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Development and Performance Evaluation of a Double Barrel Cassava Grating Machine

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Abstract

In this study, a double barrel cassava grating machine with double discharge outlet has been developed and its performance evaluated and optimized. The machine was designed to ensure very high throughput, easy decoupling and coupling and reduction in grating time. The performance evaluation of the grating machine was carried out using Design Expert Software. A central composite rotatable design of response surface methodology (RSM) was adopted in determining the optimum operating condition of the machine. The optimum operating condition obtained from the machine shows an optimum abrasive surface hole size of 6mm, feed rate of 11.8kg/min and an optimum feed rate of 20.16 kg/min; a through put capacity of 730.8kg/hr. The average mass loss, partially grated and completely grated were found to be 1.43kg, 1.48kg and 22.09kg, respectively for 25kg sample; which indicates effective grating and waste was drastically reduced with an average grating efficiency of 86.23%.

Keywords: Double barrel; Grating; Feed rate; Grating rate; Grating efficiency.

1. Introduction

Cassava, (Manihot esculenta,crantz) is a popular crop worldwide [1, 2]. Specifically, Nigeria has been a world-leading producer of cassava with an estimated annual production of 2.6 million tons from an estimated area of 1% million hectares of land [3, 4]. It is known for drought tolerance and for thriving well on marginal soils, a cheap source of calories intake in human diet and a source of carbohydrate in animal feed, Chinsman and Fiagan [5], but need to be processed to curb post harvest losses [6-8].

Obviously, one of the key constraints to cassava production is lack of mechanisation, [9]. Oyesola [10], reported that the traditional method of grating involves placing of the local grater, made from perforated metal sheet whereby the cassava is robbed on the grater. In recent times, practical efforts has been made by different researchers in this area, Odebode [11] evaluated appropriate technology for cassava processing in Nigeria. Ndukwua and Onyenwigwe [12], developed a motorized parboiled cassava tuber shredding machine. Oriola and Raji [13], studied the trends at mechanizing cassava postharvest processing operations. Malomo, *et al.* [14] carried out performance evaluation of an automated combined cassava grater/slicer. Adetunji and Quadri [15] designed and fabricated an improved cassava grater.

Kolawole, *et al.* [16] innovatively developed cassava processing machine as solution to crisis against agricultural systems. Adekanye, *et al.* [17] carried out an assessment of cassava processing plants in Irepodun local government areas, Kwara state, Nigeria. Tambari, *et al.* [18], presented a design analysis of a reciprocating cassava sieving machine. Olawale, *et al.* [19] designed a pedal driven pulverizing and sieving machine for dewatered grated cassava. Ajao, *et al.* [20] designed and fabricated a home scale pedal- powered cassava grater. Ogunkoya, *et al.* [21] design a point of use mobile cassava grater. Oriaku, *et al.* [22] designed and carried out performance evaluation of a double action cassava grating machine.

It must be noted that cost implication should equally be taken into account which appears expensive for some designs as noted by IITA International Institute of Tropical Agriculture [23]. Other researchers come up with different designs of graters [24-27]. As regards optimization of the performance evaluation of cassava graters, not much work has been done on it.

2. Materials and Methods

2.1. Components for the Development of the Double Barrel Grating Machine

The components used for the development of the grating machine are as follows: double inlet hopper (two in one), double discharge channels, two grating barrels, transmission shaft, perforated mesh (aluminium), belts, flat

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pulley, bearings, electric motor, structural frame work, keys and key sits, adjuster metal strips, rivets, bolts and nuts and metal hinges.

2.2. Design Considerations

The considerations observed in designing this machine include: employing sanitary design principles, striving to achieve very high throughput in cassava grating, reduce grating time to the barest minimum, reduce the high labour requirement of the traditional manual and single action grating machine, designing to ensure easy decoupling, cleaning and coupling of the machine. Besides, to achieve economic viability and reduce cost, the design introduced the use of a double barrel hopper and two discharge outlets for the design.

Hopper: The hopper has is a double inlet hopper and were made of stainless steel designed such that it assumed the shape of a shelled frustum of a rectangular-based pyramid. Dimensions of the double rectangular-top of the frustum are 700mm (i.e. 340mm per one) in length and 500mm in width. The vertical height was 350mm and it was inclined at angle 60^0. The Pythagoras's theorem and the tangent rule were applied to get the slant height of the hopper.

Design principles: The design principles adopted for this machine are as follows:

- The gravitational dropping of the peeled cassava tubers from the loading platform to the grating point and exist of the pulp to the two discharge outlets.
- The continuous abrasive force (frictional force) delivered to the tubers by the rough surfaces of the rotating barrels which are achieved by the rotating actions of the pulleys, bearings, belts and shafts [28, 29].

The dropping of the cassava tubers to the grating points by gravitational force (F_g) is given by

$$F_g = mg \quad (1)$$

Where, Fg = force due to gravity, m = mass of cassava tuber, g = acceleration due to gravity

The abrasive (frictional) force (F_f) is given by the equation [30]

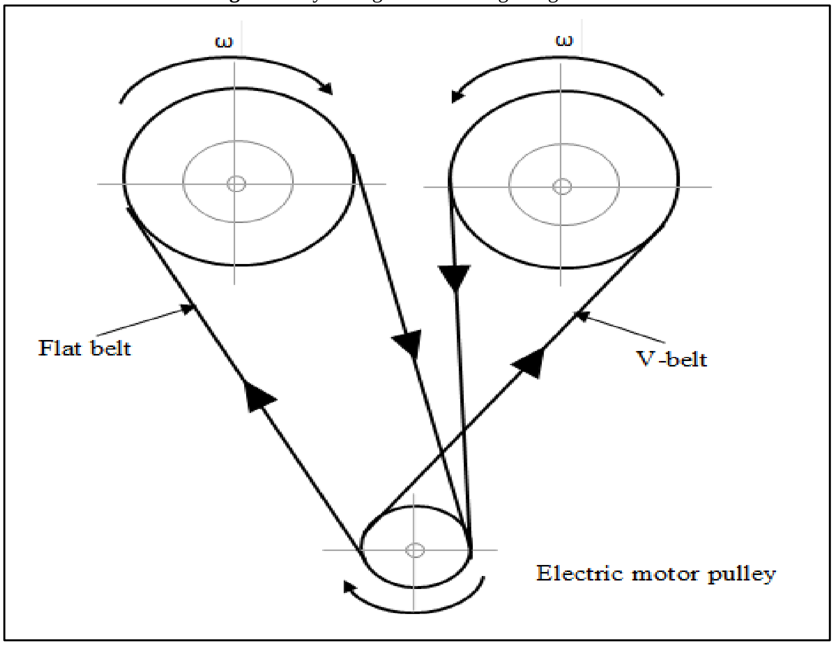
$$F_f = \mu R \quad (2)$$

For friction on an incline plane

$$F_f = \mu R = \frac{mgSin\theta}{mgCos\theta} = \tan\theta \quad (3)$$

Where, F_f = frictional force,
μ = coefficient of friction
θ = angle of friction, and
R = normal reaction

Fig-1. Pulley arrangement on the grating machine



The centrifugal force experienced by the pulleys is given by

$$F_c = Ma = M\omega^2 r = \frac{Mv^2}{r} \quad (4)$$

Where F_C = centrifugal force, M = mass of belt, ω = angular velocity, r = radius of pulley, v = linear velocity of belt.

The velocity ratio between two pulleys transmitting torque is given as noted by Evans [31]

$$\omega_1/\omega_2 = N_1/N_2 = D_2/D_1 \quad (5)$$

Where: ω_1 = angular velocity of driver pulley ω_2 = angular velocity of driven pulley
D_1= diameter of driver pulley D_2= diameter of driven pulley
N_1= rpm of driver pulley N_2= rpm of driven pulley,
Θ = angle of lap between belt and pulley

Rotational Torque (T): The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation

$T = F_C \times r$ (6)

Work done by a torque:

If a constant torque T moves through an angle θ

Work done = T * θ (7)

If the torque varies linearly from zero to a maximum value T

Work done = $^1/_2$ T*θ (8)

In general case where T = f (θ) (9)

Work done = $\int f(\theta)d\theta$ (10)

The power (P) developed by a torque T (N.M) moving at ω rad/sec is

P = Tω = 2πNT (watts) (11)

Where N is the speed in rev/min and

$\omega = \frac{2\pi N}{60}$ (12)

Tensions on Belt (T_1 and T_2): For belt transmission between two pulleys, the following equations by Hall et al., 1961 are used

$T_1/T_2 = e^{\mu\Theta}$ (13)

Also,

$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\theta}$ (14)

And, $T_c = mv^2$ (15)

$T_c = T_1/3$ i.e. $3T_c = T_1$ (16)

The power transmitted with the belt is given as

$P = (T_1 - T_2)\, v$ (17)

In this equation the power (P) is in watts, when T_1 and T_2 are in Newton and belt velocity is in metre per second.

Belt Length (L): The belt length equation is given as Khurmi and Gupta [32]:

$L = 1.57\,(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} + 2\,C$ (Open belt) (18)

$L = 1.57\,(D_1 + D_2) + \frac{(D_1 + D_2)^2}{4C} + 2\,C$ (Crossed belt) (19)

Where C = centre distance between two pulleys, D = Diameter of pulley.

Design of Shafts: The various shafts used in the design were designed according to the design pattern of Kolgiri [28], in which all the vertical loads and the horizontal loads acting on each shaft was determined. Followed determining the shear forces and bending moments. The shaft diameters will then be determined by considering the failure theories. According to Huajian [33], Burns [34], Sengupta [35] and Atiyah [36], A schematic of the shaft assembly is shown in figure 2 while figure 3 is a schematic diagram of the forces acting on it is represented schematically.

Fig-2. A Schematic of the Shaft Assembly

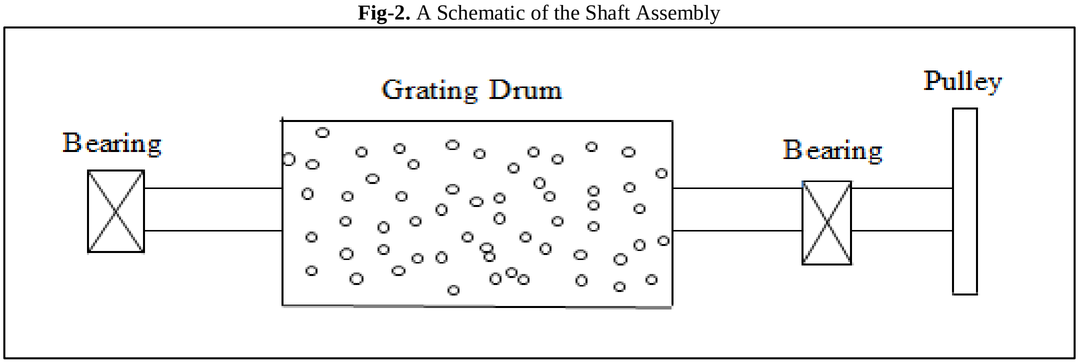
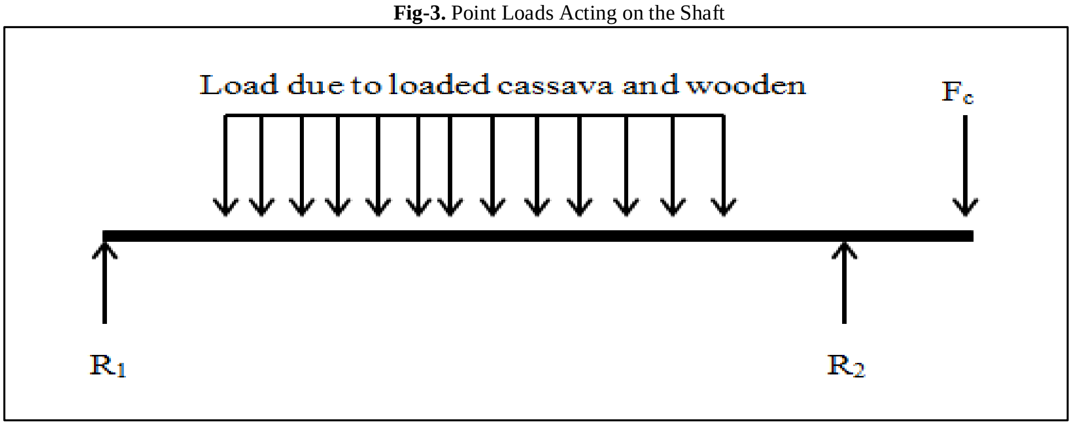


Fig-3. Point Loads Acting on the Shaft



Where, F_c = Centrifugal force,
R_1 and R_2 are Bearing reaction

From the evaluation of the forces and determination of the bearing reactions, the maximum bending moments (M_{max}) for the shaft is evaluated. The shaft diameter (D) is calculated using the ASME code standard for shafting. The ASME code equation for shafting is given as

$$D = \left\{\frac{5.1}{\tau_d}[(C_m \times M_{max})^2 + (C_t \times T)^2]^{\frac{1}{2}}\right\}^{\frac{1}{3}} \tag{20}$$

For ASME code standard, $\tau_d = 0.3б_y$ or $0.18б_u$

NB: The smaller of the two values is chosen as τ_d. The presence of key sit on the shaft reduces the value of τ_d by 75%. For rotating shafts, $C_m = 1.5$, $C_t = 1$

The Discharge Unit: The discharge unit is a continuation of the grater's frame connected to the hopper. The discharge unit directs the flow of the grated cassava to a storage pit or receptacle.

3. Description of the Developed Double Barrel Grating Machine

The developed double barrel cassava grating machine is shown in figure 4. It consists of the following components namely : Double inlet hopper (two in one), two grating barrels, two (25mm each) transmission shafts, double pulley, two bearing housings, 1hp Electric motor, structural frame work, abrasive grating mesh (two), bolts and nuts, open and crossed belts (v-belts). The machine has an overall length of 760mm, width of 520mm and a height of 1000mm. The large trapezoidal hopper has a top area of 760x520mm, base 440x600mm, and height of 300mm. The grating barrels have diameter of 150mm and a length of 420mm. And the structural frame was made with one and half inches angle iron. The wooden barrels also called the rollers have perforated alluminium steel sheet metal wrapped around it and held permanently. The perforations are very rough so as to provide the required abrasiveness for grating. The perforations were carried out on the surface area of the metal sheet before wrapping round the wooden barrel. The transmission shafts were coupled to the wooden barrel to form one rotating unit called the grating unit. The grating barrels are carried on by bearings. Through these bearings, the grating barrels were mounted on a rigid and robust structural frame work.

Figure-4. Isometric View of the Developed Double Barrel Grating Machine

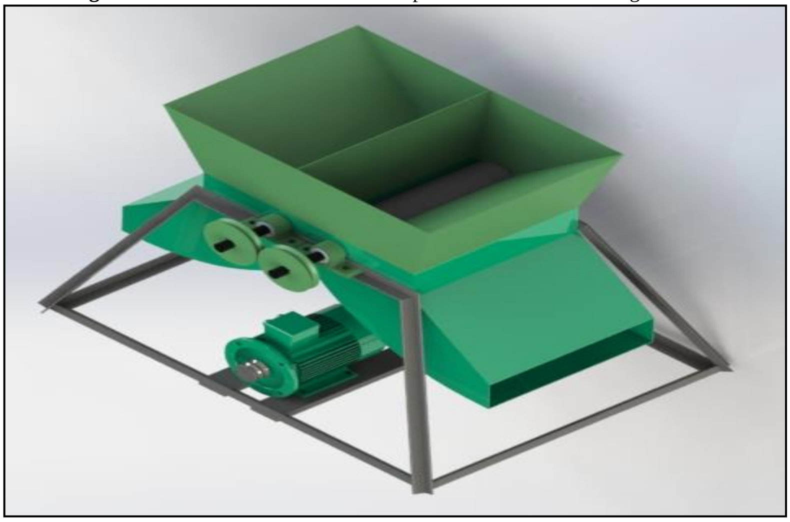
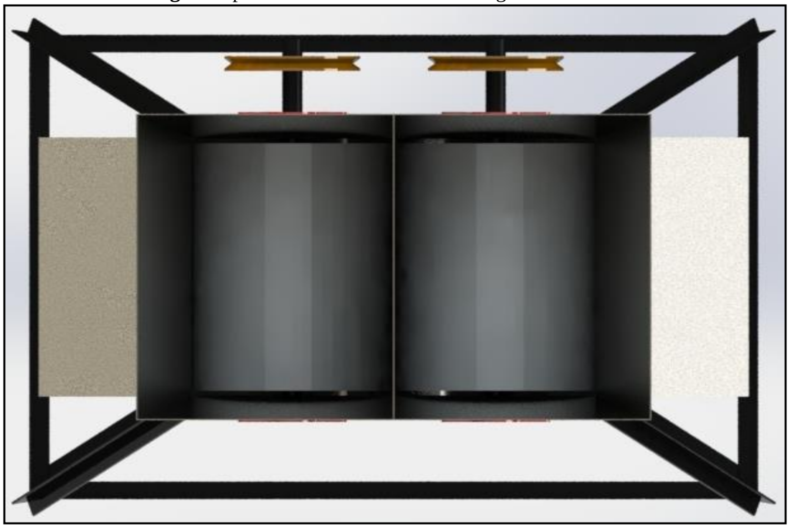


Fig-5. Top View of the Machine showing the two barrels



There are two grating barrels on this machine rotating in opposite directions as seen in figure 3. The grating barrels were mounted close to one another but separated by a mild steel plate which divided the large inlet hoppers into two separate partitions, thus, forming two different cassava tuber inlet channels to the grating points. The two grating barrels are connected together through belts and driven by electric motor. All the components of this machine are systematically assembled and are carried by a robust structural frame work.

4. Performance Evaluation of the Double Barrel Grating Machine

4.1. Design of Experiment

Design Expert software was used to evaluate and optimize the performance of the grater. The experimental design to be employed in this work will be a full factorial design. A total of 13 (i.e. 22 + 2*2 + 5) runs will be carried out using a Central Composite Response Design for the cassava samples. The response chosen is the efficiency. Five replications of centre points will was used in order to predict a good estimation of errors and testing were performed in a randomized order. The actual and coded levels of each factor comprising of feed rate and abrasive surface size will serve as independent variables. The coded values were designated by −1 (minimum), 0 (centre), +1 (maximum), −α and +α for the experiment is shown in Table 1. Alpha is defined as a distance from the centre point which can be either inside or outside the range, with the maximum value of 2n/4, where n is the number of factors. It is noteworthy to point out that the software uses the concept of the coded values for the investigation of the significant terms, thus equation in coded values was used to study the effect of the variables on the response. The empirical equation is represented thus:

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} {X^2}_i + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j \quad (21)$$

The transformation of coded value to actual value can be obtained using the equation (22):

$$X_i = \frac{x_i - \bar{x}}{\Delta x} \quad (22)$$

Where:

X_i = the coded value of i-th factor

x_i = the current actual value

$\bar{x}$ = mean value for actual values

Δx = difference between the mean actual value and actual value

Table-1. Range of Each Factor in Actual and Coded Form

Factor	Units	Low level	High level	-α	+α	0 level
Abrasive surface size (A)	Mm	5(-1)	7(+1)	4(-2)	8(+2)	6
Feed rate (B)	Kg/min	10(-1)	13(+1)	9(-2)	14(+2)	11.5

The individual run in design plan for determining the design efficiency is shown in Table 2. The performance efficiency of the double action grater for fresh cassava grating depends on the results if there is significant variation for combination of process parameters.

Table-2. Performance efficiency for each run

Run	1	2	3	4	5	6	7	8	9	10	11	12	13
% PE	75	85	78	75	68	60	77	81	83	84	78	81	83

The empirical relationship between performance efficiency (Y) and two variables in coded values obtained by using the statistical package Design-Expert for determining the levels of factors is given by the equation (23). A quadratic regression equation that fitted the data is:

$$Y = 97.16 - 1.75A + 1.22B - 6.25AB - 8.39A^2 - 6.74B^2 \quad (23)$$

Where Y is the response variable (performance efficiency) and A-B are the coded values of the independent variables. Equation (23) represents the quantitative effect of the factors (A and B) upon the response (Y). Coefficients with one factor represent the effect of that particular factor while the coefficients with more than one factor represent the interaction between those factors. Positive sign in front of the terms indicates synergistic effect while negative sign indicates antagonistic effect of the factor. The adequacy of the above proposed model was tested using the Design Expert sequential model sum of squares and the model test statistics. From the sequential test, it can be seen that the model F-value (434.27) of the quadratic model is large compared to the values for the other models for the equation. And from the statistics test, the coefficient of determination (R^2 = 0.9968) is high, and the adjusted R^2 (0.9945) is in close agreement with the predicted R^2 (0.9783) value.

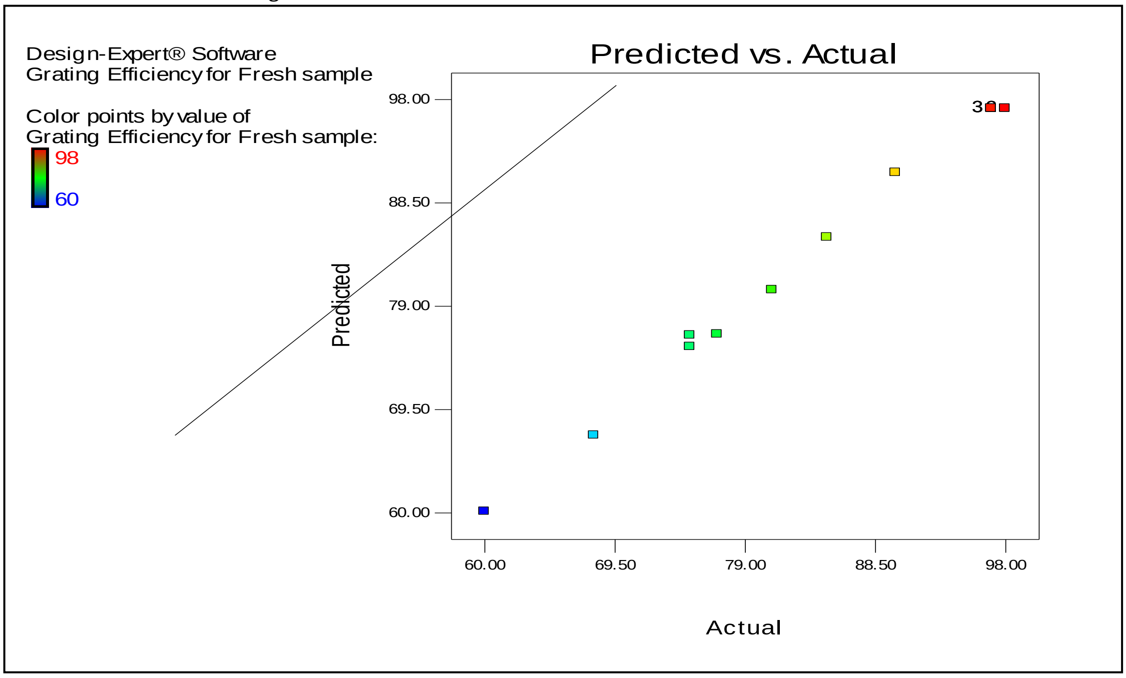
Table-3. Significance of Regression Coefficients of the Performance Efficiency of the machine

Source	Coefficient estimate	Degree of freedom	Sum of square	F-value	P-value (Prob >F)
Model	97.16	5	1978.85	434.27	< 0.0001
A	-1.78	1	36.75	40.33	0.0004
B	1.22	1	14.24	15.63	0.0055
AB	-6.25	1	156.25	171.45	<0.0001
A^2	-8.39	1	1621.29	1779.02	<0.0001
B^2	-6.74	1	521.13	571.83	< 0.0001
Residual		7	6.38		
Cor. Total		12	1985.23		

Std. Dev. = 0.95; Mean = 84.46; C.V.% = 1.13; PRESS = 43.16; R^2 = 0.9968;
Adj. R^2 = 0.9945; Pred. R^2 = 0.9783; Adeq. Precision = 57.123

The ANOVA results for the model terms are given in Table 2. Analysis of variance (ANOVA) was applied for estimating the significance of the model at 5% significance level. A model is considered significant if the p-value (significance probability value) is less than 0.05. From the p-values presented in Table 2, it can be stated that all the linear terms A and B, and interaction term AB and quadratic terms A^2, and B^2, are significant model terms. Based on this, there is no insignificant term in the model and the model remained the same as equation

Figure-6. Plot of Predicted Values Versus Actual Values for the machine



The experimental data were also analyzed to check the correlation between the experimental and predicted performance efficiency of double barrel grater, and the normal probability and residual plot, and actual and predicted plot are shown in Figure 6. It can be seen from the Figure that the data points on the plot were reasonably distributed near to the straight line, indicating a good relationship between the experimental and predicted values of the response, and that the underlying assumptions of the above analysis were appropriate. The result also suggests that the selected quadratic model was adequate in predicting the response variables for the experimental data.

4.2. 3D Response Surface and Contour Plots of the Performance Efficiency of the Machine

The 3D response surface and contour plots were generated to estimate the effect of the combinations of the independent variables on the performance efficiency. The plots are shown in Figure 7. Figure 8 shows the dependency of performance efficiency on feed rate and abrasive surface size. As can be seen from the figure, performance efficiency(%) increases as both the abrasive surface size and feed rate increased up to a point of these variables and then decreased. This could be as a result of large holes on the abrasive surface size.

Figure-7. 3D Plot showing the effect of double action grater on the cassava

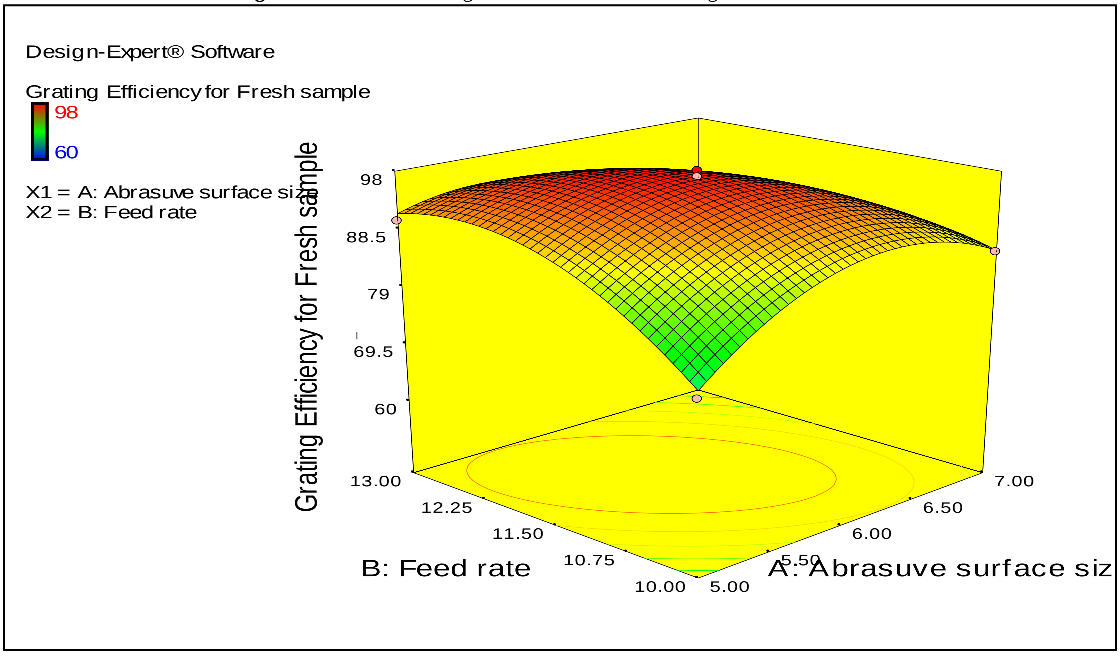
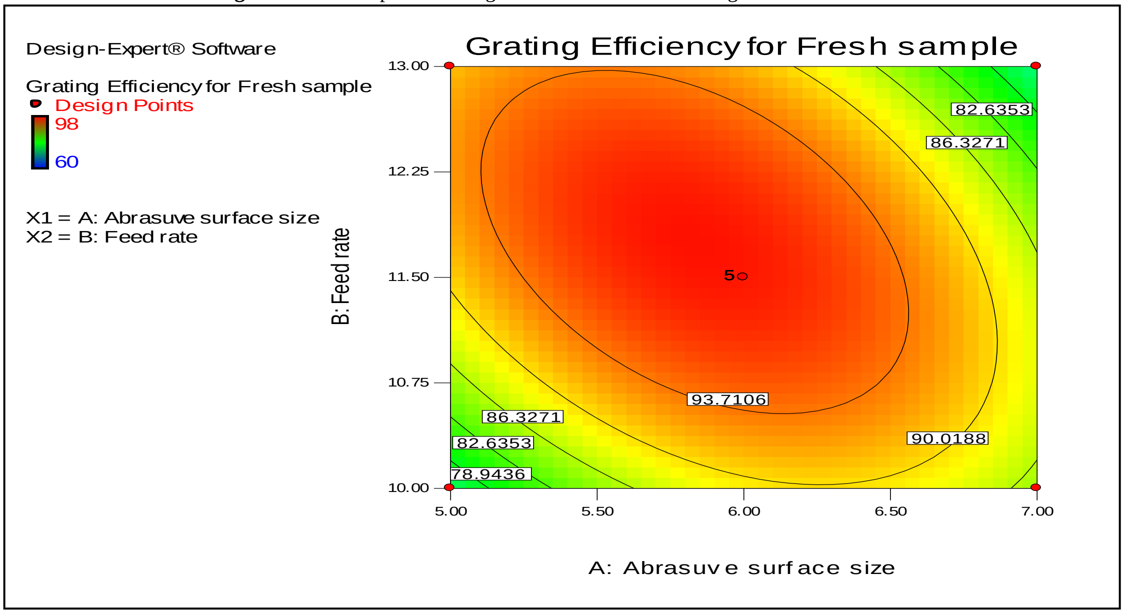


Figure-8. Contour plot showing the effect of double barrel grater on the cassava



4.3. Optimization of Double Barrel Performance Efficiencyon Fresh Cassava

The machine performance was optimized with the design expert to obtain optimal conditions for the grater. A test run under the obtained optimum operating conditions was carried out in order to evaluate the precision of the quadratic model; the measured value and predicted values are shown in Table 4. Comparing the experimental and predicted results, it can be seen that the error between the measured and predicted is less than 0.4%, therefore it can be concluded that the generated model has sufficient accurancy to predict the machine performance.

Table-4. Results of the Model Validation

Experiment	Abrasive surface sze (mm) A	Feed rate (kg/min) B	Measured Efficiency (%)	Predicted Efficiency (%)
1	6	20.16	86.23	85.67

5. Conclusion

A double barrel grating machine has been completely developed. The samples were used to carry out experiments of varying feed rate and abrasive surface hole sizes. The performance efficiency of the machine was analyzed using Design Expert software. The optimum operating condition obtained from the machine shows that the abrasive surface size of 6mm, feed rate of 11.8kg/min and an optimum feed rate of 20.16kg/min; a through put capacity of 730.8kg/hr. The average mass loss, partially grated and completely grated were found to be 1.43kg, 1.48kg and 22.09kg respectively; which indicates effective grating and waste is drastically reduced (average sample of 25 kg) with an average grating efficiency of 86.23% was obtained. These results indicate that cassava grating with large through put can be done satisfactorily by the designed machine.

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