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DEVELOPMENT AND PERFORMANCE EVALUATION OF A MOTORISED PLANTAIN CHIPPING MACHINE USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

A lot of drudgeries and unhygienic processes are involved in manual chipping of plantain. These problems necessitated the development of a motorised plantain chipping machine with a capacity of 450 kg/h. The machine is made up of a cutting device, a feeding mechanism, the support frame and an electric motor as a source of power. The cutting mechanism consists of the stainless steel blades, a connecting rod, a guide frame for the blades and pulleys. The blades are arranged perpendicular to the plantain fingers. During performance evaluation of the chipper, the effects of the number of cutting blades, inclination of the angles of the cutting blades and cutting speed as they affected the chipping efficiency were investigated. Response Surface Methodology was used in the experiments because it uses very few experimental runs to describe how the test variables affect the response. It also helps to determine the inter-relationships among the test variables on the response and also helps to describe the combined effects of all the test variables on the response. The highest chipping efficiency of 70% was obtained when the machine was operated at the speed of 975 rpm, with a blade angle inclination of 30^0 and with nine cutting blades. Generally, it was found that the chipping efficiency increased as the number of cutting blades are increased. Also the chipping efficiency increased with the speed of the machine but was not affected by the inclination angles of the blades. The linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability.

Keywords: Plantain chipping machine, Chipping efficiency, Cutting speed, Response surface methodology.

INTRODUCTION

Plantain is a basic food crop in developing countries, especially in Africa. Plantain belongs to the family *Musa Spp.* and species of *Musa paradisiacal* and it originated from Southern Asia, Arisa, *et al.*, 2013. In some parts of Africa such as Nigeria and Ghana, plantains are dried and made into flour. Plantain contains the following in the diet of man; water 10.62% protein 3.55%, fat 1.15%, carbohydrate 81.67% and ash 3.01% Arisa *et al.*, 2013. Plantain is a type of banana which is common in tropical regions. It is starchier and less sweet when compared to bananas. Plantains are usually served steamed, boiled or fried, although ripe plantains can be eaten raw. They are a rich source of antioxidants, vitamin B-6 and minerals, and their soluble fibre content may help ward off intestinal problems, www.healthy eating.com (2020). Plantain for local consumption plays an important role in food and income security and has the potential to contribute to national food security and reduce rural poverty Arisa, *et al.*, 2013. Plantains provide the essential minerals that help the body to function efficiently. A 50 g of sliced or cooked plantain has 49 mg of magnesium and 716 mg of potassium, giving the body 15 percent of the recommended daily intake for each of these minerals (www.healthline.com plantain 2020). The body needs magnesium for proper muscle contraction and nerve function, while potassium is a crucial component in the body fluids. A cup 50 g of plantain flour contains 5 to 10 percent of the iron need of the body. Iron helps to carry oxygen through the bloodstream which serves as a benefit to the muscles of the body. Although raw plantain is bitter and starchy, some people like them raw. They are more nutritious raw, with about 10 percent more magnesium, phosphorus and potassium. A cup of 50 g raw plantains has 27 mg of thiamine, a B-vitamin that helps the body's cells use carbohydrates as energy and helps ensure the proper functioning of the heart muscles and the nervous system, www.healthy eating.com (2020). Plantain processed into flour can be stored for up to a maximum of two years, Arisa, *et al.*, 2013. The ripe fruit is pureed, candied, and preserved in various forms when not eaten fresh. The extracts are used in the manufacture of catsup, vinegar, and wine. The unripe fruit can be powdered or chipped.

Slicing operation is achieved by cutting, which involves rotation of thin sharp blade with different configurations and speeds through the materials resulting in minimum rupture and deformation of the materials (Raji and Igbeka, 1994). Reducing the size of food raw materials is an important operation to achieve a definite size range (Henderson and Perry, 1980). The traditional method of cutting plantains into chips has been observed to cause drudgeries, prone to finger injury, time consuming, produces irregular sized chips, and inevitably leads to low output by processors. The existing plantain chipping machines when tested, were found to produce irregular sizes, broken and discoloured chips which make the products unacceptable. The most common methods of chipping plantain in our localities today include the use of knife, wooden platform plantain slicer, and metal cutter. These methods have a lot of deficiencies in terms of chipping efficiency, quality and safety. In view of these, there is need to improve on the existing plantain chipping machines. The purpose of the machine is to make chipping process less laborious especially for medium scale industries and for domestic purposes. The objectives of this study therefore include; to design and fabricate a motorized small scale plantain chipper and test the developed chipper for performance during operation. and to analyse the experimental results obtained using Response Surface Methodology (RSM).Response surface methodology was adopted in the experiments because it uses very few experimental runs to describe how the test variables affect the response. It also helps to determine the inter-relationships among the test variables on the response and also helps to describe the combined effects of all the test variables on the response Agriga and Iwe (2008).

MATERIALS AND METHODS

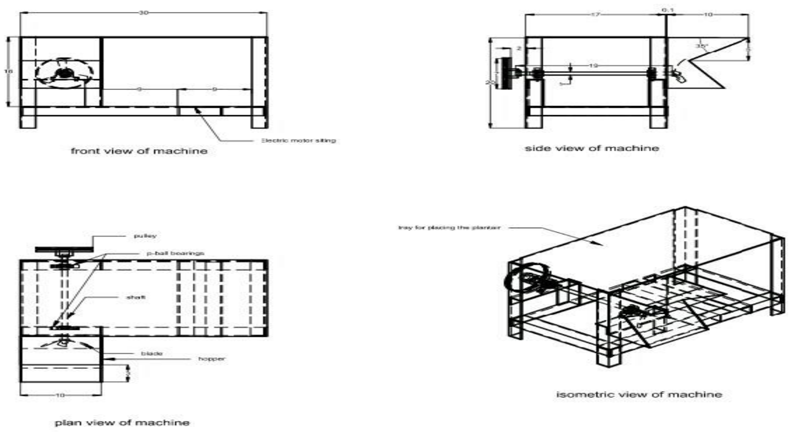
Design Considerations

The following considerations were made during the development of the machine: Develop a machine that can produce uniform size chips without discoloration.

Develop a machine that is smooth in operation with little noise, rigid and reliable in operation and also use locally available materials for its construction.

Description of the Machine

The machine is made up of a cutting device, a feeding mechanism, the support frame and an electric motor as a source of power. The cutting mechanism consists of the stainless steel blades, a connecting rod, a guide frame for the blades and pulleys. The blades are arranged perpendicular to the plantain fingers. The feeding and the discharge mechanisms consist mainly of the Geneva drive mechanism meant to deliver intermittent motion to the conveyor, thereby causing the conveyor to move in a start-stop fashion. The drive shaft is supported by two ball bearings mounted on the base frame and which provide support for both radial and thrust loads. Plantains are fed into the hopper were they are discharged into the cutting chamber and are chipped by the cutting blades. The chips are discharged underneath the machine and are collected on a collector plate. Fig. 1 shows the orthographic drawing of the machine, while Fig. 2 shows the pictorial view of the plantain chipper.



Project	PLANTAIN CHIPPING MACHINE
SCALE	1:10
UNIT	MILLIMETRES

Fig 1: Orthographic View of the Plantain Chipping Machine

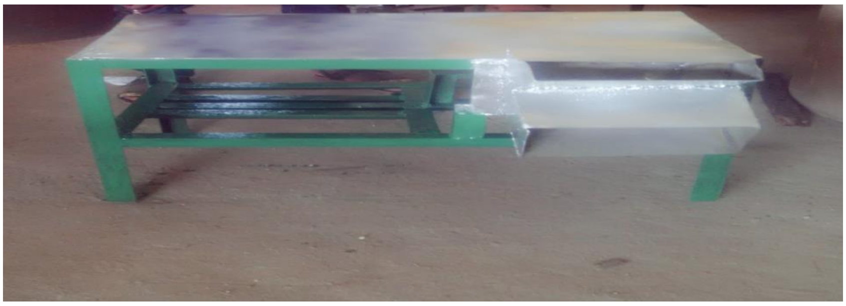


Fig 2: The Pictorial View of the Plantain Chipping Machine

Design Analysis

Volume of hopper:

The hopper is triangular prism in shape and tilts at an angle at the base towards the cutting disc or flywheel. This triangular prism shape of the hopper is also maintained in the discharge chute. This concept is preferred because of the concept of repose angle and the coefficient of friction of plantain which must be maintained for it to freely fall into the flywheel. The angle repose of plantain was experimentally determined to be 30^0 .

$V_{intake} = \frac{1}{2} a \times c \times h$ (1)

a = 17.78 cm

c = 20 cm

h = 22.86 cm

Where

V_{intake} = the volume at the intake chute

$\frac{1}{2} a \times c$ Is the base area of the triangular prism (2) $\emptyset$

h is the height of the prism

Therefore;
$V_{intake} = \frac{1}{2}\ 17.78 \times 20 \times 22.86$
(3)

V_{intake} = 8129.016 cm^3

The hopper is half a prism, hence:

0.5 $V_{intake} = 0.5 \times 8129.016$ = 4064.5 cm^3
(4)

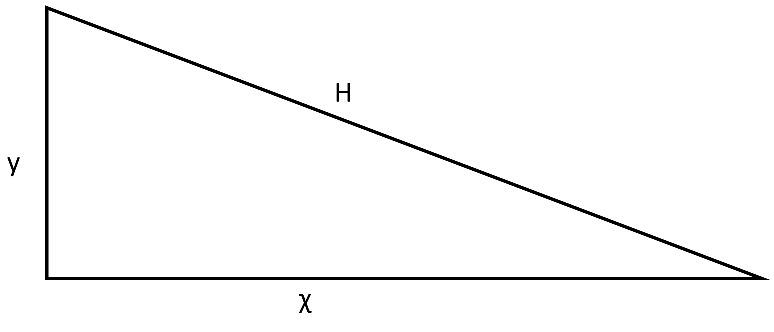


Fig 3: Relative Dimensions of the Hopper

Repose angle$\emptyset$:

This is the angle at which the plantain will slide down the slope of the hopper as shown in Fig.3

Repose angle $\emptyset$ $= tan^{-1}\left(\frac{y}{\chi}\right)$
(5)

Width of hopper = 22.86cm

$X = 17.78cm$

$Y = ?$

$H = 20.32$

Using Pythagoras theorem,

$y^2 = H^2 - x^2$ = $y^2 = 20.32^2 - 17.78^2$
(6)

$y^2 = 96.77339$; $y = 9.8373772 \cong 10cm$ (7)

Therefore,

Repose angle $\emptyset = tan^{-1}(\mathbf{10}/\mathbf{17.78})$ **(8)**

$\emptyset = tan^{-1}$ (10.363) = 30^0 (9)

Area of sliding surface (As):

$As = width \times Height\ (H) = 22.86 \times 20.32$ (10)

$Area = 464.51cm^2$ (11)

Assumed surface area of a finger of plantain from average measurement of width and length of various plantains of different species (Asoegwu *et al.*,1998)

$Width = 5.08cm$

$Height\ (H) = 22.86cm$

$Area\ of\ plantain\ (Ap) = 5.08 \times 22.86 = 116.1288cm^2$ (12)

***Area of Tray (At)*;**

$Length\ of\ tray\ Lt = 76.2cm$

$Breath\ of\ trayBt = 43.18cm$

$\boldsymbol{At} = Lt \times Bt = 76.2 \times 43.18$ $\boldsymbol{At} = 3290.316cm^2$ (13)

Diameter of the shaft

The drive shaft diameter was obtained using the expression outlined by Singh (2001) and is given as;

$$\mathbf{d^3 = 16/\pi\tau_{max}\sqrt{(M_bK_b)^2 + (M_tK_t)^2}}$$ **(13)**

Where
Mt = torsional moment (136.05Nm)
Kb = combined shock and fatique factors applied to bending
Kt = combined shock and fatique factors applied to torsional moment
Mb = bending moment
τ_{max} = allowable shear stress.(40 MN/m^2)
The diameter of the slicer blade shaft was obtained as 22 mm

Cutting blade

This is an integral part of the machine that slices the plantain. The size of chips is influenced by the cutting clearance. The clearance between the blade and the hopper is kept at $5.18cm$.

Belt:

Effective length of belt can be gotten using the formula outlined by Khurmi and Gupta (2005) as;

$$L_e = 2c + 1.57(D + d) + \left(D - d/_{4c}\right)^2$$ (14)

C = 41.91cm

D = 20.48cm

d = 16.51cm

Where;

L_e = the effective belt length (cm)

C = the design distance between the two pulleys (D and d)

D = the diameter of the driver pulley (cm)

$$L_e = 2(41.91) + 1.57(20.48 + 16.51) + \left(20.48 - 16.5/_{4(41.91)}\right)^2$$

$$L_e = 140.67cm$$

Capacity of the Machine

The machine is designed to cut a whole plantain in 4seconds. That is;

Capacity of the machine = 1 whole plantain chipped in 4 seconds. A whole plantain weighs about 500 g. This translates to 7500 g per minute or 450 kg/h.

Experimental Design

After the fabrication of the machine its operational performance was evaluated. A Faced Centred Response Surface Methodology using Central Composite Design was used to design the experiments. This method is useful because it uses very few experimental runs to describe how the test variables affect the response. It also helps to determine the inter-relationships among the test variables on the response and also helps to describe the combined effects of all the test variables on the response (Agriga and Iwe 2008). In the tests, three factors, namely speed of the machine, the number of blades and the inclination angle of the chipping blades were investigated as they affected the chipping efficiency of the machine. The regression analysis was carried out with Minitab 16 software, while the response surface graphs were plotted with Matlab R2015a software.

The chipping efficiency of the machine was obtained using the method outlined by Ndirika and Onwualu 2016 as;

$$Y = \frac{M - C}{M} \times 100 \qquad (15)$$

Where, Y = chipping efficiency in percentage (%),

M = weight of plantains fed into the machine (gms)

C = weight of unchipped plantains (gms)

In the design the linear, interactive and quadratic effects of the factors (independent variables) as they affect the response (chipping efficiency) were studied (Agriga 2008). Three levels of each of the factors were studied. They are listed as follows;

(i) Three different speeds of the machine, namely;
   a. 325 rpm (b) 650 rpm (c) 975 rpm

(ii) Three different inclination angles of the blades, namely;
   a. 30^0 (b) 45^0 (c) 60^0

(iii) Three different numbers of chipping blades, namely;
   a. 3 blades (b) 6 blades (c) 9 blades

The experimental variables and coding are shown in Table 1, while the experimental results with the independent variables (in coded terms) are shown in Table 2.

Table 1: Experimental Variables Used in the Design

Independent Variables	Variable Levels		
Speed of machine (rpm), X1	325	650	975
Blade inclination angles, X2	30^0	45^0	60^0
Number of chipping blades, X3	3	6	9
Code Designation	-1	0	1
Dependent Variable (Response)			
Chipping Efficiency (%) Y			

The coding using the design is as follows; 1 = highest factor, 0 = medium factor and -1 =lowest factor

Table 2: Experimental Results of Independent Variables and Response in Coded Terms

Runs	X1	X2	X3	Y
1	0	0	0	60
2	-1	0	0	47
3	-1	1	1	56
4	1	1	-1	58
5	1	-1	1	70
6	-1	-1	1	59
7	1	1	1	68
8	0	1	0	50
9	0	-1	0	46
10	0	0	0	50
11	-1	1	-1	47
12	0	0	0	49
13	0	0	0	48
14	0	0	0	50
15	1	-1	-1	67
16	1	0	0	67
17	0	0	-1	57
18	-1	-1	-1	46
19	0	0	0	48
20	0	0	1	68

RESULTS AND DISCUSSIONS

Table 3 : Response Surface Regression: Y versus X1, X2, X3

Term	Coef	SE Coef	T	P
Constant	51.8455	1.458	35.570	0.000
X1	7.5000	1.341	5.594	0.000
X2	-0.9000	1.341	-0.671	0.517
X3	4.6000	1.341	3.431	0.006
X1*X1	3.6364	2.557	1.422	0.185
X2*X2	-5.3636	2.557	-2.098	0.062
X3*X3	9.1364	2.557	3.573	0.005
X1*X2	-1.1250	1.499	-0.750	0.470
X1*X3	-1.1250	1.499	-0.750	0.470
X2*X3	0.3750	1.499	0.250	0.808
S = 4.23983				
R – Sq = 87.15%				

The regression equation is given as;

Y=51.85+7.50X1-0.90X2+4.60X3+3.64X1^2-5.36X2^2+9.14X3^2-1.13X1X2-1.13X1X3+0.38X2X3 (16)

Where Coef = regression coefficients, SE Coef = Standard error of regression coefficient
T = Tabulated values of the regression parameters,
P = Probability values of the regression terms, S = Standard error , R = R-squared (A standardized measure of the goodness of fit of the regression model)

The regression equation (16) was generated by the software and shows the actual numerical values of the independent variables as they affected the response.

Table 4 : Analysis of Variance for Y

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1219.19	1219.19	135.465	7.54	0.002
Linear	3	782.20	782.20	260.733	14.50	0.001
X1	1	562.50	562.50	562.500	31.29	0.000
X2	1	8.10	8.10	8.100	0.45	0.517
X3	1	211.60	211.60	211.600	11.77	0.006
Square	3	415.61	415.61	138.538	7.71	0.006
X1*X1	1	174.05	36.36	36.364	2.02	0.185
X2*X2	1	12.01	79.11	79.114	4.40	0.062
X3*X3	1	229.55	229.55	229.551	12.77	0.005
Interaction	3	21.38	21.38	7.125	0.40	0.759
X1*X2	1	10.13	10.13	10.125	0.56	0.470
X1*X3	1	10.12	10.12	10.125	0.56	0.470
X2*X3	1	1.12	1.12	1.125	0.06	0.808
Residual Error	10	179.76	179.76	17.976		
Lack-of-Fit	5	74.93	74.93	14.986	0.71	0.639
Pure Error	5	104.83	104.83	20.967		
Total	19	1398.95				

The estimated regression coefficients for chipping efficiency versus speed of the machine, blade inclination angle and the number of blades are shown in Table 3, while the analysis of variance associated with the regression are shown in Table 4. From Table 3, the linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability, ($P \leq 0.05$). These factors accounted for 87.15% of the variation in the chipping efficiency of the machine (from R-Sq value). The analysis variance Table 4 also confirms the results. From the response surface graph in Fig. 4 the chipping efficiency increased with, the speed of the machine but decreased as the cutting blade angle is increased. From the response surface plot in Fig. 5 the chipping efficiency increased as the number of cutting blades are increased. Also, the chipping efficiency increased with the speed of the machine. From Fig. 6, the chipping efficiency increased with the number of cutting blades. However, the chipping efficiency was not significantly affected by the blades inclination angles.

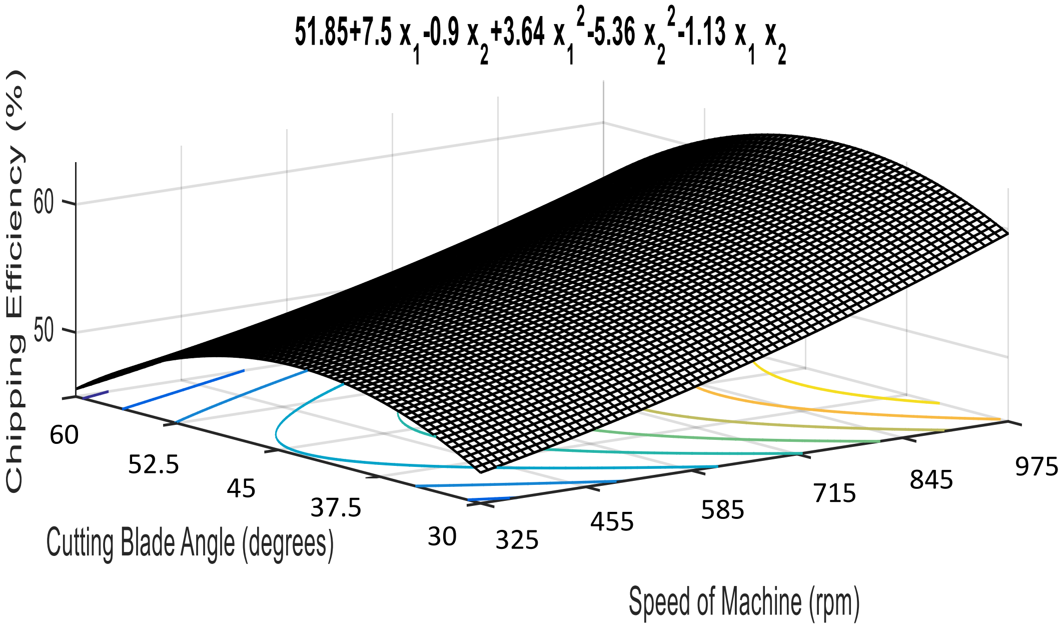


Fig 4: Response Surface Curve of the Effect of Cutting Blade Angle and Speed of Machine on the Chipping Efficiency of the Machine

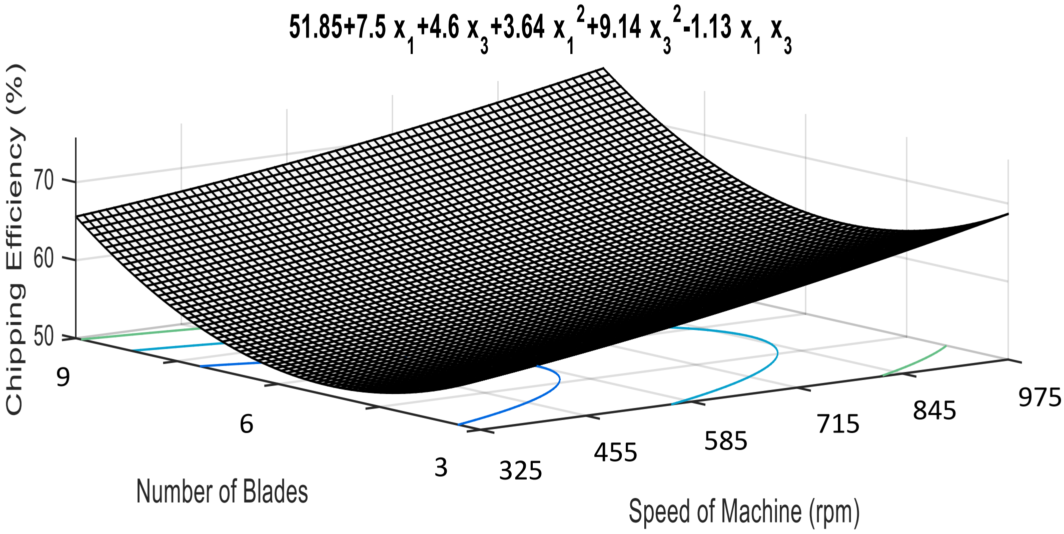


Fig 5: Response Surface Curve of the Effect of Number of Blades and Speed of Machine on the Chipping Efficiency of the Machine

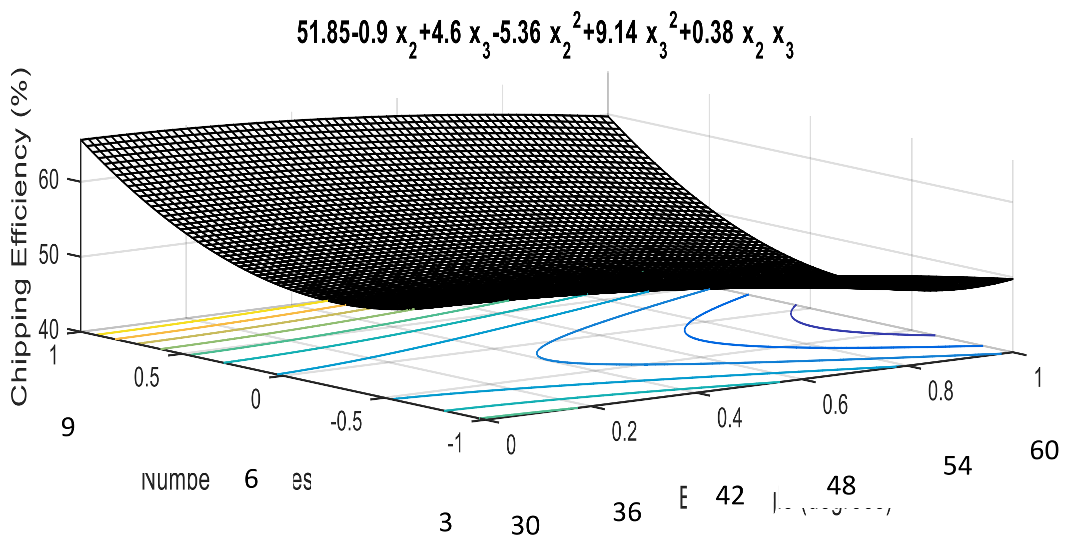


Fig 6 : Response Surface Curve of the Effect of Number of Blades and Cutting Blade Angle on the Chipping Efficiency of the Machine

CONCLUSION

A plantain chipping machine of 450 kg/h was developed. The machine performed satisfactorily during tests. The highest chipping efficiency of 70% was obtained when the machine was operated at the speed of 975 rpm, with a blade angle inclination of 30^0 and with nine chipping blades. It was also observed that the machine produced uniform sized chips without discoloration and maintained good ergonomic characteristics in terms of noise and vibrations. The chipping efficiency increased as the number of cutting blades are increased. Also the chipping efficiency increased with the speed of the machine but was not affected by the inclination angles of the blades. The linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability.

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