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Development and Performance Evaluation of a Yam Milling Machine

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Abstract The conventional method of processing yam flour is ineffective and time-consuming and this leads to low output. Automated operated yam miller was developed using simulated engineering principles from locally-sourced materials. The developed machine was evaluated to determine its functional efficiency. The major components of the machine include the following; hammer mill (enclosed in the crushers), attrition mill consisting of two cylindrical concave plates, rotating shaft, feed hopper, frame, screw conveyor, concave cylinder, and discharge outlet. The machine was powered by an electric motor of 2.5 horsepower. Results of the evaluation indicated that maximum milling efficiency of 86.20% was obtained at the lowest speed of 600 rpm with a feed rate capacity of 73.35 kg/hr and a percentage unmilled of 13.80% was obtained at a higher speed of 1050 rpm with feed rate capacity of 125.52 kg/hr, therefore milling percentage is higher when the machine is operated at a lower. It was also observed that, at lower moisture contents of 7.5%, milling efficiency of 82.40% was obtained and at higher moisture contents of 18.50%, milling efficiency obtained was 69.60% at a constant speed of 900 rpm, therefore milling efficiency is higher when the machine is operated at lower moisture content. The fineness modulus of the flour produced was found to be 0.31 with a uniformity index of 0: 1: 9 (coarse: medium: fine). With these performances, efficient milling has been achieved.

Keywords Development, Evaluation, Milling efficiency, Machine, Milling, Yam flour

1. Introduction

Yam is widely consumed in Africa and many other countries of the world [1]. It is prepared and eaten in different forms and one of the interesting eating forms of yam is pounded yam. Nigeria is reported as the world's largest producer of yam with over 6 million metric tons annually [1]. It is however estimated that about 40 percent of the harvested tubers are lost due to good storage facilities [2]. In West Africa there are many cultivars of yam; more than 95% of the world's yam is produced in Africa with the remainder grown in the West Indies, part of Asia, South and Central America. The majority of yam consumed is produced in West Africa with more than 90% of the World's production. Poorly harvesting methods contribute to yam deterioration, yams are also exposed to pathogens, and insects, and pests during storage [3].

In West Africa, a major proportion of yam is eaten as boiled yam, roasted yam, fried yam, pounded yam, and Amala which is stiff glutinous dough. The most processed traditional yam product is yam flour [4] which contains protein carbohydrates, and trace amounts of minerals and vitamins. Yam flour is traditionally processed by peeling, sometimes slicing parboiling in hot water (65 ºC) for a varied time followed by steeping for 13-24 hrs and dried to give a dry yam which is milled into flour 'Elubo'. The flour is used in making a thick paste by stirring it in boiling water to produce a product known as 'Amala', which is eaten with stew by the consumer [5-6].

The quality of a product is commonly thought of as a degree of excellence. It is also considered as a product of various attributes which include composition, nutritional value, purity, appearance, taste, colour, and consistency [7]. The lack of quality consciousness by the producers and sellers is astonishing, considering the fact that *Elubo* is a major staple food in the country, there are many export opportunities for Nigerian products to countries in the West African sub-region [8]. Yam flour is one of the Nigerian Food products which could be exported if produced and displayed in a more hygienic condition. It is interesting to note that the storage life of yam is greatly improved when in flour state. However, traditional processing and preparation are cumbersome, laborious, time and energy-consuming, and with low production output. In other to eliminate the drudgery and improve the quality of pounding yam, especially at a commercial level, this project is therefore considered timely. In a bid to reduce the labor involved in yam pounding came the manufacturing of Hebert grinder, the Kenwood mixer, and hammer mill in early 1985. These intended yam flour machines failed due to some limitations in their operational functions which include low grinding efficiency and poor product quality [5].

The factors affecting the performance of the machine are classified into two categories, machine-based factors which are; concave clearance, sizes of seizing, and non-machine factors which include; moisture content, feed rate of the products, skill, and experience of the operator. The performance indicator parameters are machine capacity (kg/hr), moisture content of the products, waste products efficiency, unmilled efficiency, and milling efficiency of the machine. Therefore, the project work focuses on the design and fabrication of a yam milling machine that crushes and grinds slices of dried yams into powder form for proper storage and preservation.

2. Materials and Methods

Some factors were considered during the design and fabrication of the machine which include positioning of the hopper, selection, and positioning of an electric motor to aid adequate control of milling, stability, height, size of individual components, maintenance, profitability, and efficiency.

2.1 Description of the Machine

The machine is made up of two basic units; the hammer mill and burr mill. The hammer mill unit consists of the hopper through which the dried yam is fed into the machine. The product is crushed or broken into desired pieces with the aid of rotational hammers. The burr mill chamber consists of two cylindrical plates in contact, one side of the plate is stationary while the other side of the plate rotates freely; and when the rotating side of the plate rolls against the product in contact, the product is grinded into flour form due to compressive force. The machine consists of two belts and two pulleys for power transmission. This will be run using an electric motor. The machine mainframe, on which other parts of the yam flour machine rest on was constructed with a mild steel angle bar. The hammer mill unit, burr mill casing, and hopper were constructed using galvanized metal as shown in Fig. 1-4.

2.2 Components of the Machine

These are unit components of the machine that are assembled together to form the entire machine. The machine components include; the machine structural frame, trough, hammer impeller, pulleys, shaft and the electric motor which was selected, hopper, discharge chute, etc.

2.2.1 Electric Motor

The electric motor used for this project is 3.0 HP (horsepower). It produces a rotary motion which is transferred by a belt and pulley drive to the feed roller shaft. The electric motor is an essential part of the machine that has to be handled by trained personnel if found faulty.

2.2.2 Hopper

This can also be referred to as the inlet of the machine or feed hopper. The hopper size was 30 cm by 30 cm and tapers downward at an angle of 100 and made of galvanized steel since it has contact with only the unfinished products.

2.2.3 Discharge Chute

This structure delivers and discharges the cleaned seed into a trough at the base of the machine. The structure is made of a metal sheet tapering slightly towards the base to ensure smooth delivery in shape.

2.2.4 Hammer mill unit

The unit is made up of the crushers mounted on the horizontal rotating shaft. The length of the units is 39.1mm long, each is mounted on the shaft connected to the pulley of the hammer mill.

2.2.5 Burr mill unit

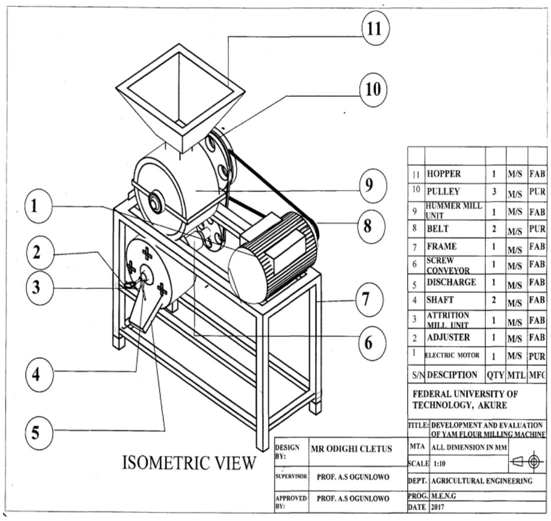
The rotor drives the hunger of the grinding roller to rotate through pulley and Centre bearing. The two concave rollers are made of galvanized metal sheet mounted on a shaft. The whole assembly is enclosed in a metal housing.

2.2.6 Housing or Casing

The housing also known as the casing is made of steel. It is a cylinder sliced laterally into two. The housing is cut into two halves in order to make repairs easy and for cleaning of the internal parts. The upper half has the hopper attached to it and the roller unit while the lower part has the delivery chute attached to it. The design of the casing is one of the most technical aspects of the project.

2.2.7 Frame

The frame is made of cut angle iron which provides supports to the entire machine; it carries the prime mover, hopper, hammer mill unit, roller mill, etc. The frame provides rigidity and also resists the vibrations created as a result of the motion of the electric motor.



S/N	DESCIPTION	QTY	MTL	MFC
11	HOPPER	1	M/S	FAB
10	PULLEY	3	M/S	PUR
9	HUMMER MILL UNIT	1	M/S	FAB
8	BELT	2	M/S	PUR
7	FRAME	1	M/S	FAB
6	SCREW CONVEYOR	1	M/S	FAB
5	DISCHARGE	1	M/S	FAB
4	SHAFT	2	M/S	FAB
3	ATTRITION MILL UNIT	1	M/S	FAB
2	ADJUSTER	1	M/S	FAB
1	ELECTRIC MOTOR	1	M/S	PUR

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TITLE:	DEVELOPMENT AND EVALUATION OF YAM FLOUR MILLING MACHINE
MTA	ALL DIMENSION IN MM
SCALE	1:10
DEPT.	AGRICULTURAL ENGINEERING
PROG.	M.E.N.G
DATE	2017

Figure 1: AutoCAD view of the machine

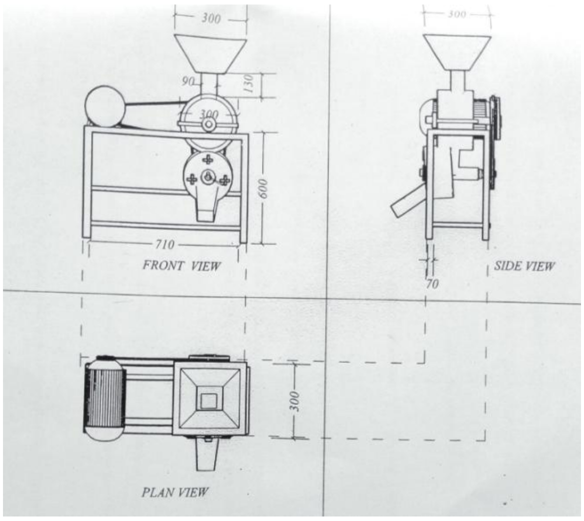

Figure 2: Orthographic of the machine

Figure 3: Assembly machine after Fabrication

Figure 4: Testing of machine after Fabrication

2.4 Design Analysis and Calculation

In design of any agricultural machine, the properties of the crop must be taken into consideration. Since the mixer will be employed to mix feed, some relevant physical properties of the feed needs to be understood. These properties include moisture content and bulk density

Design of Hopper

Volume of Hopper = $\left\lfloor \frac{1}{3}\left(A^{1}+A^{2}\right)+\left(A^{1}/A^{2}\right)\right\rfloor XB$ (1)

Design of shelling chabel

Volume = L x b x h (2)

Total volume of mixing tank is $\frac{1}{2}\left(\pi r^{2}H\right)$ **(3)**

Where

L = Length of the rectangular body

B = Breath of the rectangular body

H = height of the rectangular body

R = radius of the cylinder

H = Height of cylinder

V_T = Total volume of mixing tank

Power Requirement

$$P = \frac{Q \times L \times K}{407} \quad (4)$$

P = Power in kw

Q = Capacity in 1000kg/hr

L = Conveyor auger length

K = Friction Coeffcient

Design of Belt Length

$$L = 2a + \pi\frac{(D_L + D_S)}{2} + \frac{(D_L + D_S)^2}{4a} \quad \textbf{(5)}$$

Where

L = Length of belt

A = Centre distance between the shaft pulley and engine pulley.

For V-belt the value of a is given as

A = $0.55 \times (D_L + D_S) \times t$

D_L = Diameter of large pulley

D_S = Diameter of small pulley

L = 915mm

Belt Tension

$$\frac{T_1 = e\mu\phi}{T_2} \quad (6)$$

Where

T = Tension on the tight side

T = Tension of the slack side

N = Coefficient of friction between the belt and the pulley

ϕ = Angle of contract between the belt and the pulley

Power Transmitted by the Belt

$$P = (T1 - T2)V \quad (7)$$

Where

V = Velocity of belt in nils

V = $\frac{\pi DLN}{60}$

Diameter of the sharp

$$d^3 = 16/\pi sc\sqrt{(K_b M_b)^2 + (K_1\ M_1)^2} \quad (8)$$

Where

M_t = tensional moment

M_b = bending moment

K_b = combine shock and fatigue factor applied to torsional moment

S_c = allowable where, ASME code specifies that for commercial shaft with key way.

d = 15.1 mm.

2.5 Performance Evaluation

The yam milling machine was developed using locally-available materials. These selected materials were based on their suitability, affordability, and viability. The major components of the machine include the following; hammer mill (enclosed in the crushers), attrition mill consisting of two cylindrical concave plates, rotating shaft, frame, and delivering chute. The hammer mill chamber was constructed using stainless steel and consists of 12 crushers of 80 mm length each mounted on the horizontal rotating shaft diameter of 39 mm. The attrition mill chamber was also constructed using stainless steel and consists of two cylindrical plates in contact with a diameter of 180 mm each. The transmission components on the machine consist of vertical and horizontal belts with lengths of 500 mm and 700 mm driven with two pulleys of 180mm per diameter. The hopper was constructed using mild steel of 2 mm gauge with an estimated volume of 0.00073 m^3. The machine mainframe was constructed using angular bar mild steel of 45 mm gauge. The machine works on the principle of crushing-compressive force and was driven by an electric motor of 2.5 hp at a pre-set speed of 600 rpm, 750 rpm, 900 rpm, and 1050 rpm respectively. Peeled yam tubers were cut into smaller sizes and fed into the hopper at 5.0 kg per batch after oven-dried at a different moisture content of 7.5 %, 11.50 %, 14.00 %, and 18.50 % respectively. The products were crushed by the hammer mill in the first chamber and conveyed into the second chamber for final grinding using an attrition mill. A sieve of 0.001 mm diameter was arranged under the miller which allowed only milled flour to pass into the delivery chute for collection. Milling time for 9 mm constant clearance was recorded with an automatic stopwatch. The Milled yam flour was collected and weighted using an electronic weighing balance of ±0.1 g resolution. 128 g of yam flour was poured into a Mechanical sieve shaker of No. 100 and vibrated for 5 min. The amount of yam flour that passed through the No. 100 sieve was collected and weighed. The experiments were replicated three times and parameters such as moisture content M.C (%) [9], milling efficiency (%) [10], feed rate capacity (kg/hr) [10], fineness modulus and uniformity index [11], were evaluated using the following equation:

$$\text{Moisture Contents M.C (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (9)$$

$$\text{Milling efficiency } M_{FF}, \text{(\%)} = \frac{M_{BM} - M_{AM}}{M_{BM}} \times 100 \qquad (10)$$

$$\text{Feed Rate Capacity (FRC)} = \frac{M_{TM}}{T_{TM}} \qquad (11)$$

$$\text{\% Sieve of Retained} = \frac{\text{Weight of Sample}}{\text{Total Wight}} \text{x}100 \qquad (12)$$

$$\text{Finess Modulus (FM)} = \frac{\sum CumulativePercentRetained}{No.\ of ScreenMesh} \qquad (13)$$

$$\text{Uniformity Index (UI)} = \frac{PercentMaterialsRetainedoneachScreen}{GrantTotalofParticles} \qquad (14)$$

3. Results

3.1 Effect of Speed on Milling Time

Fig. 5 and Table 1 show the effect of moisture contents on milling efficiency. The variation of milling efficiency decreased with an increase in moisture contents. It was observed from the experiment that, at lower moisture contents of 7.5%, milling efficiency was 92.40% and at higher moisture contents of 18.50%, milling efficiency obtained was 69.60%, therefore milling efficiency is higher at lower moisture contents.

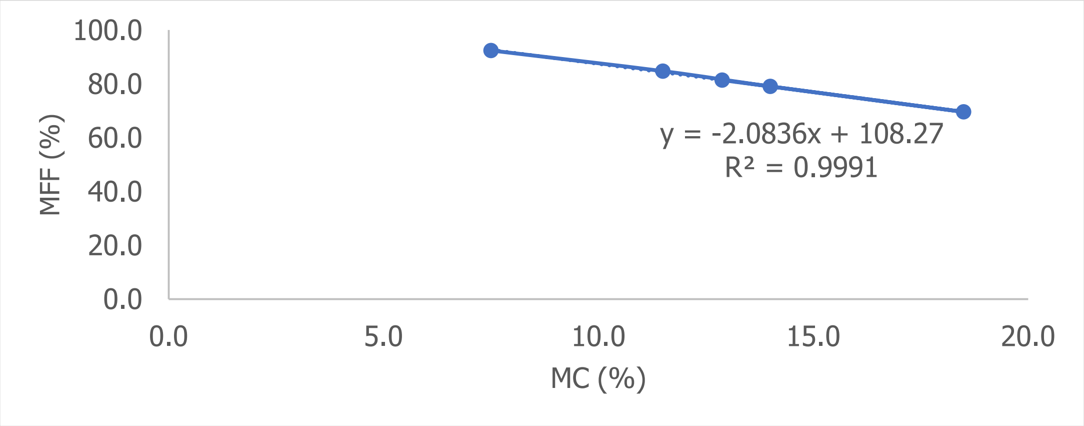

Figure 5: Effects of moisture contents on milling efficiency

Table 2: Different Moisture Contents at constant speed

MC (%)	Time (mins)	M_{BM} (kg)	M_{AM} (kg)	M_{UM} (kg)	M_{FF} (%)	M_{UF} (%)
7.5	4.1	5.0	4.6	0.4	92.4	7.6
11.5	5.8	5.0	4.2	0.8	84.7	15.3
14.0	6.2	5.0	4.0	1.1	79.1	21.0
18.5	6.6	5.0	3.5	1.5	69.6	30.4
12.9	5.7	5.0	4.1	0.9	81.4	18.6

3.2 Effect of Speed on Milling Time

Fig. 6 shows that; the effect of speed on the milling time. As observed in the graph, the variation of the milling time increases as the speed of the machine decreases. The minimum speed of 600rpm take 4.09 minute and the maximum speed of 1050 r.p.m take 2.39 minutes to mill 5.00kg of yam.

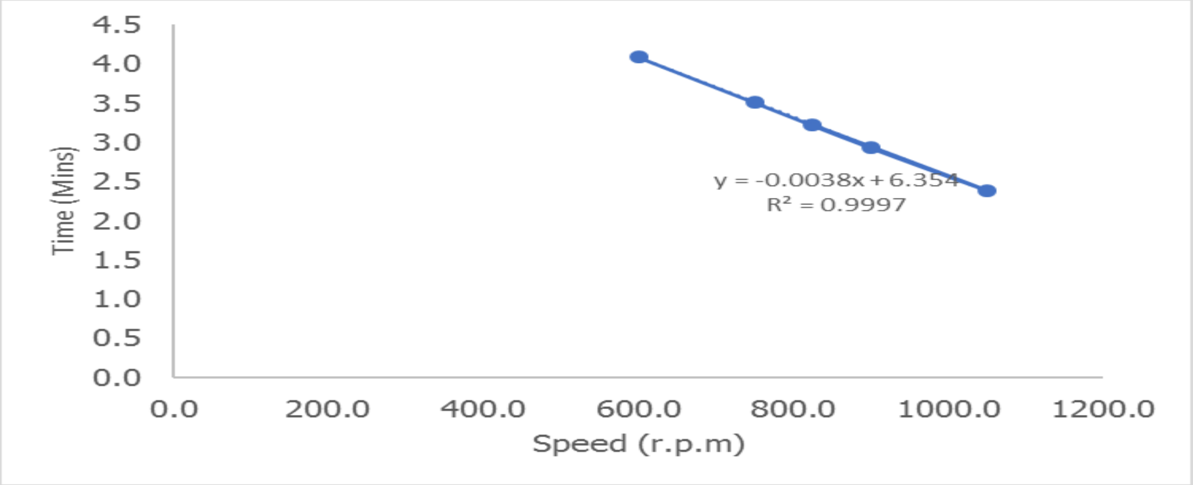

Figure 6: Effects of speed on milling time

Table 2: Test at different Speed for constant Moisture Content

Time (mins)	Speed (rpm)	M_{BM} (kg)	M_{CM} (kg/hr)	M_{AM} (kg)	M_{UM} (kg)	M_{FF} (%)	M_{UF}(%)
4.1	600.0	5.0	73.4	4.3	0.7	86.2	13.8
3.5	750.0	5.0	85.5	4.1	0.9	82.4	17.6
2.9	900.0	5.0	102.4	4.0	1.1	79.0	21.0
2.4	1050.0	5.0	125.5	3.5	1.5	69.6	30.4
3.2	825.0	5.0	96.7	4.0	1.0	79.3	20.7

3.3 Effect of Speed on Milling Efficiency

The variations of milling efficiency with the increasing speed of the machine are shown in Fig. 7 and Table 3.2. The graph shows that the milling efficiency reduced with increasing speed and decreasing time. The maximum milling efficiency of 86.20% was observed at the lowest speed of 600rpm with a feed rate of 73.35kg/hr.

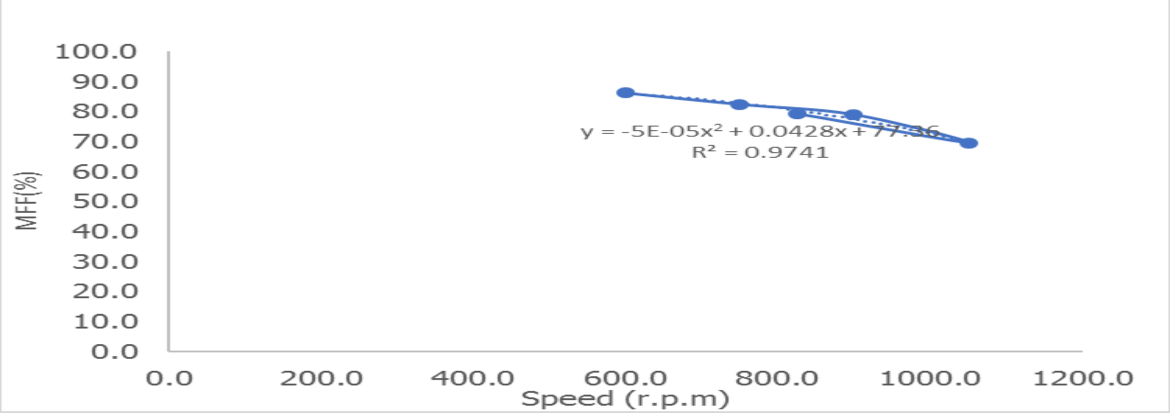

Figure 7: Effects of speed on milling efficiency

3.4 Effect of Speed on percentage of Unmilled Efficiency

Fig. 8 shows that; the effect of speed on the percentage of the unmilled efficiency. The variation in the percentage of unmilled increased with an increasing speed. It was observed from the experiment that; at lower speeds of 600 r.p.m, a percentage unmilled of 13.80% was obtained and at a higher speed of 1050rpm, the percentage of unmilled obtained was 30.40%, therefore percentage unmilled is lower when the machine is operated at a low speed and higher when the machine is operated at a higher speed.

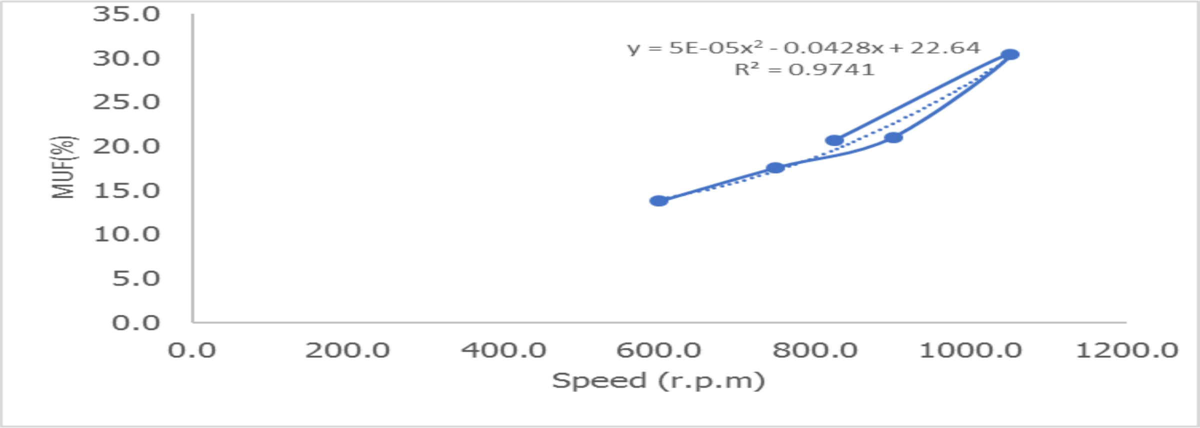

Figure 8: Effects on speed on unmilled efficiency

3.5 Modulus of Fineness and Uniformity Index

The result of the fineness test carried out on the milled yam flour is shown in Table 3 and Table 4 respectively and the following were taken into consideration.

Table 3: Result of fineness test on milled yam flour

No of sieve	Weight of empty sieve (g)	Weight of sieve sample (g)	+ Weight of sample (g)	Assigned number
4	492	492	0	5
10	414	414	0	4
30	379	379	0	3
50	325	337	12	2
100	310	326	16	1
Pan	372	427	100	0

Table 4: Modulus of fineness and modulus of uniformity index

No. of sieve	% retained	Assigned number	Product	Sum of % retained ÷10	Nearest whole number
4	0.000	5	0.00	0	0
10	0.000	4	0.00		
30	0.000	3	0.00	0.9275	1
50	9.275	2	18.75		
100	12.500	1	12.50	9.0725	9
Pan	78.225	0	0.00		
	100		31.25		

Where M_{BM} is the Mass of yam before milling (kg), M_{AM} is the mass of yam after milling (kg), M_{UM} is the mass of yam unmilled (kg), M.C is moisture content of the yam (%), M_{FF} is milling efficiency (%) and F.R.C is the feed rate capacity of the Machine (kg/hr).

3.5 Statistical Analysis of the Yam Flour milling Machine

The result of the fineness test carried out on the milled yam flour is shown in Table 1 and Table 2 respectively and the following were taken into consideration. Table 5 shows the output of statistical analysis using ANOVA.

Table 5: Statistical Analysis using ANOVA

	ANOVA	**RESULT**			
	Df	**SS**	**MS**	**F**	**Signif F**
Regression	1	11683.62	11683.62	28.62298	**0.033207**
Residual	2	816.3804	408.1902		
Total	3	12500			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
I Intercept	1071.625	130.6004	8.20537	0.01453	509.6965	1633.553	509.6965	1633.5
M_{FF}	-8.78468	1.641982	-5.35004	0.033207	-15.8496	-1.7198	-15.8496	-1.7198

4. Discussion

The performance of the machine was evaluated in terms of its milling efficiency at different moisture contents and pre-set speed. The following parameters were varied; Operational speed and moisture contents against the milling efficiency. The obtained values from the experiment in Tables 4.3 and 4.4, the milling efficiency of the machine was 79.20% when the machine was operated at an average speed of 825 rpm. At an average moisture content of 12.88%, the milling efficiency obtained was 81.40% at a constant speed of 900 rpm. As observed in the experiment, maximum milling efficiency of 86.20% was obtained at the lowest speed of 600 rpm with a feed rate capacity of 73.35kg/hr, and a percentage unmilled of 13.80% was obtained at a higher speed of 1050rpm with a feed rate capacity of 125.52kg/hr, Therefore percentage milled is higher when the machine is operated at a lower speed and higher when the machine is operated at a higher speed. It was observed from the experiment also that, at lower moisture contents of 7.5%, milling efficiency 92.40% was obtained and at higher moisture contents of 18.50%, milling efficiency obtained was 69.60%, therefore milling efficiency is higher when the machine is operated at lower moisture content. From the fineness test carried on the yam flour produced by the machine, the fineness modulus was obtained as 0.31 and the uniformity index as 0: 1: 9 (coarse: medium: fine). A fineness modulus of 2.10 and below signifies fine flour [11]. From the uniformity modulus obtained, it implies that the produced flour contains more fine materials. The two basic variables are Predictors: (Constant) TIME, SFF. MFF and Dependent Variable: SPEED. As observed in the table, the significance value is 0.033207 (i.e., p = 0.033207), which is below 0.05, meaning that, therefore, there is a statistically significant difference between the operational speed of the yam milling machine at 0.05 of level significance confident.

5. Conclusion

The yam milling machine was developed and performance evaluation showed that the moisture content, materials feed rate and interaction between them had a significant effect on the performance indices. It was concluded that; milling efficiency decreased with an increase in moisture content, milling time increases as the speed of the machine decreases and Milling efficiency reduces with an increasing speed. The machine was operated with 5 kg of slices dried yam sample and the milling efficiency obtained was 82.3% at an average speed of 825 rpm and 81.40% milling efficiency was recorded when operated at average moisture of 12.88 %. Also, the fineness modulus of the flour produced was found to be 0.31 with a uniformity index of 0: 1:9 (coarse: medium: fine). Thus, the yam flour mill when operated within the designed parameters will produce flour of fineness 0.31. With these performances, efficient milling has been achieved. The milling machine, if made available to small and medium-scale farmers, more yam flour will be produced with less drudgery in lesser time.

6. Recommendations

Based on the findings of this study on design and development of yam milling machine, the following recommendations were made for future improvement:

i. The performance evaluation was conducted for only one clearance, for better efficiency, it is recommended that other clearance values should be used to test the machine so as to derive the clearance that gives the highest efficiency for different times and feed rates.

ii. In other to improve the performance of the yam milling machine, the working components should be modified and assembled to withstand the stresses of the shelling operation over time.

iii. Complete automation of this machine will be a welcome idea since it will make it easier and more convenient for use.

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