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Development and Performance Evaluation of a Reciprocating Motion Cassava Shredder

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--ABSTRACT--
A reciprocating motion cassava shredder was designed, fabricated and evaluated. The machine consists essentially of a hopper where peeled cassava roots are put. Directly beneath the hopper is the shredding plate coupled to a horizontal shaft which when in operation undergoes reciprocating motion. The shredding plate is enclosed within the collector assembly. The horizontal shaft derives its motion through a slider and crank mechanism coupled to an electric motor via a belt drive with a pulley for primary speed reduction and regulation. A rugged framework is provided for mounting the machine and electric motor. The capacity of the machine is 320kg/hr. Experimental evaluation results showed that the size of the shredding aperture of the machine significantly affected the shredding efficiency of the machine. The shredding efficiency of the machine decreased with increasing shredding aperture, but increased with shredding speed. Maximum shredding efficiency of 92% was obtained when the shred aperture was 3mm and the shredding speed was 975rpm. The throughput capacity of the machine increased with speed of shredding with a maximum value of 319.89kg/hr at 975rpm and a minimum value of 301.54kg/hr at 325rpm.

KEYWORDS: *cassava,shredder,reciprocating,motion,shredding efficiency,throughput capacity*

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I. INTRODUCTION.

Cassava is one of the most important crops in Africa. It belongs to *Plantae* kingdom, *Euphorbiaceae* family and genus *Manihot* (FAO 1995). It is the third largest source of food carbohydrates in the tropics after rice and maize. (Olsen and Schael 1999). The leaves and tender shoots of cassava are also consumed as vegetables that are rich in vitamins and proteins (Krochmal and Hahn, 1991).Over two thirds of the total production of the cassava crop is consumed in various forms by humans and livestock. Its usage as a source of ethanol for fuel, energy in animal feed, and starch for industry is increasing. The crop is amenable to agronomic as well as genetic improvement, has a high yield potential under good conditions and performs better than other crops under sub optimal conditions. It is grown widely in several countries in sub-Saharan Africa and Madagascar. It was introduced into Africa in the latter half of the 16th century from South America. Nigeria is rated as the world largest producer of cassava, (IITA, 1990).Cassava is classified as sweet or bitter. Like other root and tubers cassava contains antinutritional factors and toxins. It must be properly prepared before consumption. Improper preparation of cassava can leave enough residual cyanide to cause acute cyanide intoxication, paralysis and death (FAO 1990). Storage of fresh cassava roots is often unsatisfactory because of high spoilage rate and deterioration of quality of the stored whole roots with time (Jeon and Halos, 1991). Cutting of cassava tubers into small chips or shreds is an efficient way to aid drying. Drying provides a solution to maintain the quality of roots and improves the storability of the products. Chipping has been found to hasten the drying rate and improve the quality of the product (Rupert, 1979).

Shredding is a size reduction process (Brennan and Butters, 1981).Therefore shredding has potentials to improve cassava products quality, even though the process is not widely used in cassava processing. Reducing the size of the roots to be processed into a food product which requires fermentation and drying has been recognized as an effective method of reducing processing time and improving the product quality (Jeon and Halos, 1991). Cassava shreds known within the Eastern parts of Nigeria as *Ighu*, *Nsisa* or *Abacha* are a local delicacy. It is made from peeled and shredded cassava roots, after steaming and fermentation for about 24 hours. The product is then washed and eaten as a snack or made into a main meal or dried for storage. Cassava shredding is still done manually. Peeled and steamed cassava is moved vigorously by hand over metallic shredding plates to effect the shredding action, or by the use of kitchen knives. The mechanization of cassava shredding introduces changes in the quality characteristics of the shreds produced. The nature of these changes will depend on the interaction of the machine, process and raw material variables.Hence the objective of this work is to design and fabricate a reciprocating motion cassava shredder that will be suitable for small scale cassava shreds (A*bacha*) production and evaluate the machine for performance during testing.

II. MATERIALS AND METHODS

2.1 Design Considerations

The following factors were considered for successful design, fabrication and operation of the machine

2.1.1 Mechanical Factors

[1] Strength, rigidity and simplicity of materials for the construction of the machine.
[2] The shredder should accommodate different speeds of operation.
[3] The hopper is to be designed in such a way as to accommodate different sizes of cassava tubers available locally.
[4] The shredding plate must be made of stainless steel plate for food hygiene purposes.
[5] The sizes of the shredding holes will be such as to produce desired size of cassava shreds.
[6] The collector should be designed in such a way as to collect all the shredded cassava and not allow them to be thrown away or to fall on the floor.
[7] The shredding plate must be designed to use reciprocating motion for its operation as it is done traditionally to achieve uniform sized shreds.
[8] The machine will be coated with non toxic corrosion resistant paints to avoid rust.
[9] The machine should be serviceable.
[10] The noise level of the machine should be low.

2.1.2 Operational Factors

[1] The cassava root shredder should ensure uniformity of shreds produced.
[2] The capacity of the machine should be high enough to achieve fast processing of the cassava roots.

2.1.3 Economic Factors

The economic factors considered in the development of the motorized cassava shredder were:
[1] Availability and the cost of its construction materials.
[2] Manufacturing methods employed in its fabrication.

2.2 Description of the Motorized Cassava Shredding Machine

The machine consists essentially of a hopper where peeled cassava roots are put. Directly beneath the hopper is the shredding plate coupled to a horizontal shaft which when in operation undergoes reciprocating motion. The shredding plate is enclosed within the collector assembly. The horizontal shaft derives its motion through a slider and crank mechanism coupled to an electric motor via a belt drive with a pulley for primary speed reduction and regulation. A rugged framework is provided for mounting the machine and electric motor. The capacity of the machine is 320kg/hr. The isometric and orthographic drawings of the machine are shown in Figures 1 and 2. Plate 1 shows the developed machine, while plate 2 shows cassava shreds produced with the machine.

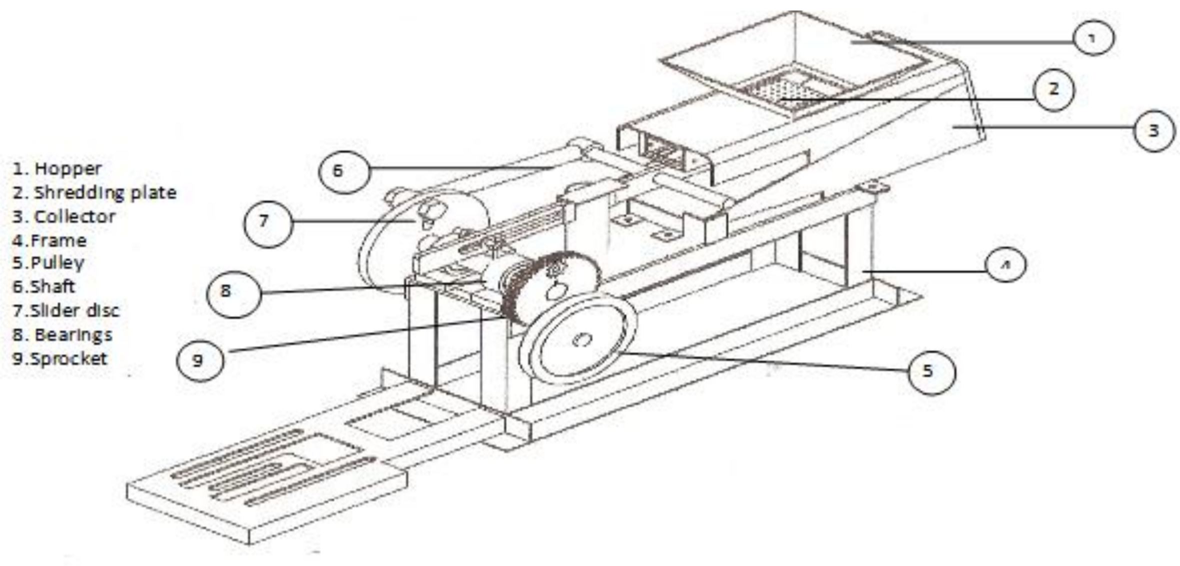

Fig 1: Isometric Drawing of the Cassava Shredding Machine

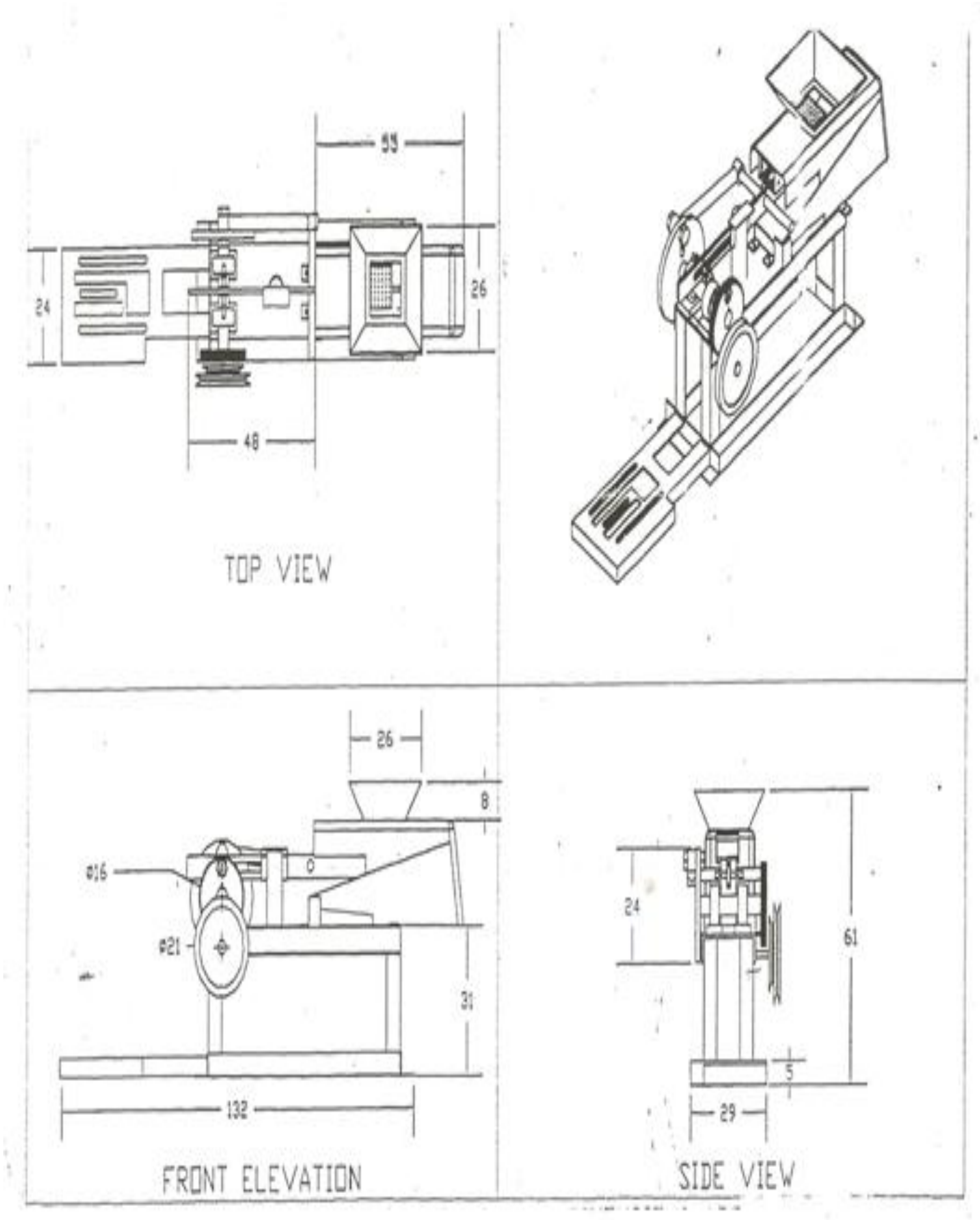

Fig 2: Orthographic Projection of The Cassava Shredder

Force Required to Shred the Cassava Tuber

To determine the force required to shred a cassava root, the following experiment was performed.

Plate 1: The Developed Machine

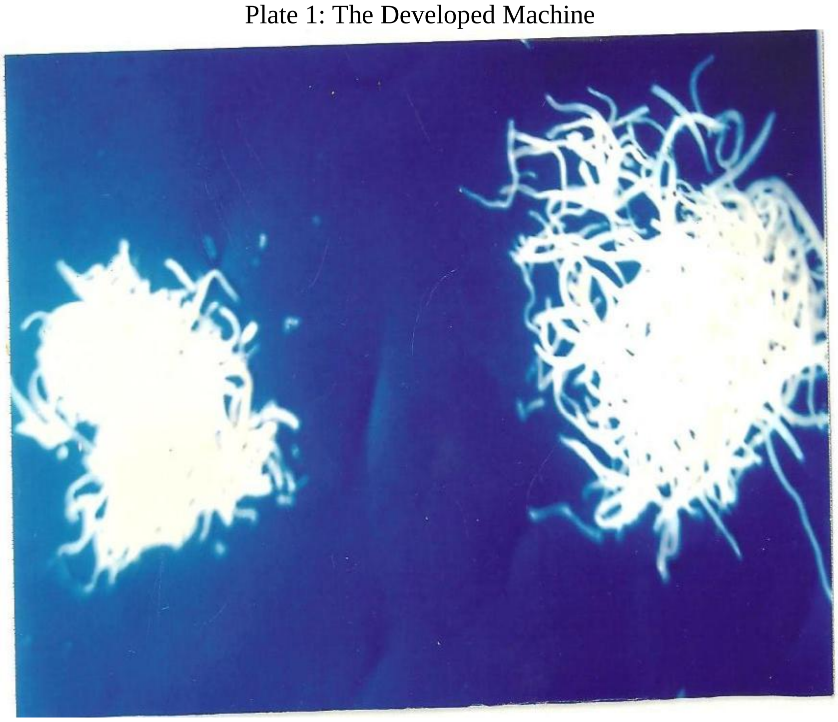

Plate 2: Shredded Cassava Samples Produced By the Machine

2.3 Design Analysis.

Freshly harvested root was peeled and washed. The peeled root was attached to a spring balance by tying an end of the cassava root to the end of the spring balance hook, with a binding wire.The cassava root was then dragged on top of a stationery shredding plate. When the root skin begins to shred, the reading on the spring balance was taken. The experiment was replicated twenty times. The weight obtained from the spring balance reading is multiplied by the acceleration due to gravity to obtain the force needed to shred the cassava roots by the following equation;

$$F = Mg(Newtons) \quad (1)$$

Where F = Force required to shred cassava root

M = Weight obtained from the spring balance
g = acceleration due to gravity.

2.3.1 Electric Motor Power

The power required to shred the cassava root was derived as follows;
Shredding force = Weight obtained from spring balance due to cassava resistance to shredding x Acceleration due to gravity.

$$(F = M \times g) \qquad (2)$$

Work done = Shredding force x Distance moved by the cassava root on the shredding plate (length of shredder)

$$(W = F \times d) \qquad (3)$$

Power = Work done/time

$$P = \frac{W}{t} \qquad (4)$$

Where
F = shredding force
M = weight obtained from spring balance due to cassava root resistance to shredding
g = acceleration due to gravity
W = work done to shred cassava root
P = Power required to shred cassava root
t = Time required to shred root.
From my experiments,

$M = 25.7$ Kg

$. F = 25.7 \times 9.8$

$= 252N$

Since, work done = Force x Distance
And distance moved by root (length of shredder) =0.1m

Work done $= 25 \times 0.1$ = 25.2 Joules.

Power = <u>Work done</u>
Time required for shredding root
Time experimentally determined to shred root = 2.1 seconds.

$$\therefore \ power = \frac{25.2}{2.1} = 12 watts$$

In Horse powers (HP) $= \frac{12}{746} = 0.016HP$

To ensure that the electric motor is able to drive all the machine moving parts, shred the tubers efficiently, and to avoid any underestimation, I selected one Horse power (1Hp) electric motor.

2.3.2 Pulleys

The expression for diameter of driven pulley or shaft pulley is given by Khurmi and Gupta {2006) as;

$$D_s = \frac{D_m w_m}{w_s} \qquad (5)$$

Where
D_s = Diameter of shaft pulley (mm)
D_m = Diameter of electric motor pulley (mm)
ω_m = Speed of electric motor (rpm)

ω_s = Speed of shaft (rpm)

The shaft pulley selected was 20cm (0.2m) in diameter, while the electric motor pulley was 5cm (0.05m) in diameter. The speed of the electric motor selected was 1300 rpm.

Therefore the speed of the driven shaft $w_s = \dfrac{D_m w_m}{w_s}$ (6)

$$= \frac{5 \times 1300}{20} = 325 rpm$$

2.3.3 V – Belt Length

According to Khurmi and Gupta (2006), the expression for the V-belt length is given as;

$$L = \frac{\pi}{2}\left(D_s + D_m\right) + 2C + \frac{\left(D_s - D_m\right)^2}{4c} \quad (7)$$

Where

$\pi = Pi$ = 3.14

C = centre distance between pulleys

Substituting values, we obtain the V-belt length as;

$$L = \pi/_2\left(20 + 5\right) + 2 \times 80 + \frac{\left(20 - 5\right)^2}{80}$$

$$= 39.25 + 160 + 0.7$$

$$= 199.5 cm (2m)$$

2.3.4 Shaft Design

To estimate the diameter of the shafts used in the machine, we use the Maximum Shear Stress Theory. This theory according to Khurmi and Gupta (2006) is appropriate for shafts subjected to combined bending and twisting moments, as it is the case with the shafts in this machine. It also suitable for mild steel shafts, (which are ductile materials). The shafts used in the machine are made of mild steel.

The diameter of the shaft was determined using the maximum stress theory by Hall et al (1980).

$$d = \left[\frac{16}{\pi s}\left(\sqrt{\left(K_b M_b\right)^2 + \left(K_t M_t\right)^2}\right)\right]^{\frac{1}{3}} \quad (8)$$

I

Where, M_b = maximum bending moment on shaft (1000Nmm)

M_t = maximum torsional moment on shaft(16540 Nmm)

s = allowable shear stress for steel (310 N/mm^2)

K_t , K_b= fatigue and shock factor for torsion and bending moments (1.5 and 1.0).

Five shafts are involved in the development of the machine. The shafts are.

[1] The shaft connecting the driven pulley to the driver sprocket
[2] The shaft connecting the driven sprocket to the slider and crank mechanism
[3] The main shaft of the slider and crank mechanism
[4] The perpendicular shaft of the slider and crank mechanism
[5] The shredding plate shaft

The diameters obtained for the shafts based on equation above are 20mm, 20mm, 20mm ,20mm and 15mm respectively.

2.3.5 Design of the Frames

The frames are to be made of mild steel bars of rectangular cross-section.

The frames are to carry the weights of the five shafts, the electric motor, the pulleys, the sprockets, the hopper and cassava tubers in it, the slider-crank mechanism and the collector assembly.

To estimate the thickness of the frame, we use the procedure outlined by Black and Adams (2000) for determining the thickness of rectangular bars of known width. We use the equation;

$$S_r = \frac{Se}{Fs} - \frac{Se}{S_{yp}} \times Sm \qquad (9)$$

S_r= Superimposed alternating stress

$$S_r = \frac{\text{Maximum stress-Minimum stress}}{2} \qquad (10)$$

Minimum stress is due to the weight of the machine components on the frame like the hopper, the shafts, electric motor, pulleys and sprockets only. While the maximum stress is due to all the weights above plus the weight due to cassava tubers used in filling the hopper and the force exerted by the electric motor on the machine members.

Se = Maximum endurance stress of mild steel = 107.696 x 10^3KN/m^2
Syp = Yield strength of mild steel = 801.414 x 10^3KN/m^2
Sm = Mean stress = $\frac{\text{Maximum stress + Minimum stress}}{2}$ (11)

A 3mm thick steel plate with 40mm width was selected to avoid any underestimation.

2.3.6 Bolts Selection for the Frames.

The bolts are determined with consideration to the shear stress on the machine. It is given by Shigely and Mischke (2006) as;

$$S_e = \frac{F\max}{\pi d^2/4} \qquad (12)$$

Where Se = allowable endurance stress of mild steel = 107.969.X10^3KN/m
Fmax = Fmin + weight of cassava filling the hopper
Fmin = force due to total weight of the machine without load = 0.8KN

$$d = \sqrt{4F_{\max}/\pi S_e} \qquad (13)$$

d= 0.003m =3mm
4mm bolts were selected for fastening the machine to the frames.
After the design, fabrication of the motorized cassava shredding machine was carried out, with strict adherence to design values.

III. RESULTS AND DISCUSSION.

3.1 Shredding Efficiency.

After the fabrication of the machine it was tested for performance during operation. Experiments were conducted with the machine with steamed peeled cassava roots to determine the shredding efficiency of the machine at three different speeds of shredding. Shredding efficiency was determined as follows;

$$SE = W_C/W_T \times \tfrac{100}{1} \ (\%) \qquad (14)$$

Where, SE=Shredding efficiency , W_C == Weight of shreds more than 5cm in length,and
W_T = total weight of the shred roots.

The experimental design used was a central composite design exploring the effects of three levels of two variables of shredder speed (rpm) and shredding aperture(mm) on the shredding efficiency of the machine. In this design the variables were coded, with -1 as low value, 0 as medium value, while 1 is the high value.

Table 1: Variables in the RSM Design

Variables	Levels Used		
	Low	Medium	High
Shredder speed (rpm),X1	325	650	975
Shredding aperture (mm),X2	3	6	10
Statistics Coding	-1	0	1

Output Variable (Response) Shredding Efficiency (%) Y

Table 2: Experimental Data and Observed Response Values

Runs	Speed, (X1)	Aperture, (X2)	Shredding Efficiency (%)
1	-1	-1	89
2	-1	1	78
3	1	-1	92
4	1	1	80
5	-1	0	84
6	1	0	85
7	0	-1	86
8	0	1	79
9	0	0	82
10	0	0	82

Table 3: Estimated Regression Coefficients for Shredding Efficiency versus Speed of Shredder

Regression equation is $Y = 82.4 + 1.00X1 - 5.00X2 + 2.14X1^2 + 0.143X2^2 - 0.25X1X2$

Predictor	Coeff	SE Coeff	T	P
Constant	82.4286	0.8470	97.31	0.000
X1	1.0000	0.5786	1.73	0.159
X2	-5.000	0.5786	-8.64	0.001
$X1^2$	2.1429	0.9279	2.31	0.082
$X2^2$	0.1429	0.9279	0.15	0.885
X1X2	-0.2500	0.7087	-0.35	0.742

S=1.4173 R-sq=95.4% R-sq (adj) =89.7%

Table 4: Analysis of Variance for Shredding Efficiency

Source	DF	SS	MS	F	P
Regression	5	167.564	33.513	16.68	0.009
Residual Error	4	8.036	2.009		
Total	9	175.600			

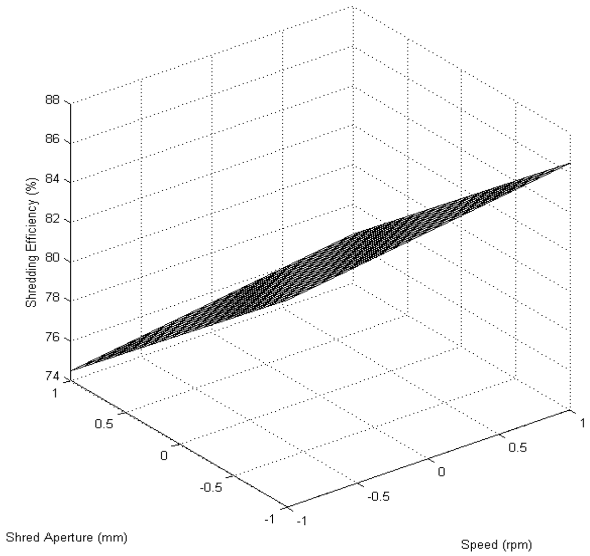

Fig 3: Response Surface Curve of the Effects of Shred Aperture and Speed on the Shredding Efficiency of the Machine

3.2 Throughput Capacity

Throughput capacities of the machine at three different speeds of shredding were determined. Throughput capacity was determined as $TPc = W_T / T$ (kg/hr) (15)

where T is time required to complete the shredding operation.

The results of the Throughput Capacity at the three speeds of operation are shown as follows;

Table 3: Speeds of the Machine and Corresponding Throughput Capacities

Speed (rpm)	**Throughput Capacity (kg/hr)**
325	301.54
650	311.34
975	319.89

3.3 Discussion of Results

The regression effects of the experimental variables on the shredding efficiency are shown in Table 4.Only the linear effects of the shredding aperture of the machine had significant effects ($P \leq 0.05$) on the shredding efficiency of the machine. This factor alone accounted for 95.4% of the variation of the shredding efficiency. The analysis of variance in Table 5 showed that the variable had significant effects ($P \leq 0.05$) on the shredding efficiency of the machine. From the response surface curve in Fig.4, the SE increased with decreasing shred aperture of the machine. The shredding efficiency of the machine decreased with increasing shredding aperture, but increased with shredding speed. Maximum shredding efficiency of 92% was obtained when the shred aperture was 3mm and the shredding speed was 975rpm.The throughput capacity of the machine increased with speed of shredding with a maximum value of 319.89kg/hr at 975rpm and a minimum value of 301.54kg/hr at 325rpm.

IV. CONCLUSIONS

A reciprocating motion cassava shredding machine was developed using locally available construction materials and technology. The machine performed satisfactorily well during tests. Results showed that the size of the shredding aperture of the machine significantly affected the shredding efficiency of the machine. The shredding efficiency of the machine decreased with increasing shredding aperture, but increased with shredding speed. Maximum shredding efficiency of 92% was obtained when the shred aperture was 3mm and the shredding speed was 975rpm. The throughput capacity of the machine increased with speed of shredding with a maximum value of 319.89kg/hr at 975rpm and a minimum value of 301.54kg/hr at 325rpm.

REFERENCES

[1]. Black, P.H and Adams, O.E. (2000). Machine Design 6th Edition. McGraw-Hill Kogakusha Ltd. Tokyo,pp 277-278.
[2]. Brennam, J. G., Butters J. R., Cowell, N. D. and Lilly, A. E. V. (1981). Food engineering Operations, 2nd Edition. Applied Science Publishers ltd London, pp 116.
[3]. Food and Agriculture Organization of the United Nations (1990): Cassava;Toxic Substances and Anti-nutritional Factors.
[4]. Food and Agriculture Organization of the United Nations (1995);Dimensions of Need: An Atlas of Food and Agriculture.
[5]. Hall, S.S., Mitchell, L.D. and George, E. (1980). Mechanical Design. Mc.Graw-Hill. Mechanical Engineering Series,pp116-117.
[6]. International Institute for Tropical Agriculture (1990) Cassava In Tropical Agriculture. A Reference Manual. Balding and Mansell International Wisbech. pp 86-97.
[7]. Jeon, Y.W. and Halos L.S. (1991) Technical Performance of A Root Crop Chipping Machine. Proceedings of The Ninth Symposium of the International Society for Tropical Root Crops Accra Ghana, pp 94-101.
[8]. Khurmi, R.S. and Gupta, J.K. (2006). A Textbook of Machine Design. Eurasia Publishing House PVT. Ltd. Ram Nagar New Delhi.
[9]. Krochmal, A. and Hahn, S. K. (1991) Tropical Root Crops in A Developing Economy: Proceeding of the Ninth Symposium of the International Society for Tropical Root Crops Accra, Ghana,pp 57-62.
[10]. Olsen,K.M and Schael,B.A.(1999)Evidence on Origin of Cassava:Phylogeography of *Manihot esculenta*.Proceedings of the National Academy of Sciences of the United States of America,96(10):5586-5591
[11]. Rupert, B. (1979).Cassava Drying: Cassava Information Centre. Centro International De Agricultural Tropical. Cali Colombia,pp45-47.
[12]. Shigley, J.E. and Mischke, C.R. (2006). Mechanical Engineering Design (In S.I units) 6th Edition. Tata McGraw-Hill Publishing Company Ltd New Delhi,pp156-158.