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Design and Fabrication of an Improved Continuous Plantain Slicing Machine

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Abstract: *Plantains are of great nutritional importance. In Nigeria, plantain chips are in high demand and this demand is not being met due lack of mechanization of the production process. The major limitations towards attaining self-sufficiency in the production of plantain chips is the intensity of labour involved and the tediousness of the process which often culminate into prolonged production time. Thus, this research work is aimed at the design and fabrication of an improved continuous plantain slicing machine. In this research work, slicing of ripe plantain using different cutter blades with varying thicknesses of 3mm, 4mm, 5mm, 6mm and 7mm in a shear action was carried out to improve on damage efficiency, machine capacity and efficiency. Also, major components of an existing plantain slicer manually operated was modified and designed to specifications. The machine was powered using a 1.5hp motor with a rotational speed of 480 revolutions per minutes. Performance evaluation of the improved continuous plantain slicing machine recorded values of rotational speed at 45.7r.p.m for ripe plantain at a low damage efficiency value of 1.8% with a machine capacity of 641.7Kg/hr. for ripe plantain only. Chips of uniform sizes were produced in a short time of 270 seconds with a weight of 11.12kg for ripe plantain. Existing results from literature, strongly correlates with the results from this research work. Therefore, with this improvement in this new design, the aforementioned limitations will be overcome thereby making processing of plantain chip relatively easy.*

Keywords: *Rotational Speed, Slicing Time, Machine Capacity, Damage Efficiency, Varying Thickness Sizes of Cutter Blades*

INTRODUCTION

Nigeria is the largest producer of plantain in West Africa with large percentage of it obtained in the southern part of the country (Akinyemi *et al*., 1999; Adeoye et al., 2013; Akinsanmi *et al*., 2015; Ayanwale *et al*., 2016; Oyejide *et al*., 2018). Plantain is an extremely perishable crop. However, it can be processed and stored like chips and flour (Ikechukwu *et al*., 2014). Plantain can either be used for local consumption or used as byproducts for other production. When plantain is locally consumed, it plays a significant role in food and income security, and has the potential to contribute to national food security (Zapkaa *et al*., 2010; Arisa *et al*., 2013). It is useful as food to be consumed by human as flour or as jams and jellies; in chips etc. It can be processed via slicing, drying and grinding for production of plantain flour which is also consumed when baked (Okafor, and Okafor, 2013; Oyejide *et al*., 2018). There is high demand for plantain slices in form of fried plantain chips by travelers, office workers, school children, and families as part of breakfast. In an effort to make it readily available, several means have been devised in slicing plantain into pieces which is further processed into chips, flour, baked or fried (Okafor, and Okafor, 2013). The traditional method of plantain slicing via kitchen knife remains a primitive way of producing plantain chips in large quantities in small, medium and large scale industries. In this case, a sharp knife is used to slice the plantain usually placed on a wooden cutting board. The problems associated with this method are fatigue, low speed which leads to poor output and low income generation, too many staff, hand injury, poor uniformity of plantain chip thickness, and high productive time and energy consumption (Okafor, and Okafor, 2013).

Although, improved processes have made it possible to utilize plantain fiber for ropes, table mats and handbag (Chandler, 1995; Yomeni et al., 2004; Usman and Bello, 2017) but a lot still need to be done in the area of reduction in damage efficiency, machine capacity and improved efficiency. Ezugwu *et al.* (2019) investigated the design and fabrication of a motorized operated plantain slicer for optimum chips production. The machine produced chips of uniform sizes in a short time of 3 seconds and had a slicing efficiency of 96.84% and could effectively slice a 70 arm diameter of unripe plantain. Okafor and Okafor (2013) investigated plantain chip slicing machine that was designed, fabricated and tested to use a carrier spring return mechanism to achieve both the feeding option and the slicing operation. A slicing efficiency of 74% was recorded. Adesina *et al.* (2015) designed and developed a plantain slicing machine that was tested and evaluation with its performance for machine capacity of 52Kg, slicing efficiency of the machine was at 80% and the value of the length of the belt was calculated at 1039.85mm. The machine solved the problem of non-uniformity of chip thickness associated with traditional slicing methods as the time of slicing plantain for mechanical slicing was shorter but longer for traditional slicing method. Oloruntomilola *et al*. (2019) researched on solving the problem associated with tomato slicing. The throughput capacity was recorded as 468Kg/hr with a damage efficiency of 4% and a slicing efficient of 60.24%. However, percentage damage reported in the aforementioned research work was large. Thus there is the need to redesigned plantain slicing machine to curb the problem of percentage damage, also to improve in the machine capacity and efficiency.

MATERIALS AND METHODS

2.1 Material

The materials used for the project work include;

i. Mild steel angle bar
ii. Plantains
iii. Stainless steel sheet (SS410)
iv. V-belt (A-size)
v. Pulley (cast iron)
vi. Bolts and nuts

2.2 Methods

The following methods were carried out to achieve the aim of this research work.

A. Design Analysis

The following design analysis was carried out.

i. Determination of damage efficiency
ii. Determination of reciprocating arm speed (motor required)
iii. Determination of Torque
iv. Determination of Crippling load (LCR) of the connecting rod
v. Design for factor of safety

Damage Efficiency

The damage efficiency (DE) was determined, using Equation (1)

$$DE = \frac{Wdrp}{WT} \times 100 \quad (1)$$

where,

DE = Damage efficiency (%)

Wdrp = Weight of damage ripe plantain

WT = Total weight of sliced ripe plantain

Determination of Reciprocating Arm Speed (Motor Required)

The speed of reciprocating arm was determined used Equation (2)

$$R_S = \frac{2LN}{60} \quad (2)$$

where,

Rs = Arm speed (ms^{-1})

L = length of the longest ripe plantain pulp

Length of the longest ripe plantain pulp = 400mm

N = 1440 rpm

$$R_S = \frac{2 \times 400 \times 1440}{60} = 1.92 m/s$$

Determination of Torque

The required torque is given by Equation (3)

$$T = \frac{P \times 60}{2\pi N} \quad (3)$$

where,

T = Torque

P = Power of electric motor = 1.5hp or 111.19KW

N = reciprocating arm speed

$$T = \frac{111190 \times 60}{2 \times 3.142 \times 1.92} = 552.94\ Nm$$

Determination of Crippling Load of the Connecting Rod

The crippling load of the connecting rod is given by Equation (4).

$$L_{cr} = \frac{\pi EI}{L} \quad (4)$$

where,

Lcr = Crippling load of the connecting rod

E = Young modulus of elasticity of mild steel = 20.0GPa

I = 1.563 x 10^3mm^4

L = 400mm (length on ripe plantain pulp)

$$L_{cr} = \frac{\pi \times 200 \times 1.56}{400} = 6.13\ KN$$

Design for Factor of Safety

The machine frame designed was done considering factors of safety in order to validate the functionality of the continuous plantain slicing machine. The factor of safety was above 1; hence, there will not be any structural failure of the designed frame for the improved continuous plantain slicing machine. The factor of safety was determined from Equation (5).

$$F_s = \frac{Y_S}{W_S} \quad (5)$$

where,

Y_S = Yield strength of the mild steel material for the frame

F_S = Factor of safety

W_s = Working stress of the mild steel material for the frame

$$F_s = \frac{5.29 \times 10^8}{4.04 \times 10^8} = 1.31$$

Table 1 shows the properties of the material.

Table -1 Properties of the Materials Selected for the Improved Continuous Plantain Slicing Machine

Number	Property	Material	Values
1.	Yield strength	Mild steel	$5.29x10^8 N/m^2$
2.	Elastic modulus	Mild steel	$2.04x10^8 N/m^2$

3.	Mass density	Mild steel	$7846Kg/m^3$
4.	Poisson's ratio	Mild steel	0.27
5.	Tensile strength	Mild steel	$6.20x10^8N/m^2$

Assembly Process

The assembly process involves the joining of the different parts of the machine. The joint can be temporary or permanent. Some parts/components of the machine was assemble temporary while other parts/components permanently.

Safety Precaution Taken

Hazard is being posed during and after fabrication. For safety use of the machine domestically and commercially, necessary safety precautions were taken. The following safety precautions were taken;

i. Operator of the machine should be familiar with the mode of operation of the machine
ii. The machine should be switch off when not in use

Configuration of the Machine

Fig. 1 shows the picture of the fabricated continuous plantain slicing machine

Fig.1 Fabricated Improved Continuous Plantain Slicing Machine

Fig. 2 shows the front view of the improved continuous plantain slicing machine.

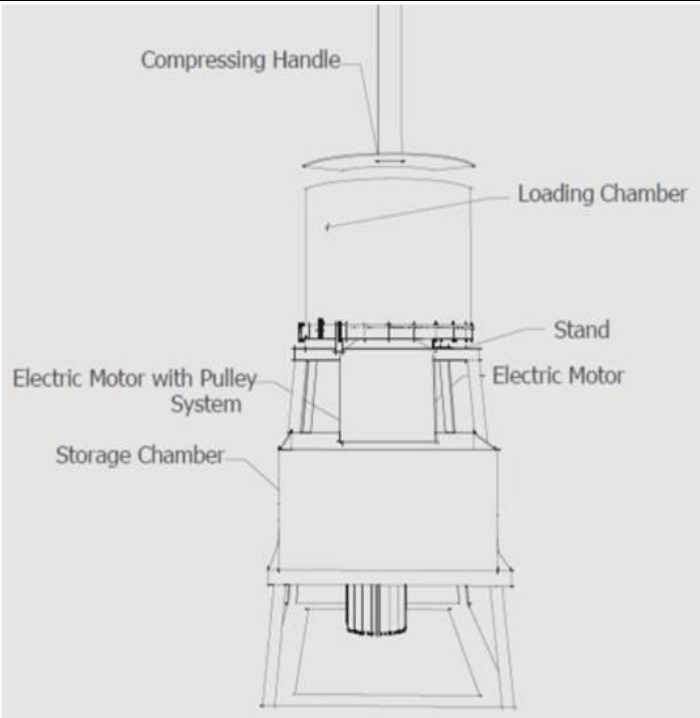

Fig. 2 Front View of the Improved Continuous Plantain Slicing Machine

Fig. 3 shows the left side view of the improved continuous plantain slicing machine.

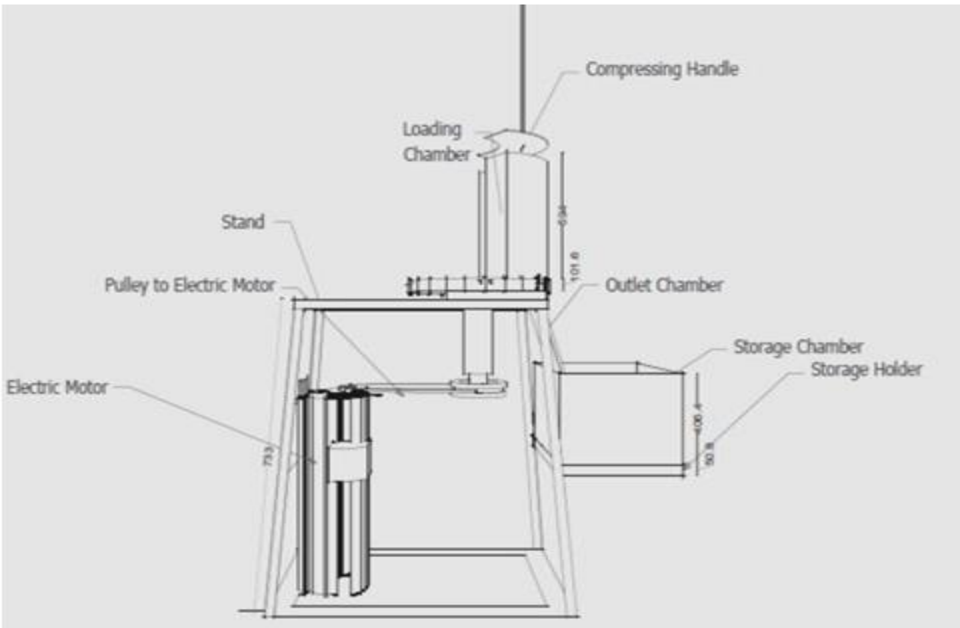

Fig. 3 Left Side View of the Improved Continuous Plantain Slicing Machine

RESULTS AND DISCUSSION

An improved plantain slicing machine has been designed, fabricated and evaluated using procedures that are standard. The results for rotational speed, machine capacity, obtained and the damage efficiency of the modified plantain slicing machine are presented in Table 2 and Table 3.

Testing Parameters

Data collected was carefully recorded and used for the analysis of the improved plantain slicing machine using the following output parameters:

i. Damage efficiency (%)
ii. Machine capacity (Kg/hr.)
iii. Rotational speed (rpm)
iv. Slicing Time (minutes)

The machine parts were assembled firmly and lubricated within the rotating parts. Without wobbling or making of noisy sound, the blades freely rotated during testing without load. When fully loaded, the modified plantain slicing machine chipped pulps of ripe plantain in a short time. Manually, 14 plantain pulps were peeled and fed into the feeder assembly after been sorted and weighed using a digital measuring scale. The time taken to slice the plantain pulps were recorded for 10 experimental runs using different speed ranges of 248rpm, 355rpm, 450rpm, 460rpm and 500 rpm with the average rotational speed recorded. The damaged slices per experiment were also weighed in order to determine damages and losses. Damage efficiency of the improved continuous plantain slicer was obtained.
The machine operated for 15 minutes which gave 14 slices in 3 seconds, thus 14 pulps of plantain were sliced in 3 seconds in one full evolution of the input shaft for flywheel.
Production rate = 14 plantain in 3 seconds.
Capacity per 1 hour = 641.8Kg/hr. (ripe plantain)

Table-2 Experimental Run for Ripe Plantain

Experimental Runs	Initial Weight (kg)	No of plantains sliced	Weight of chips produced (kg)	Weight loss (kg)	Slicing Time (Hour)	Throughput capacity (kg/hr.)
Test 1	12.26	61	4.84	7.42	0.091	53.187
Test 2	10.51	50	4.26	6.89	0.075	56.80
Test 3	13.59	68	5.09	8.50	0.071	71.69
Test 4	10.83	54	4.69	6.14	0.065	72.15
Test 5	10.76	53	4.91	5.85	0.072	68.19
Test 6	10.74	53	4.90	5.84	0.073	67.12
Test 7	10.61	52	4.85	5.76	0.081	60.62
Test 8	10.69	53	4.81	5.88	0.082	60.12
Test 9	11.38	56	4.91	6.47	0.080	61.38
Test 10	10.15	50	4.23	5.92	0.06	70.51
Total	Total=111.16kg Average=11.12kg	Total=550 Average=55 plantains	Total=47.49kg Average=4.75kg	Total=64.67kg Av=6.47kg	Total=0.747 Ave=0.075 hr	Total=641.77 Average=64.18 kg/hr

Total plantain = 550 Average = 55 plantain pulps
1 plantain weights 0.20143Kg
61 plantain = 12.26Kg pulps
Totals slicing time = 0.747hr

Average slicing time = 0.0747hrs= 4.48 minutes equivalent of 270 seconds
A set of ten (10) test samples were carried on the improved plantain slicing machine for rotational speed and time taken. The following results were obtained:

Table -3 Results of Rotational Speed (rpm) and Time Taken (minutes)

Ripe plantain pulps.	Rotational speed	Time taken (minutes)
1.	40.5	5.46
2.	42.6	4.5
3.	43.3	3.9
4.	49.1	4.32
5.	45.3	4.32
6.	46.4	4.38
7.	47.2	4.80
8.	48.6	4.80
9.	44.1	4.80
10.	50.1	3.60
	Total speed = 457.2	∑= 44.82
	Average 45.7r.p.m,	Average 4.48 minutes

A DT – 2234C+ Tachometer tachometer was used to measure the rotational speed of the shaft and the following values were recorded as shown in Table 3.

Performance Evaluation of an Improved Plantain Slicing Machine
Evaluation of the performance of the improved plantain slicer was carried out to establish slicing time as the capacity of the machine was determined by the time taken to slice a pulp of ripe plantain. The machine capacity is expressed as (Orhorhoro *et al.,* 2018):

$$Machine\ Capacity = \frac{Mass\ of\ Plantain\ Pulp}{Time\ Taken}\ (\frac{kg}{hr}.) \quad (6)$$

The damage efficiency is given by Equation (7).

$$D_e = \frac{W_{dp}}{T_{wgt}} \times 100\% \quad (7)$$

where,
W_{dp} = Weight of damaged sliced ripe plantain pulps
T_{wgt} = Total weight of all sliced ripe plantain pulps
De = Damage efficiency (ripe plantain pulps)

Ten (10) experimental replicates were done using the improved plantain slicer with 5 varying cutter blades. But for ripe plantain (7mm thickness was selected). In an average time of 4mins, the experiments were carried out with records taken per duration of time. Slices obtained were of uniform thicknesses, the thickness was checked using a vernier caliper and the weight of damage ripe plantain pulps calculated as shown in Table 4. From the results of damaged plantains, damage/loss of plantain pulp was very minimal and this was as results of improvement in the scraper in the cutter blade to scrape the residue and prevent clogging that may impede fast flow of discharge of slices into the collection tray. Besides, a cutter blade of 7mm was used. Uniform sizes of slices for ripe plantain pulps were obtained. Very minimal damage because the blades were very sharp, the cutting was smooth without obstruction. Only 0.89 of the total sliced plantain of 47.49kg was damaged showing that, the modified slicer in this research work is economical and suitable for slicing ripe plantain pulps for both down and commercial purposes due to the machine capacity of 641 Kg/hr. obtained. Furthermore, the difficulty of removing and sharpening of the cutter blades, and ripe plantain sticking to the cutting chamber and the blade edges as reported in Ekunwe *et al.,* (2010), have been addressed in this research work.

Table 4. Weight of Damaged Plantain

S/N.	Test samples	Weight of sliced ripe plantain (Kg)	Weight of Damaged plantain (Wdp)= Weight of sliced ripe plantain – Total weight of damage ripe plantain.
1	Test 1	4.84kg	0.1019
2	2	4.26	0.0897
3	3	5.09	0.1071
4	4	4.69	0.0987
5	5	4.91	0.1033
6	6	6.90	0.1032
7	7	4.85	0.1021
8	8	4,81	0.1013
9	9	4.91	0.1033
10	10	4.23	0.0891
	10 samples	Total = 47.99kg Average = 4.74kg	Total = 0.8965 0.8965 kg Average= 0.0896

Table 5 Bill of Engineering Measurement and Evaluation (BEME) used for the design and fabrication of the improved plantain slicing machine for ripe plantain.

Table 5. Bill of Engineering Measurement and Evaluation (BEME)

S/N.	Description	Materials	Quantity	Rate	Total Cost (₦)
1.	Mild steel				
2.	Electric motor	111.19KW(1.5hp)	1	15,000	15,000
3.	Electric cable	1.5x3core	4yrds	200	800
4.	Bolts and Nuts	Steel M 101.25	12	50	600
5.	Electrode	Guage 14	1 packet	1,650	1,650
6.	Belt	A37	1	550	550
7.	Angle bar	40x40x3mm	1	3,500	3,500
8.	Cutting disc		3	400	1,200
9.	Paint	4 litres	2 cups	1,850	3,700
10.	Bearings		1	2000	2,000
11.	Labour			10,000	10,000
12.	Miscellaneous			5,000	5,000
			Total	40,200	134,000

Table 6 shows the results of damage efficiency, rotational speed and machine capacity (ripe plantain)

Table-6 Results of Damage Efficiency, Rotational Speed and Machine Capacity (Ripe Plantain)

Output Parameters (Responses)	Units	Calculated Value
Damage efficiency	%	1.8 %
Rotational speed (speed of pulley)	rpm	457
Machine capacity	Kg/hr.	64.1
Speed ratio for belt drive	rpm	480
Slicing efficiency	%	98.1

Power	hp	1.51

CONCLUSION

An improved continuous plantain slicing machine was successfully designed, fabricated and evaluated for performance. The results of the performance evaluation showed that the improved plantain slicing machine has a machine capacity of 641Kg/hr., average slicing time of 4 minutes, damage efficiency of 1.8% and average rotational speed for using the pulley at 45.7 rpm. Maintenance of the machine is easy as rotating parts are lubrication and cleaned after usage. With this new plantain slicer, the problems of safety, quality and quantity of sliced plantain associated with manual slicing have been eliminated. The plantain slicer is environmentally and user friendly and does not require any special skill to operate.

CONFLICT OF INTEREST

There is no conflict of interest in this research work.

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