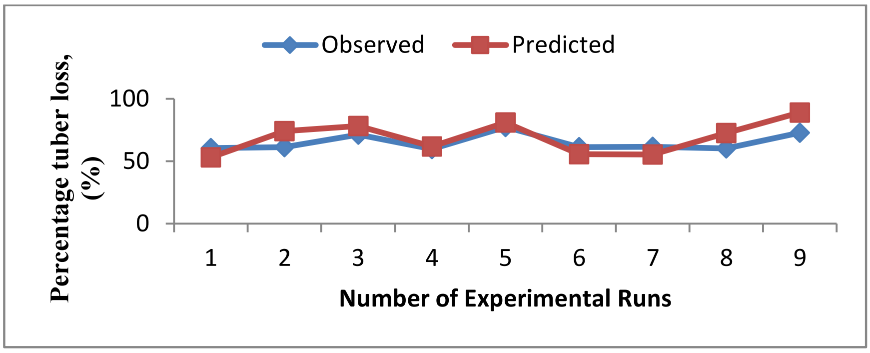
$$\%\text{Tf. loss} = 65.1810 + 2.5922S + 0.1852F - 17.1688SF - 1.2432S^2 - 1.0094F^2 + 0.4859S^2F + 2.1194\,F^2S + 2.5922S^3 + 0.1852F^3 \quad (8)$$

Machine Operation under 11 – 17 N load category

$$\%\text{Tf. loss} = 58.5946 + 6.0407S + 3.3568F - 15.1153SF + 0.9946S^2 + 1.5376F^2 + 0.3464S^2F + 0.9788\,F^2S + 6.0407S^3 + 3.3568F^3 \quad (9)$$

Validation of the Models for predicting percentage of tuber flesh loss with 11 - 40 mm diameter under 5 - 11 N and 11 - 17 N loads are shown in Figures 5.

(a)



(b)

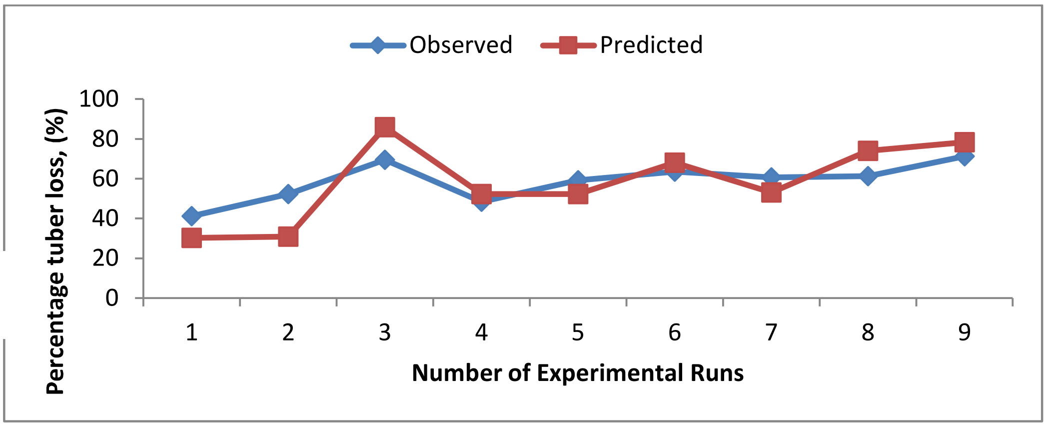


Figure 5: Model Validations of percentage tuber flesh loss with 11 - 40 mm diameter range

a) Under 11 - 17 N loading range b); under 5 - 11 N range

(ii) Percentage tuber flesh loss (41 – 70 mm diameter)

Machine Operation under 5 – 11 N load category

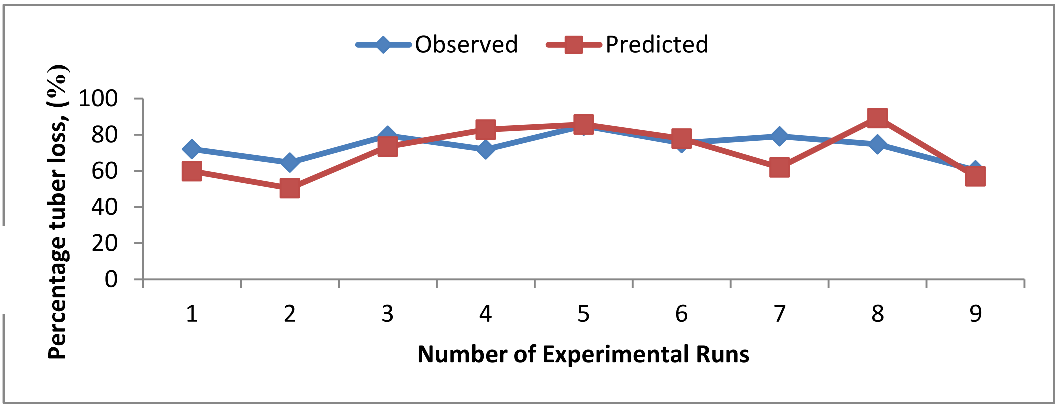
$$\%\text{Tf. loss} = 71.4184 + 1.3785S - 2.4409F - 19.5682SF - 3.3389S^2 - 5.9829F^2 - 5.8270S^2F + 0.1815\,F^2S + 1.3785S^3 - 2.4409F^3 \quad (10)$$

Machine Operation under 11 – 17 N load category

$$\%\text{Tf. loss} = 68.9971 + 2.5642S + 1.7901F - 15.6965SF + 1.5783S^2 + 0.8123F^2 + 3.4407S^2F + 1.5174\,F^2S + 2.5642S^3 + 1.7901F^3 \quad (11)$$

Validation of the Models for predicting percentage tuber flesh loss with 41-70 mm diameter under 5-11 N and 11-17 N loads are shown in Figure 6.

(a)



(b)

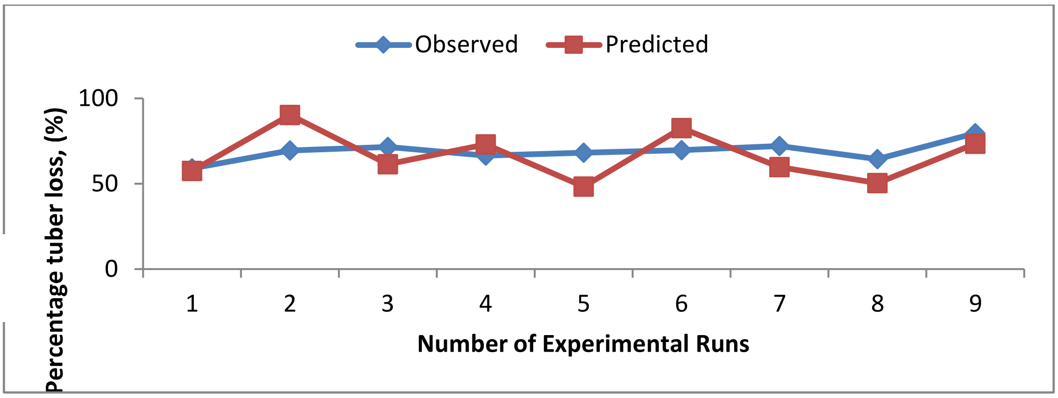


Figure 6: Model Validations of percentage tuber flesh loss with 41-70 mm diameter range

a) Under 11-17 N loading range b) under 5-11 N range

(iii) Percentage tuber flesh loss (71 – 100 mm diameter)

Machine Operation under 5 – 11 N load category

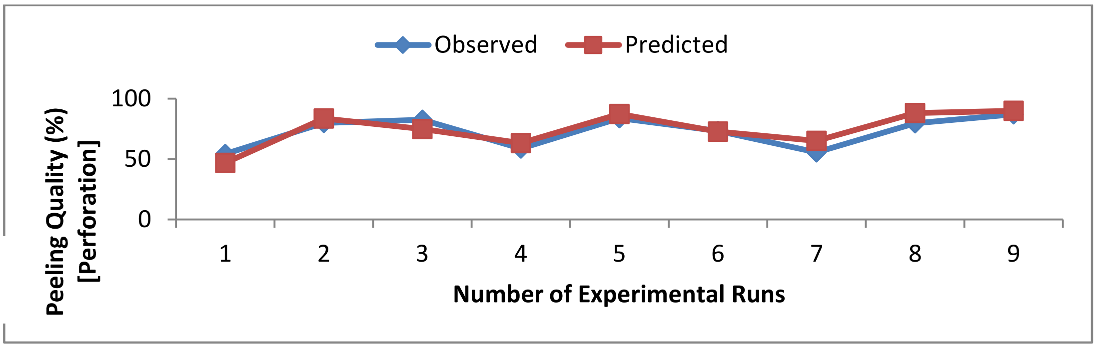
$$\%\text{Tf. loss} = 72.7852 + 8.2829S + 0.6045F - 18.3184\,SF - 8.4213S^2 + 0.7420F^2 + 0.6973S^2F + 3.4493F^2S + 8.2829S^3 + 0.6045F^3 \quad (12)$$

Machine Operation under 11 – 17 N load category

$$\%\text{Tf. loss} = 73.0995 + 7.5336S - 1.5844F - 14.4823SF - 1.6427S^2 + 3.0532F^2 - 3.7725S^2F + 0.1033F^2S + 7.5336S^3 - 1.5844F^3 \quad (13)$$

Validation of the Models for predicting percentage tuber flesh loss with 71 - 100 mm diameter under 5 - 11 N and 11 - 17 N loads are shown in Figure 7.

(a)



(b)

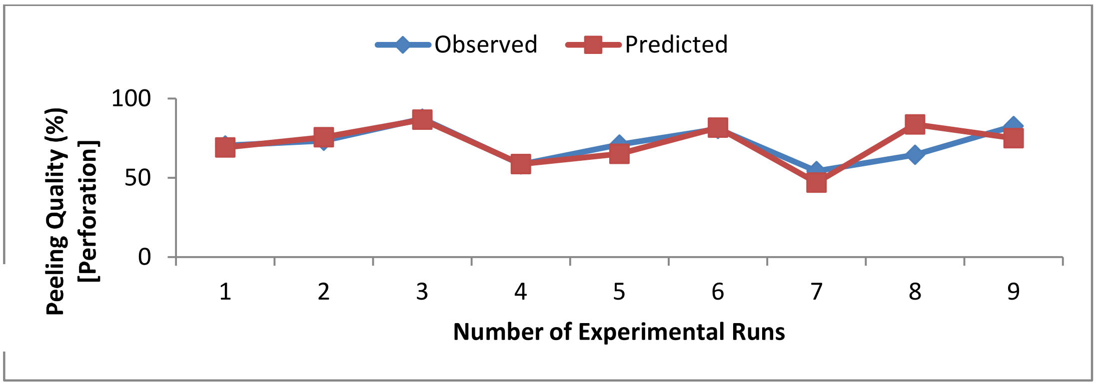


Figure 7: Model Validations of percentage tuber flesh loss with 71-100 mm diameter range

a) Under 11-17 N loading range b) under 5-11 N range

CONCLUSION

The performance evaluation of perforated type cassava peeling machine was carried out using cassava variety - TSM 82/00661 grown in Niger State, Nigeria. The machine has 420 kg/h throughput capacity. The percentage of the cassava peel removed increased with the combined effect of the speed of operation of the machine and force applied on tuber irrespective of category of the tuber diameter used. The efficiency of peeling also increases with the individual effect of speed but decreases when the applied load is above 17 N. The models developed for predicting the peeling efficiency and percentage of tuber flesh loss are adequate and valid between the predicted and the observed values.

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Table 1: Efficiency of Cassava Peeling under different Speeds and Loads

Load, N	Speed, rpm		
	370	570	770
	Efficiency, %	Efficiency, %	Efficiency, %
5	54.62	51.22	68.49
8	51.85	39.11	66.67
11	57.41	52.66	52.78
14	57.41	57.12	69.33
17	66.67	53.11	69.93

Table 2: Analysis of variance (ANOVA) of the model for peeling efficiency prediction

Source of Variation	df	SS	MS	F-Cal	P > F
Model	11	3267.59	297.05	13.51	< 0.0001*
A-Speed	1	825.41	825.41	37.54	< 0.0001
B-Load	1	269.88	269.88	12.27	0.0013
C-Cylinder	2	15.31	7.66	0.35	0.7086
AB	1	129.68	129.68	5.90	0.0208
AC	2	115.34	57.67	2.62	0.0877
BC	2	6.02	3.01	0.14	0.8726
A^2	1	1855.04	1855.04	84.36	< 0.0001
B^2	1	50.91	50.91	2.32	0.1376
Residual	33	725.64	21.99		
Cor Total	44	3993.22			

* Significant at 5 % level.