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Research Article

Development and Optimization of a Manual Fed Cassava Root Chipper for Household Cassava Processors

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ABSTRACT

A motorized, manual fed cassava root chipping machine was developed, evaluated and optimized. The objective of the research is to investigate the effect of moisture content and speed on the chipping sizes, efficiency, throughput and machine capacities. Obtained results showed that the cassava initial moisture content significantly affected the chipping size, machine capacity, throughput capacity and chipping efficiency within the tested moisture content range of 52 to 68% w.b. The machine speed also affected the chipping size, chipping efficiency, machine and throughput capacity. The average chipping size for the cassava chips at the four ranges of moisture content, speeds and constant feed rate of 89±26.6 kg h^{-1} ranged from 0.56 to 0.96 cm with optimum thickness 0.618 at 450 rpm and moisture content of 65.27% based on desirability factor. The average chipping efficiency ranged from 60 to 90% with an optimum value of 79.57% at 533 rpm and moisture content of 68 % while the throughput capacities of the machine ranged from 49 to118 kg/h with optimum value of 118 kg/h at a speed of 600 rpm and 68% moisture content.

RESEARCH ARTICLE

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INTRODUCTION

Cassava (Manihot esculanta Crantz,) is a perennial plant that belongs to the family of Euphorbiaceae. Cassava root is regarded as a vital source of food energy in Nigerian dietary, given its distinct role in easing food scarcity due to its regular obtainability all through the year, appropriateness to the farming technique of Nigerian farmers (Ajibola *et al.,* 2007). The advent of cassava in Nigeria was traced to the returning of slaves from South America (Ikugbayigbe, 2012). It grows well in tropical climate and Nigeria is considered a major producer of cassava in the globe (FAO, 2006). It produces good yield even in poor soil and the ability to stay in the soil for long-duration post maturity makes it a veritable part of food security crops for low-income countries. Cassava has become a major cash crop, food, and an industrial raw material for making of starch, alcohol, pharmaceuticals and confectioneries (Francisco, 2004). Cassava forms a base for a wide variety of fermented foods in the most emergent country and serves as an unprocessed substance in the manufacture of processed foods, animal feed and industrial products (Igboayaka *et al.,* 2018). It can be consumed by means of garri, tapioca chips, flour, fermented pastes, starch, etc. (Anuebunwa *et al.,* 2008). Therefore, it has formed a major part of the staple food and major source of carbohydrates in most tropical countries competing with other tubers like yam (Balagopalan *et al.,* 2008).

Cassava deteriorates fast and must be processed to other forms if it must be stored (Silayo *et al.,* 2007). Thus, there is a need for rapid processing of the tubers into a more shelf-stable form (IITA, 2011). Nigeria currently is the largest producer of cassava in the world (Ndunguru *et al.,* 2009). Processing the roots into dried chips reduces the moisture content to a very low level and reduces postharvest losses (Ndukwu *et al.,* 2018). In a country like Nigeria, separately from undeviating processing at the local level and utilization, animal feed, the verdict of the Federal Government for the addition of cassava flour of about 10% in bakery and cassava chips send abroad mission, improved the stipulate for cassava manufacture. In a continent like Asia, more than 40% of cassava is for undeviating human utilization, with greatly of the remnants distributed via export as chips. In India, scorched roots are transformed into small chips and flour. In a country like Indonesia, 57% production of cassava is for human utilization whereas 43% are consumed cooked or handled into dried chips before consumption (IITA, 2011). Cassava processing into chips aids in the rapid drying of the crops lowers its bulk density and eases its packaging, transportation and export. Some designs of cassava chippers have been presented in literature (Adejumo *et al.,* 2001; Adewumi *et al.,* 2005; Bolaji *et al.,* 2008; Ndunguru *et al.,* 2009; Ndukwu *et al.,* 2019a); however, there is a scarcity of information on optimum operational parameters for the machine capacities and thickness of cassava chips produced under the operating conditions. The diminutive shelf-life and cumbersomeness of cassava roots pose a major challenge when it is transported from the field to the market or industrial locations due to its extremely perishable nature. Processing of cassava into chips by manual methods like the application of a knife involves high labour input and also results in low product quality. To surmount this bottleneck in the sales and consumption of cassava products, as well as to circumvent huge loss after harvest, it is paramount to convert the fed (roots) to dry products (garri, tapioca, etc.) which are characterized with enhanced storage duration. The easiest and ever frequent means of treating cassava is the alteration of the roots to dry chips. Processing of cassava into chips by manual approach which entails the practice of the knife is labour-demanding with lots of human drudgery involved; but the appliance of enhanced processing knowledge (skill) has a drastically abridged processing period and labour and boosts advance production. This work, therefore, focuses on the development of cassava chipper, determining the effects of moisture and chipping speed on machine operating parameters; and optimizing the process parameters of the cassava chipper using response surface optimization tools.

MATERIAL and METHODS

Design and Features of the Cassava Chipping Machine

For effective operation, the manually operated cassava root chipper will consist basically of the following components: chipping blade, feeding chute, shaft, pulleys, ball bearing, mainframe, power unit and outlet chute. The choice of the component parts used in building the cassava chipping equipment was founded on the obtainability, strength, suitability, characteristics and economic considerations. Therefore, the machine design considerations are as follow:

i. Compactness and simplicity of use.
ii. Corrosion inhibition ability of the chipping parts of the machine as a result of the toxic and moisture laden characteristics of cassava roots.
iii. The magnitude of requisite force for slicing of cassava roots.
iv. Shape and size regularities of the cassava chips.

The shaft diameter (30mm), pulley size (D1, 0.18m), belt length (0.98 m) and center distance (0.3 m), belt wrap (168^o) and contact angle (12^o), tensions on the belt (208 and 14 N), speed ratio (1:3) and power transmitted (1.1 kW) were determine from the generic equations presented in Khurmi and Gupta (2005) and Ndukwu and Onyenwigwe (2013). The load arrangements of the chipping machine are shown in Figure 1. The free body diagram shown in Figure (number 1) is the representation of the vertical forces acting on the shaft. To obtain the reactions at each bearing, moment is taken about the two expected bearing points independently. The total reaction on the bearing is given as follows

$$R_B + R_C = W_{cb} + W_p$$

Where; R_B = Reaction on bearing B, R_C = Reaction on bearing C, W_{cb} = Weight of cutting blade (3.92 N), W_p = Weight of pulley (10.79N).Taking moment about point B;

$$\sum M_B = 0$$

Therefore, resolving the forces

$$170\ R_C + 70\ W_{cb} - 230\ W_p = 0$$

R_C was calculated as 12.98 N.

Also taking moment about point C

$$\sum M_C = 0$$

$$170 R_B - 240 W_{cb} + 60 W_p = 0$$

R_B was calculated as 1.73 N

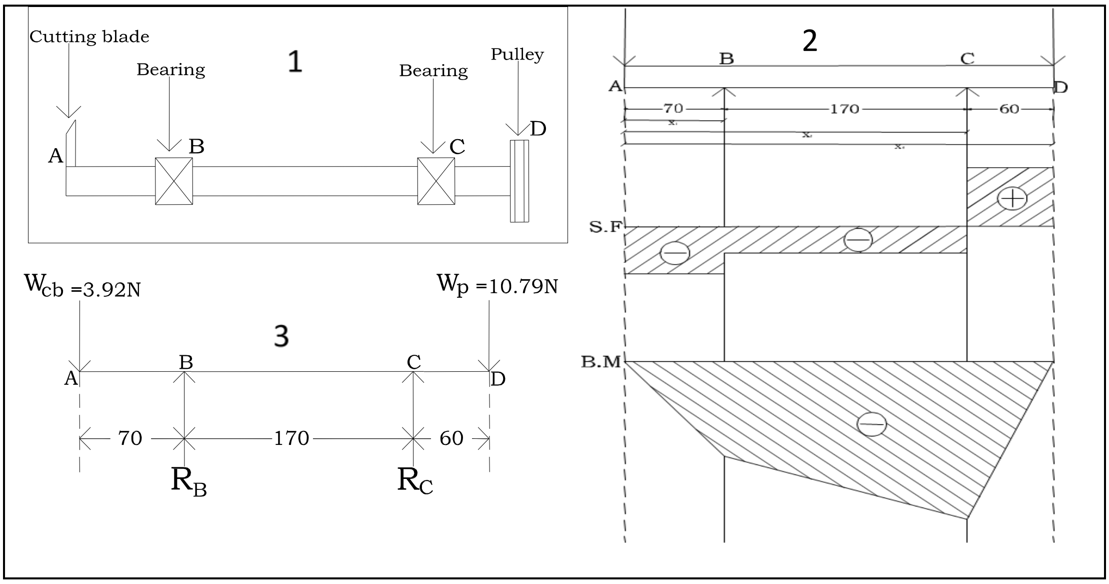

Figure 1. Load arrangement for the developed cassava tuber chipping machine (1) shaft, bearing, cutting blade and pulley assembly (2) Shear force (S.F) and bending moment (B.M) diagram (3) Moment about the bearing points.

Material Selection

The material used for the fabrication of the components of the cassava chipper and the cost of the materials is presented in Tables 1 and 2. The total cost of fabricating the cassava chipper is about $ 82.00.

Table 1. Material selected for fabrication.

S/N	Component	Selected materials
1	Feeding chute	Mild steel sheet (16 gauge).
2	Pulley	Chilled cast iron
3	Chipping blade	Stainless steel
4	Shaft	Alloy steel rod (θ25mm)
5	Outlet chute	Mild steel sheet (16 gauge)
6	V-belt (A43)	Leather

Table 2. Materials and costs (6/2/2019).

S/N	Materials	Quantity	Unit Price ($)	Amount ($)
1	16-gauge mild steel metal sheet	½ full sheet	25.00	12.50
2	Shaft rod (θ25mm)	1	2.78	2.78
3	Electrodes	1 packet	3.33	3.33
4	Bearings (θ25mm)	2	1.39	2.78
5	Pulley	2	2.78	5.56
6	V-belt (A43)	1	1.39	1.39
7	Angular mild steel	1 length	5.56	5.56
8	Fasteners	½ dozen	0.83	0.83
9	Variable speed motor (5.5 HP/kW)	1	25.00	25
10	Paint	1 can	2.78	2.78
11	Labour	-	-	20.00
	Total			**82.00**

Description and Principle of Operation of a Cassava Chipping Machine

Figure 2 shows the picture of the cassava chipping machine. It consists of a cuboid-shaped enclosed hopper with a feeding chute by the side. The feeding chute is provided by a guide by the sides. The feeding chute is designed to permit horizontal movement of tuber against the vertical rotary motion of the chipping blade for effective chipping. The cassava tuber is fed by the hand into the chipping chamber, where the rotating stainless chipping blade chips the cassava radially. The blade is powered by the 5.5 HP internal combustion petrol engine through the shaft, pulley and v-belt connections. The chipped cassava leaves the chipping chamber through the outlet chute where it is collected in a bag, tray or open basin. The entire components are housed in a frame made of angular iron. The designed machine requires one operator at a time due to its simplicity in design.

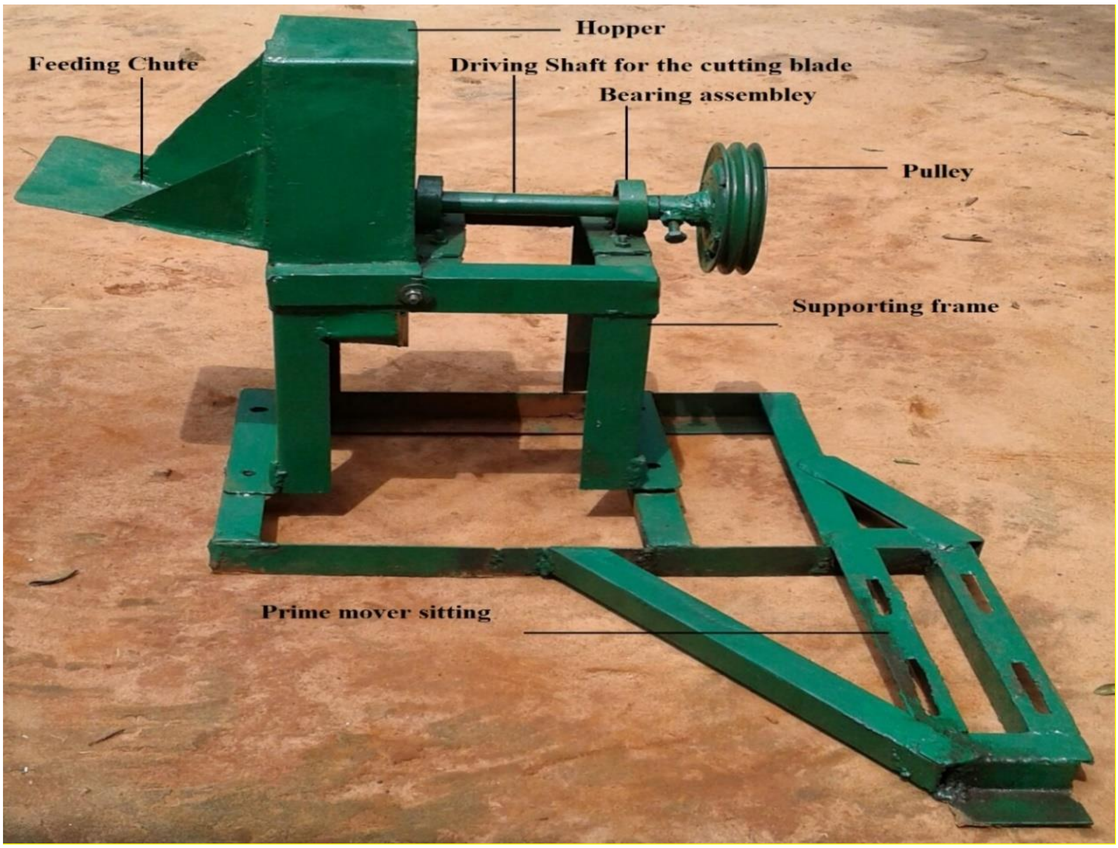

Figure 2. The picture of the cassava chipping machine

Performance Evaluation

The machine capacity, chipping efficiency, throughput capacity and feeding rate were computed using the following Equations (1) – (4) (Ndukwu and Asoegwu, 2010; Ndukwu and Asoegwu, 2011; Akintunde and Akintunde, 2001 Igboayaka *et al.,* 2018):

$$\text{Machine Capacity } (M_c) = \frac{W_f}{T} \quad (1)$$

$$\text{Chipping Efficiency } (\eta) = \frac{W_f}{W_p} \times 100\% \quad (2)$$

$$\text{Throughput capacity (TC)} = \frac{W_p}{T} \quad (3)$$

$$\text{Feeding Rate} = \frac{W_p}{t} \quad (4)$$

Where: W_p = weight of peeled cassava tubers (kg), W_f = weight of fine or normal chipped cassava (kg), T = total time taking during the chipping operation (h), t = the feeding time (h).

Experimental Evaluation Procedure

The developed cassava chipping machine was tested to appraise its performance based on chipping efficiency, throughput capacity, feeding rate and machine capacity. Freshly harvested cassava roots (*NICASS 25*) were peeled by manual means, washed and weighed using a weighing balance scale (NBT-A200, NANBEI,) with a sensitivity of 0.01 g (Ndukwu *et al.,* 2019b). The chipping machine was powered with a 5.5 HP internal combustion (petrol) engine (model GX160). The variable speed for the evaluation was obtained by adjusting the choke of the internal combustion engine and the corresponding speed measured with a tachometer (RL-HM026A, Contempo views).

The various speeds of operations were measured, marked and recorded as 600, 550, 500, and 450 rpm, respectively. The chipping operation was performed at four different moisture contents of 68, 63, 58 and 52% wet basis, obtained by harvesting on a different day and sun drying. Preliminary evaluation of the chips showed with hand feeding of the cassava, the feeding rate was determined as 89±26.6 kg h^{-1}. The moisture content of the cassava roots was determined with a digital pin-type moisture meter. For each experiment, 2 kg of cassava root was weighed and manually hand-fed into the chipping chamber. The time of feeding and the total time of chipping was recorded respectively. Completely chipped, unchipped and chipped and damaged cassava was also separated, and their weight recorded. Thickness of completely chipped and undamaged chips were measured with a Veneer caliper (Axminster) and their means was recorded for analysis.

Data Analysis and Optimization

A 4-factor, 4-level experimental design was formulated to test the level of variation of obtained results. One-way ANOVA without repetition was used to test the level of significance amongst the mean at 95% (0.05) of obtained data using 2013 Microsoft Excel Software. Optimization was based on the desirability factor by minimizing the speed and keeping the moisture content in the range using response surface tools of Design Expert 12 software (Ndukwu *et al.,* 2019a; Nwakuba *et al.,* 2020; Uzoma *et al.,* 2020). The results were further analyzed with Restricted Maximum Likelihood (REML) analysis Kenward-Roger p-values and coefficient of determination and the significant level was at 5%.

RESULTS and DISCUSSION

Influence of Speed and Moisture Content on Chipping Size of Cassava Chips

Figure 3 demonstrates the consequence of machine speed on the chipped sizes of cassava chips. Interpreting the figure shows the colours of the mesh moves from red to yellow, green and blue which also indicates the decreasing order of values (Ndukwu *et al.,* 2019a). Therefore, the figure showed that at a higher speed, the sizes of cassava chips tend to reduce in thickness due to the high revolution of the cutting blade. When the speed is low, the size of chips tends to increase in thickness. There is the tendency of repeated chipping of already chipped cassava at high speed before it leaves the chipping chamber unlike at lower speed which might have resulted in lower chip thickness at a higher speed. The average chipping size for the cassava at the four ranges of moisture ranged from 0.70 to 0.96 cm for chipping at 450 rpm, 0.57 to 0.86 cm for 500 rpm, 0.59 to 0.86 for 550 rpm and 0.56 to 0.80 for 600 rpm. Analysis of variance based on two factors without replication in Table 3 shows that speed has a significant ($P < 0.05$) effect on the chipping thickness of the chips. The implication is based on the utilization of the chips, increasing the speed will produce chips of smaller thickness while reducing the speed will increase the chip sizes.

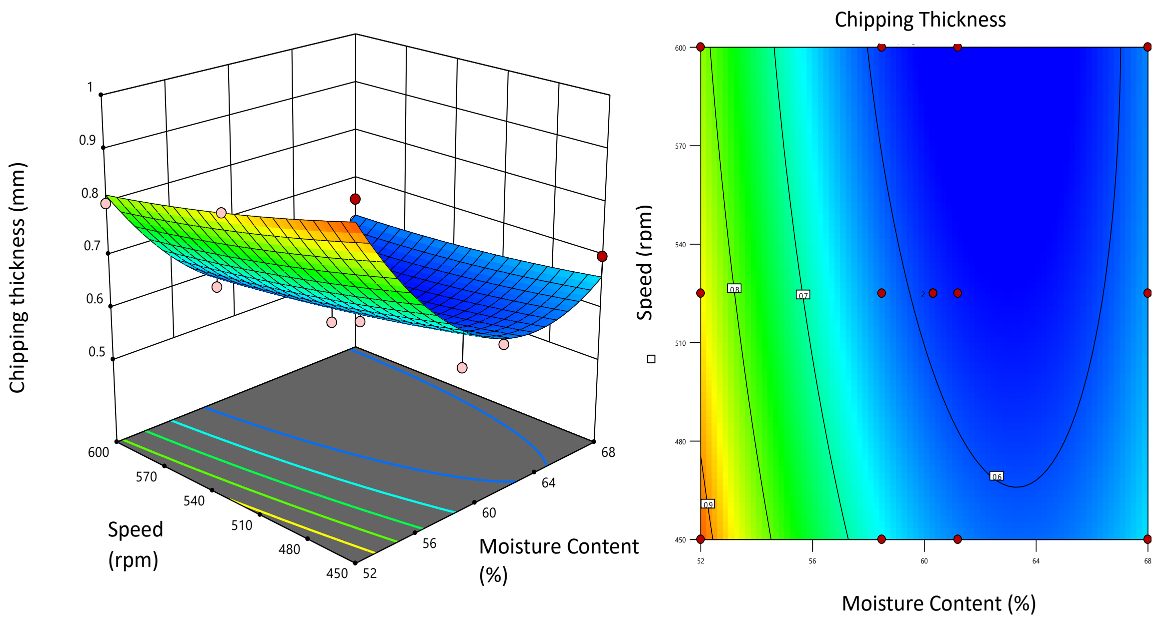

Figure 3. Influence of machine speed and moisture content on the chipped thickness of cassava chips.

Table 3. REML analysis Kenward-Roger p-values table for the interaction of chipping size at different moisture contents and chipping speeds.

Source	Term Df	Df	F-value	P-value
Whole-plot	2	2.03	3.60	0.2145ns
M-Moisture content	1	1.94	18.15	0.0536
M^2	1	2.08	17.67	0.0489*
Subplot	3	6.64	2.37	0.1613ns
V-Speed	1	6.33	6.18	0.0454*
MV	1	6.33	0.7328	0.4232
V^2	1	7.30	0.1334	0.7253

** = significant, ns = not significant*

Figure 3 also shows the effect of moisture content on the chipped sizes of cassava chips. The Figure showed that chip thickness was almost similar at a moisture content of 61-64% but increased at 52%. This shows the higher force require to chip at 52% and which might lead to irregular cutting of the cassava at lower moisture content. The average chipping size for the cassava at the four ranges of speed ranged from 0.6 to 0.7 cm for chipping at 68%, 0.6 to 0.64 cm for 64%, and 0.57 to 0.62 cm for 61% and 0.8 to 0.96 cm for 52%. Analysis of variance based on two factors without replication in Table 3 illustrates that moisture content has a substantial effect ($P<0.05$) on the chipping thickness of the chips. The response surface optimization of the chipping thickness based on the desirability factor gave an optimum chipping thickness of 0.618 at 450 rpm and moisture content of 65.27%.

Influence of Speed and Moisture Content on Chipping Efficiency

Figure 4 expresses the result of machine speed on the chipping efficiency of the cassava chipping equipment. The figure showed that the chipping efficiency increased as the chipping speed increases but reached its maximum value at 550 rpm before decreasing. Research has shown that the impact force is proportional to rotating speed (Ndukwu *et al.,* 2019a). Therefore, as the speed increases, the force of chipping increases. However due to the higher force, there is the tendency of an increase in the speed of the chips as it is chipped off from the cassava which might result in damaging the chips as they strike the inner walls of the chipping chamber. This might be the result of decreased efficiency obtained in 600 rpm as less mass of properly chipped cassava will be recovered, thus decreasing the efficiency. Also repeated chipping of already chipped cassava at a very high speed may damage the chips. The average chipping efficiency for the cassava at the four ranges of moisture ranged from 60 to 85% for chipping at 68% moisture content; 60 to 85% for 63%; 60 to 90% for 58%, and 60 to 75% for 52%. Analysis of variance based on two factors without replication (Table 4) shows that speed has a significant (P<0.05) effect on the chipping efficiency of the chips. The efficiency is also altered due to the high rate of non-uniform production of cassava chips at a higher speed.

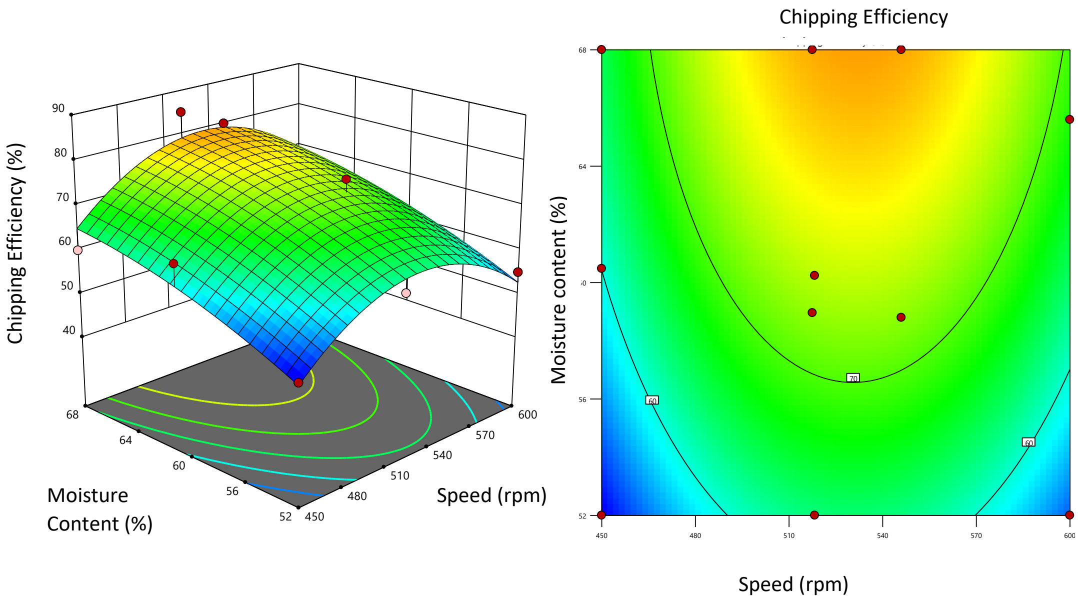

Figure 4. Influence of speed and moisture content on the chipping efficiency of the cassava chipper at the different moisture contents.

Table 4. REML Analysis Kenward-Roger P-values table for the interaction of chipping efficiency at different moisture contents and chipping speeds.

Source	Term Df	Error Df	F-value	P-value
Whole-plot	2	5.00	7.48	0.0314*
V-speed	1	5.00	0.6619	0.4529
V^2	1	5.00	12.84	0.0158*
Subplot	3	5.00	5.11	0.0554^{ns}
M-moisture content	1	5.00	14.95	0.0118*
VM	1	5.00	0.0103	0.9231
M^2	1	5.00	0.4631	0.5264

** = significant; ns = not significant*

Figure 4 also shows the impact of moisture content on the chipping efficiency of the cassava chipping machine. The figure showed that the chipping efficiency was almost constant at the same speed for the moisture constants with the exception of chipping at 550 rpm. The average chipping efficiency for the cassava at the four ranges of speed was 60 to 65% for chipping at 450 rpm; 70 to 85% for 500 rpm; 75 to 90% for 550 rpm, and 60 to 65% for 600 rpm. Analysis of variance based on two factors without replication (Table 4) indicates that moisture content had no substantial effect ($P<0.05$) on the chipping efficiency of the system. However, the influence of moisture content and speed on chipping efficiency (η) at the optimum value obtained is expressed in Equation (5) below with an R^2 value of 0.876

$$\eta = 2.29V + 5.23M + 0.005MV - 0.0022V^2 - 0.037M^2 - 722.38 \quad (5)$$

The response surface optimization of the chipping efficiency based on the desirability factor gave an optimum chipping efficiency of 79.57% at 533 rpm and moisture content of 68%.

Effect of Speed and Moisture Content on Throughput Capacity and Machine Capacity

Figures 5 and 6 show the effect of speed on the cassava chipping machine throughput capacity and machine capacity respectively. The throughput capacity is defined as the ratio of the total weight of cassava fed into the machine to the total time taken to completely chip the fed cassava while the machine capacity, in this case, is defined as the weight of properly chipped cassava chips produced to the total time for complete chipping. Both results showed that the machine capacity and throughput capacity increased with an increase in speed due to reduced time taken to chip at a higher speed. The average throughput of the machine at the four ranges of speeds was 49 to 80 kg h^{-1} for chipping at 450 rpm; 54 to 91 kg h^{-1} at 500 rpm; 63 to 100 kg h^{-1} at 550 rpm; and 80 to 118 kg h^{-1} at 600 rpm. Also, for the machine capacity the average values obtained were 44 to 64 kg h^{-1} for 450 rpm, 51 to 82 kg h^{-1} at 500 rpm; 63 to 95 kg h^{-1} at 550 rpm; and 76 to 100 kg/h at 600 rpm. The value of machine capacity was in most cases lower than the throughput capacity because not all the cassava fed into the machine was properly chipped. However, the lower variation between the two parameters accounted for higher machine efficiency achieved. Analyses of variance based on two factors without replication (Table 5 and 6) show machine speed has significant ($P<0.05$) effect on both throughput capacity and machine capacity of the chips.

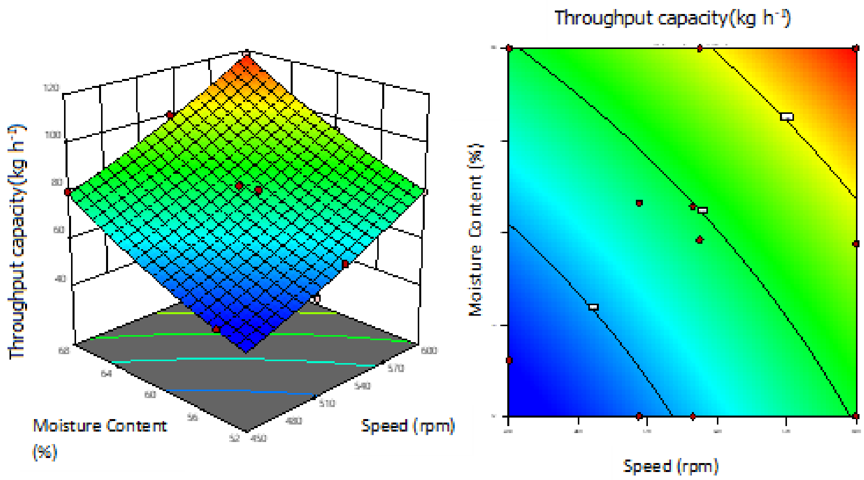

Figure 5. Impact of speeds and moisture contents on the throughput capacity of the cassava chipper.

Table 5. REML (Restricted Maximum Likelihood) analysis Kenward-Roger p-values ($R^2 = 0.9989$)

Source	Term Df	Error Df	F-value	P-value
Whole-plot	2	1.96	49.49	0.0210*
V-speed	1	1.95	100.96	0.0106
V^2	1	1.97	0.5919	0.5231
Subplot	3	3.02	858.62	< 0.0001*
M-moisture content	1	3.06	2506.54	< 0.0001
VM	1	3.00	3.81	0.1459^{ns}
M^2	1	3.00	28.74	0.0127

** = significant, ^{ns} = not significant*

Table 6. ANOVA Table for the interaction of machine capacity at different moisture content and chipping speed.

Summary	Count	Sum	Average	Variance		
Analysis of variance						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	2425.25	3	808.4167	68.47765	1.62E-06	3.862548
Columns	1502.25	3	500.75	42.41647	1.23E-05	3.862548
Error	106.25	9	11.80556			
Total	4033.75	15				

$$TC = 0.003V^2 - 0.13V - 3.72M + 0.001MV + 0.046M^2 + 87.49 \quad (6)$$

The optimization of the above results shows that optimal throughput of 118 kg h^{-1} was obtained at a speed of 600 rpm and 68% moisture content.

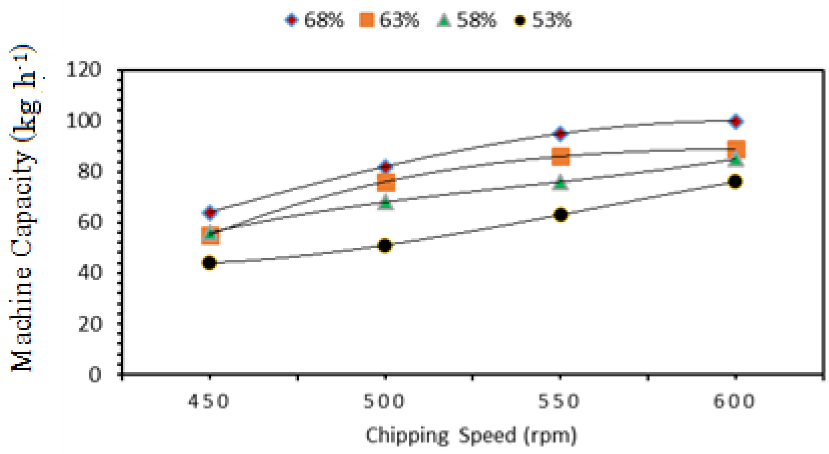

Figure 6. Effect of speed on the machine capacity at different moisture contents.

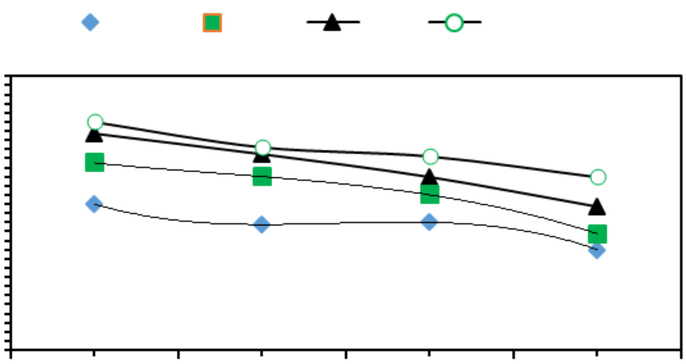

Figure 7. Effect of moisture content on the machine capacities at different speeds.

CONCLUSION

A motorized cassava tuber chipping machine has been designed, constructed and tested. The cassava initial moisture content affected the chipping size, machine capacity and throughput capacity and chipping efficiency within the tested moisture content. The machine speed affected the chipping size, chipping efficiency, machine and throughput capacity. The average chipping size for the cassava chips at the four ranges of moisture content, speeds and constant feed rate of 89 ± 26.6 kg h^{-1} ranged from 0.56 to 0.96 cm. The average chipping efficiency ranged from 60 to 90% while the throughput capacities of the machine ranged from 49 to118 kg h^{-1}. Also, for the machine capacity the average values obtained were 44 to 100 kg h^{-1}. Optimum equations obtained for chipping efficiency and throughput capacity can be applied in the evaluation of similar machine. Low cost of the machine makes the machine affordable for farmers in Africa with low income per capita.

DECLARATION OF COMPETING INTEREST

The authors have declared no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.

Macmanus Ndukwu: Conceptualization of idea, methodology, design of experiment, review and editing of manuscript, data analysis, validation, & visualization.

Gabriel Afam: Writing of original manuscript draft, data collation, formal analysis, investigation, validation.

Nnaemeka Nwakuba: Methodology, formal analysis, validation, review and editing of manuscript.

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