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DESIGN AND FABRICATION OF A MOTORIZED/ POWER OPERATED PLANTAIN SLICER FOR OPTIMUM CHIPS PRODUCTION

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ABSTRACT
In Nigeria, plantain chips are in high demand and this demand is not being met by most small scale food industries and shops due to some critical factors. Shops are only able to fulfill approximately two-thirds of the demand. The biggest obstacle towards attaining self-sufficiency in the production of plantain chips is the intensity of labor involved and the tediousness of the process which often culminate into prolonged production time. Plantain has a large amount of sap and this causes the skin to adhere to the fruit inside. After peeling, they must be sliced into discs to fry into chips. Worker will hold up to eight plantains in one hand and rapidly slice them using a wooden mandolin. Because of the rapid pace at which they slice plantain and the absence of

hand gloves on the workers, accidents are very often unavoidable. These presents health hazards to both the worker, who may develop infections from their injuries, and customers who may consume an unsanitary product. This development is very uncomfortable and tasking on the workers. They must hold the mandolin over the fryer so the plantains will fall in, which causes splashing of the boiling hot oil that occasionally hits and injures the worker.

This research focused on design and fabrication of motorized / power operated plantain slicer to meet the raising demands for plantain chips in Nigeria. The objectives of this research was met as the machine has the capacity to produce plantain chips of uniform size in shorter time and a greater slicing efficiency of up to 96.84% while keeping the cost of the machine at an affordable price.

Key words: Plantain Chips, Uniform Size, Motorized, Slicer, Power Operated.

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1. INTRODUCTION

Plantain contains more starch and less sugar than dessert bananas; therefore, they are cooked or otherwise processed before being eaten [1]. They are always cooked or fried when eaten green. At this stage, the pulp is hard and the peel is often so stiff that it has to be cut with a knife to be removed. Mature plantain can be peeled like typical dessert bananas. The pulp is softer than in immature, green fruit and some of the starch have been converted to sugar [2, 3]. They can be eaten raw but are not as tasty as dessert bananas, so are usually cooked. When mature, yellow plantains are fried, they tend to caramelize - turning a golden brown color. They can also be boiled, baked or grilled over charcoal - both peeled and still in the peel [4, 5]. An average plantain has about 220 calories and is a good source of potassium and dietary fiber.

Plantains are a staple food in the tropical regions of the world, specifically the tenth most important staple that feeds the world. Plantain is treated in much the same way as potatoes and with a similar neutral flavor and texture when the unripe fruit is cooked by steaming, boiling or frying [6, 5].

Plantain fruits all year round, which makes the crop a reliable all-season staple food, particularly in developing countries with inadequate food storage, preservation and transportation technologies [7]. In Africa, plantain and bananas provide more than 25 percent of the carbohydrate requirements for over 70 million people. In Ghana and Nigeria, most farmers are unable to meet the export requirements for green plantain because of poor post-harvest handling practices and strict quality standards required for the export market [8, 9 10]. To avoid blackening and fungal decay of harvested plantains, most farmers sell their produce cheaply to middlemen at the farm gate. Slicing, frying and packaging as snack food, that is plantain chips, is a method that reduces post-harvest losses to green or ripening plantain. The use of a power operated plantain slicer can simplify the processing method [11].

The conventional method of cutting plantain into chips is to use a sharp kitchen knife to cut the pulp of the plantain fruit on a board. This method is labor intensive, time-consuming and prone to injury and it can only be practiced on a very small scale of production [12, 13]. Plantain chips produced this way are never of uniform size, which is why the use of a power operated plantain slicer is very necessary to reduce the labor associated with continuous cutting of bulk plantains with a knife. The use of a power operated plantain slicer will facilitate mass production of plantain chips. More so, this can contribute to food security, export earnings and economic growth [14, 15, 16].

Okafor B.E and Okafor V.C.,2013[16]designed a plantain chips slicing machine, which is made up of a cutting device, a feeding mechanism, a support frame and an electric motor as a source of power. Stainless steel was used as the cutting blades; the blades are arranged perpendicular to the plantain chips. They used a Geneva drive for the feeding and discharge mechanisms. The Geneva drive was designed to deliver intermittent motion to the conveyor, thereby causing the conveyor to move in a start-stop fashion.

G.Y.Obeng, 2004, [17] also designed a plantain slicer, the plantain slicer consists of a main frame, cutters, bottom plate and a container, all fabricated from 2mm stainless sheet, a wooden mesh made from oak wood, bolts and nuts, woodscrews and pins. The cutters of the slicer are designed to be parabolic in shape and are arranged at intervals that will enable the required thickness of plantain chips to be attained.

Relating to gross value of production, Plantain and banana are one of the very most crucial/important fruits in developing world [18, 19].

There are four main types of plantain available in Nigeria distributive, which are strictly based on the bunch characteristics and they include the following horn types: French type, false type and French –horn type but in Nigeria the false hone type is the most widely distributed because of its ability to tolerate poor soil condition than others [20].

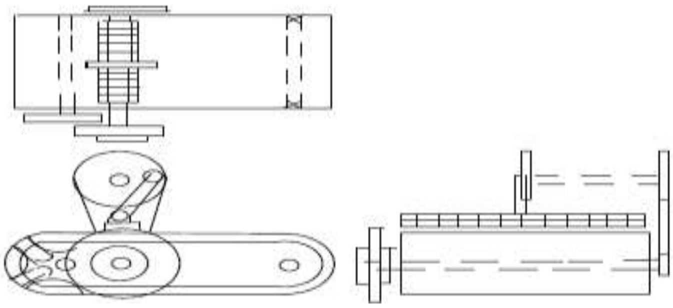

Figure 1 Orthographic View of Plantain Slicing Machine

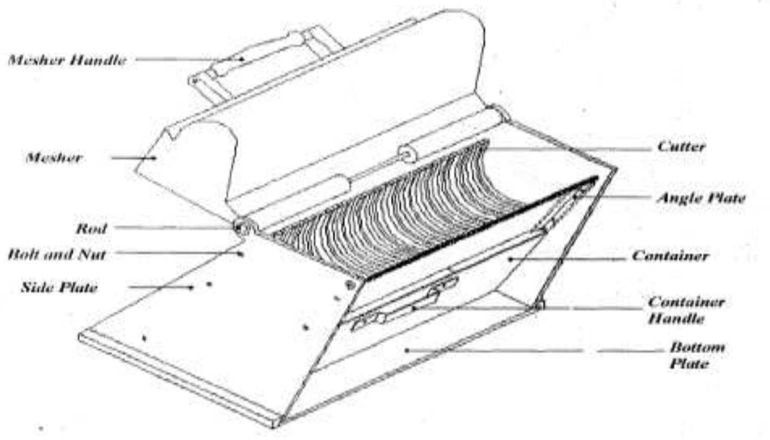

Figure 2 Pictorial View of Plantain Slicer, G.Y.Obeng, 2004 [17]

2. MATERIALS AND METHODS

2.1. Material Selection

The knowledge of materials and their properties is very important before design and consequently construction. The machine members and/or elements would be selected based on the following factors which include:

- The Physical and Mechanical properties
- Physical properties: these include properties such as density, co-efficient of linear expansion, thermal conductivity, melting point etc.
- Mechanical properties: This includes properties such as strength, stiffness, elasticity, ductility, shear stress, toughness, yield strength etc.
- Suitability of the materials for the working conditions in service. For example, whether corrosion is involved or not.
- Cost of the materials
- Durability of the materials,
- Availability of the materials,
- Manufacturing requirements.

This data was documented by S.P Sonawane, G.P, Sharma, and A.C Pandya [18]. The physical and mechanical property of raw plantain is given in the table below:

Table 1 Physical and mechanical Property of Raw Plantain

S/N	PROPERTIES	VALUE
1	Diameter (max) (mm)	40
2	Length (max) (mm)	200
3	Average weight of single fruit (g)	201.43
4	Average specific gravity (dimensionless)	1.005
5	Force required to cut plantain (max) (N)	30
6	Cutting load per unit width (N/mm)	0.821

2.2. Design Consideration

The following were the main consideration in the design of the motorized plantain slicer:

- The machine should be able to slice the required number of plantain efficiently and should be simple as possible to ensure ease of operation.
- In the selection of materials for construction, adequate care was taken not to use materials that can contaminate the plantain and also materials that cannot corrode easily due to the high acidic content of the plantain
- The product surface must be free from crevices which can harbour bacteria

3. DESIGN CALCULATIONS

3.1. Design for Hopper

The hopper was designed to accommodate the allowable volume of plantain per charge. A convenient dimension was selected for the hopper design. The hopper was designed to take the shape of a trapezoidal prism with only one sloppy side, to control the slanting position of the plantain. With a 1mm stainless steel plate, the volume of the hopper occupied by steel was calculated using the formula

Volume of trapezoidal prism = Area of trapezoidal prism x height (1)

$V = A \times H$

Area of the prism = $\frac{1}{2} \times (a+b) \times h$ (2)

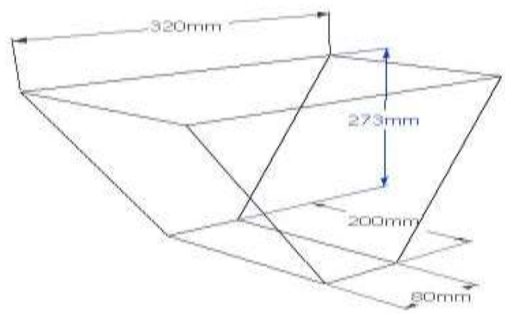

Figure 3 Isometric view of Exaggerated Hopper

From above figure,

$a = 80mm$,

$b = 320mm$,

$h = 250mm$,

$H = 200mm$

Therefore volume of the trapezoidal prism:

$A = \frac{1}{2} \times (80+320) \times 250$

$A = 50{,}000mm^2$

$V = A \times H$

$V = 50000 \times 200 = 10{,}000{,}000mm^3$

$V = 10^7 mm^3$

Unwanted section

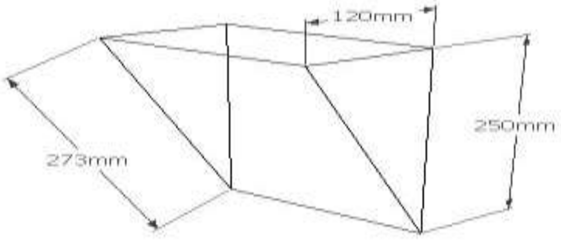

Figure 4 Isometric view of unwanted triangular prism

Volume of triangular prism = ½ x b x h x H (3)

Where:

b = triangle base length (120mm)

h = triangle height (250mm)

H = distance between triangles (200mm)

Therefore,

Volume of unwanted triangular prism = ½ x 120 x 250 x 200 . (4)

Volume of unwanted triangular prism = $3x10^6mm^3$

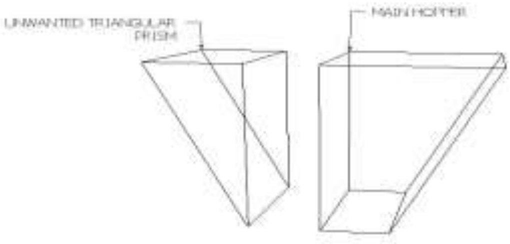

Figure 5 Isometric view of main hopper separation

Required hopper Volume = [Trapezoidal prism Volume] – [Triangular prism volume] (5)

Hopper Volume = $10^7mm^3 - 3x10^6mm^3 = 7x10^6mm^3$

Thus the weight of the hopper would be obtained by:

W = ρ x v x g …… (6)

Where

W = Weight of the hopper [N]

P = Density of the hopper [kg/m^3]

g = Acceleration due to gravity [m/s^2]

= 7800 x $7x10^{-3}$ x 10

= 546N

3.2. Design for Cutting Chamber

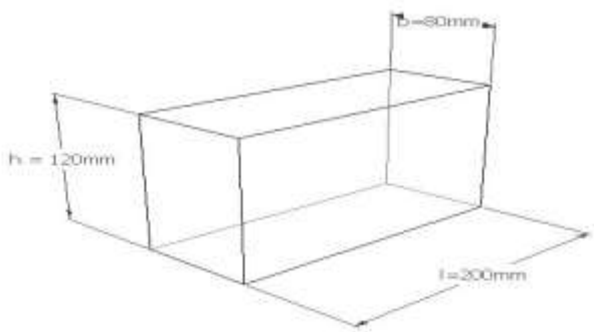

Figure 6 Isometric view of the Cutting chamber

Volume = l x b x h………………………… (7)

Where: l = length of cutting chamber [mm] b = base length of the cutting chamber [mm]

h = height of cutting chamber [mm]

= 200 x 80 x 120

= $1.92\text{x}10^6 mm^3$

= $1.92\text{x}10^{-3} m^3$

Thus the weight of the cutting chamber can be calculated as

$$W = \rho \text{ x } v \text{ x } g$$

Where: W = Weight of the hopper [N]

P = Density of the hopper [kg/m³]

g = Acceleration due to gravity [m/s²]

$$W = 7800 \text{ x } 1.92\text{x}10^{-3} \text{ x } 10$$

$$= 149.76N$$

3.3. Power Required to Cut a Single Plantain

Depending on the thickness of plantain chips, one plantain gives an average of 12 chips. [6]

Energy required to cut one slice of plantain (measured value) = 0.0736 kgm

Torque required for cutting a slice of plantain = Energy x Gravitational Acceleration …. (8)

Torque, T = 0.0736 x 9.81 = 0.72 N-m

Considering a factor of safety of 1.5;

Required Torque, T = 0.72 x 1.5 = 1.08 N-m

But angular velocity, $\omega = 2\Pi n/60$ (9)

= 2Π (75)/60 = 7.86 rad/sec

Thus, power needed to cut a plantain, P = Tω (10)

= 1.08 x 7.86 = 8.48 Watts

Power required to cut 12 plantain, P = 12 x 8.48 = 101.8W

=0.102kW = 0.137hp [6]

Electric motor specification

Motor Speed = 1400rpm

Current = 5.1A

Power = 0.75kw = 1hp

Speed Reduction

To reduce the output speed of the shaft to 35rpm, a reduction gear is used and the gear ration is calculated below

$$\text{Ratio} = \frac{\text{Current motor speed [N1\}}}{\text{Required motor speed [N2\}}} \quad (11)$$

$$= \frac{1400}{35} = 40{:}1$$

A gear of ratio 40:1 is used to give us the required speed of 35rpm.

3.4. Crank Slider Mechanism

The crank slider mechanism used to transmit rotational torque from the electric motor to the pressing bar is as shown in fig below. There are two major types of crank slider mechanisms which are:

In–line crank-slider

Offset Crank-slider

The crank slider mechanism adopted in this project is the in-line crank-slider mechanism and it is explained thus:

In-line Crank-Slider

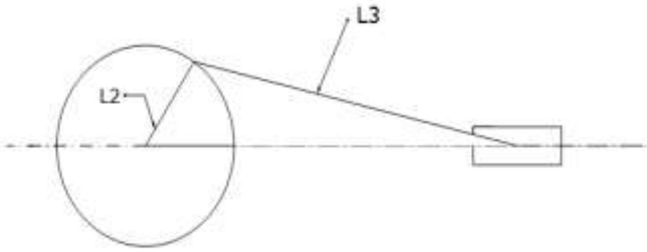

Figure 7 Crank slider mechanism

Q (time ratio) = $\frac{\text{Time of slower stroke}}{\text{Time of faster stroke}}$… (12)

Q = $\frac{4.2 \text{ secs}}{3 \text{ secs}}$ = 1.4

The imbalance angle (β):

$\beta = 180^o \times \frac{Q-1}{Q+1}$ (13)

$\beta = 180^o \times \frac{1.4-1}{1.4+1} = 30^o$

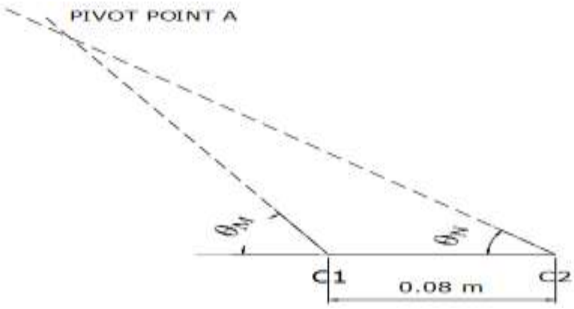

Figure 8 How to locate the axis of the pin joint C

The pin joint C moves over the axis of the stroke, we can draw the stroke line and determine the extreme axis of the stroke and call them C1 and C2 as shown above. The line shown in fig (3.5) of C1 and C2 is 80mm and is showing the extreme position of the slider. At C1 we draw a line at an angle of θ_M, also we draw a line that crosses the line from C1 at point A, at an angle of θ_N.

Therefore, $\theta_N = \theta_M - \beta$. (14)

$\theta_N = \theta_M - 30^o$

Knowing that the crank radius = ½ x Stroke length

Therefore, Crank radius = ½ x 80mm = 40mm

L2 = 40mm

L3 = AC1 + 40mm

The measured value of AC1 = 160mm

L3 = (160 + 40) mm = 200mm

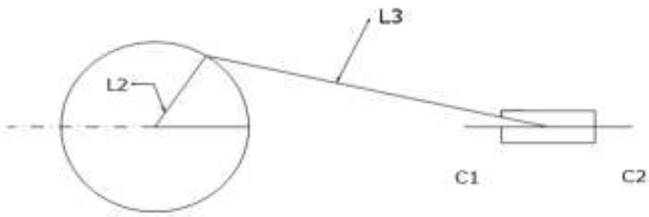

Figure 9 Crank Slider Mechanism Showing the Maximum Displacements C1 & C2

3.5. Capacity of the Machine

The slicing machine is designed to cut 6 pieces of plantain in 4 seconds.

Therefore;

Production Rate =6 plantains in 4 seconds

This implies that the machine slices 6 pieces of plantains in 4 seconds during one full crank revolution.

Average weight of Plantain = 0.20143kg

Weight of 6 Plantain = 0.20143 x 6 =1.20858kg

Capacity (Kg/sec) = 1.20858/4 = 0.302145

Capacity (kg/hour) = 0.302145 x 60 x 60 = 1087.72 kg/hr.

Capacity for 8 working hours (kg/day) = 1.087.72 x 8 = 8701.776 kg/day

4. PERFORMANCE EVALUATION

Prior to the testing, the machine was firmly assembled and aligned as shown in the figure below. The parts were also lubricated to reduce friction within the rotating members. The belt was connected to the pulley and the electric motor. The electric power was provided to the machine by the means of electric engine and test running was carried out for ten minutes without load in order to understudy the behavior of the machine. It was observed during this testing that the blade rotated freely without wobbling. Thereafter, the machine was tested with load and during the process, the raw plantain held by hand was forced into the chute and with the aid of a short wooden stick with a stopper, the raw plantain was forces into the cutter which slices it in the shortest possible time. In this case, it took 2-3 seconds, depending on the length, to slice a finger of raw plantain.

Figure 10 The Designed plantain slicer

5. CONCLUSIONS

The research focused on the design and fabrication of a motorized/ power operated plantain slicer for raw plantain chips. The raw materials used for the fabrication were sourced locally. The machine was designed for food industries but it can also be used for domestic purposes. The slicing efficiency of the machine was found to be 96.84% and can slice up to a maximum of 70mm diameter of raw plantain. The duration for slicing a finger of raw plantain was found to be between 2-3 seconds. The machine is user friendly and requires regular lubrication of the rotating parts to reduce wears and tears.

RECOMMENDATION

From the performance evaluation carried out, there are some improvements that can be carried out in order to further advance the processing of raw plantain into chips. The spacer should be designed and positioned away from the cutting chamber and more suitable means of varying the thickness of cut should be provided

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