Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.7, No.4, 2016

Modification of a Locally Made Palm Fruit (Elaeis Guineensis) Stripping Machine

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Abstract
Palm fruit is an edible oil crop which needs to be processed for oil extraction. However, the manual method of stripping and the existing palm stripper are found ineffective due to prolonged stripping time leading to low quality and quantity of oil produced. Modern methods of stripping have greatly improved production rates and reduced stripping time. The main objective of this study was to improve on the design of an existing palm fruit stripping machine so as to optimize its efficiency at low cost, reduce total time of stripping and produce hygienic and quality oil. The improvements on the design of the palm fruit stripping machine were achieved by increasing the throughput on the capacity by improving the material selection and other design criteria for various component parts. An adequate size electric motor to power the speed of stripping and a new stripping chamber were installed in the stripper. The machine consists of stripping unit, gear system frame, and discharge outlets for stripped fruitlets and empty bunches. The results of the improvements carried out on the design of this stripping machine shows that maintenance cost and stripping time are reduced, operation of the machine does not require special skill, the machine is easy and safe to operate, it is noise and vibration free, the energy required for loading and unloading have reduced since stripping chamber and discharge outlet are enlarged. The results indicated that stripping efficiency of the machine and the clean fruit recovery were 98.91 % and 96.03 %, respectively. The feed rate of the stripper ranges between 341.4 kg/h and 360.02 kg/h, the output capacity ranges between 227.47 kg/h and 275.78 kg/h while the operating capacity is 70.54 g/s. Therefore, the palm fruit stripper is recommended for the small and medium scale oil palm fruit processing industries.
Keywords: Design and fabrication, palm fruit, stripping, clean fruit recovery.

1. INTRODUCTION

Palm oil plays an important role in the agricultural and economic sectors of those countries where it is found. The discovery of oil palm fruit (*Elaeis guineensis*) is as old as man, although the production involved purely manual and traditional tools. It is originated in the tropical rain forest region of West Africa, in which the main belt runs through the southern latitudes of Cameroon, Cote D'ivoire, Ghana, Liberia, Nigeria, Sierria Leone, Togo and into the equatorial region of Angola and the Congo (FAO, 2004). Samuel and Alabi (2012) reported that productivity in Nigeria was poor and such important vegetable oils should be highly produced to meet demands. The total money of $186.65 million was spent by Nigeria to import vegetable oil from Malaysia in 2001, this showed sad state affair of the country (Samuel and Alabi, 2012).

The palm oil and palm kernel oil have a wide range of applications; about 80 % of the palm oil produced finds its way into food products while the rest is feed stock for a number of non-food applications. The by-products of oil palm fruit processing such as empty bunches and fibres can further be processed as raw materials for potash fertilizer, pulp and paper manufacturing (Ologunagba *et al.,* 2009; Salamiah, 2000). The kernels contain 80 % oil and 9 % protein (FAO, 2009) and are processed for oil and cake. The oil is used for the producing edible oil, margarine, confectionary, soap, candle glycerin and ice cream. The cake is used for formulation of animal feeds. The shell fragments can be used as renewable energy (fuels) and for decoration of living apartments (FAO, 2009; Mahmud *et al*., 2009; Antia *et al.,* 2014).

Stripping or threshing of palm fruit involves separating the sterilized fruits from the bunch stalks. Sterilized fresh fruit bunches are fed into a drum stripper and the drum is rotated, causing the fruits to be detached from the bunch; the bunch stalks are removed as they do not contain any oil (FAO, 2004). Traditionally, the harvested palm fruit bunches are heaped and allowed to ferment to facilitate easy stripping of the fruits. The picked fruits are then collected and digested into a mash, after which it is mixed with water and agitated in a pit to separate the crude oil from the mixture. After adequate mixing, the oil that floats at the tip is scooped off for clarification (Ologunagba *et al.,* 2009). Apart from the drudgery, time wasting and high labour requirement in this method, it gives less quality oil and the period of fermentation increases the free fatty acid content of the oil. Hence, it is important that fresh fruit bunches be processed as soon as possible so as to prevent a rapid rise in free fatty acid which normally affects the quality of the crude palm oil been produced (Ologunagba *et al.,* 2009).

In Nigeria today, a lot of work has been done on palm fruit stripping and most of the mechanized systems of stripping oil from palm fruit bunches consist of a rotating drum or fixed drum equipped with rotary beater bars detach the fruit from the bunch, leaving the spikelet on the stem. These strippers are available in NIFOR, Benin and Nigeria (FAO, 2004). Ologunagba *et al.* (2009) reported that when manually operated a dual powered palm fruit stripper, the machine had a through put capacity of 0.612 tons/h, stripping efficiency of 68.9% and quality performance efficiency of 47.4% at a sterilization time of 90 minutes. When tested with 2.25KW electric motor at three beater speeds (250, 350 and 450 rpm) and at sterilization time of 30, 60 and 90 minutes, the machine gave best performance at 450 rpm and sterilization 90 minutes.

In Southwestern Nigeria, oil is extracted by crude method, the palm fruit bunches are heaped to ferment for about five days and later beaten with stick to detach the fruit lets from the bunches (Jekayinfa and Bamigboye, 2008). The picked fruits are cooked and digested into a mash which is mixed with water and agitated in a pit. The edible oil is separated and floated on the top where it is scooped off for clarification (Ojomo *et al.,* 2010). The crude techniques of producing palm oil are inefficient, time wasting, arduous and requires high labour (Bamigboye and Jekayinfa, 2007). It was reported by Badmus (1991) that highest oil extraction of 87 % could be produced if fruits were processed without delay or fermentation and better quality oil with low fatty acid and carotenoid content would be yielded. This means fresh fruit bunches must be processed as soon as possible to prevent a rapid rise in free fatty acid which normally affects the quality of the crude palm oil (Badmus, 1991; Wan Ishak *et al.*2011).

It was reported by Jekayinfa and Bamigboye (2004) that shortages of palm oil production might be due to energy required in processing, over the years in West Africa in particular, and other parts of the world, have necessitated the need to improve upon the design of various palm oil processing machines. By so doing, there will be enhancement in the productivity, efficiency, ergonomics and safety of handling the machine in order to achieve its cost effectiveness and its operation in a more hygienic, conducive and environmentally friendly conditions (Uthman *et al.,* 2016).

It has been observed in our localities that the traditional method of stripping palm fruits by peasant farmers and resource poor is stressful because it involves a lot of drudgery during the peak of harvest. This method is time consuming and ultimately resulting in poor quality products due to contamination while the materials are exposed and stripped with bare feet. Thus, low income output is produced by the farmers. The fact that the cost of imported strippers are often beyond the reach of the peasant farmers who constitute the critical mass of the farmers group has made the modification of the stripper in this study inevitable. The products processed with the existing palm fruit stripper are often under stripped and sometimes end product contains a lot of fruit fibre thus resulting in diminished quality oil content. The stripper also has a lot of deficiency in terms of stripping time, efficiency and productivity. There is need to modify the stripper with a view to improve its efficiency and reliability.

In view of this, there is need to improve on the existing design of a palm fruit stripping machine for high production rates at low cost and with locally available materials that allow for easy operation and maintenance. The main objective of this study is to redesign a palm fruit stripper for stripping palm fruits by reconstructing the machine frame, stripping chamber, discharge outlets and incorporate a prime mover and evaluate its performance so as to:

- Reduce total time of stripping
- Produce quality edible oil (acceptable colour)
- Increase the stripping efficiency at low cost
- Achieve noise free operation and vibration

2 MATERIALS AND METHODS

The problems associated with the operation of manual methods and existing stripper due to the shortcomings in its design were identified. The necessary procedures were carried out to eliminate the causes of the shortcomings observed vividly. Problems identified with the manual and existing design of palm fruit stripper are:

- Fermentation period that increases the free fatty acid content of the oil.
- Longer stripping time of the fruits
- High noise and vibration during operation
- Difficulty of clean fruit recovery

2.1 The redesigned palm fruit stripper

The improvement on the existing machine for stripping palm fruit was carried out based on the problems associated with its design, that is, reconstructing the machine frame, stripping chamber, discharge outlets and incorporate an adequate electric motor. The dimensions of the component parts are shown orthographic projection of the palm fruit stripping machine in Figure 1 while Figure 2 shows the isometric view of the machine.

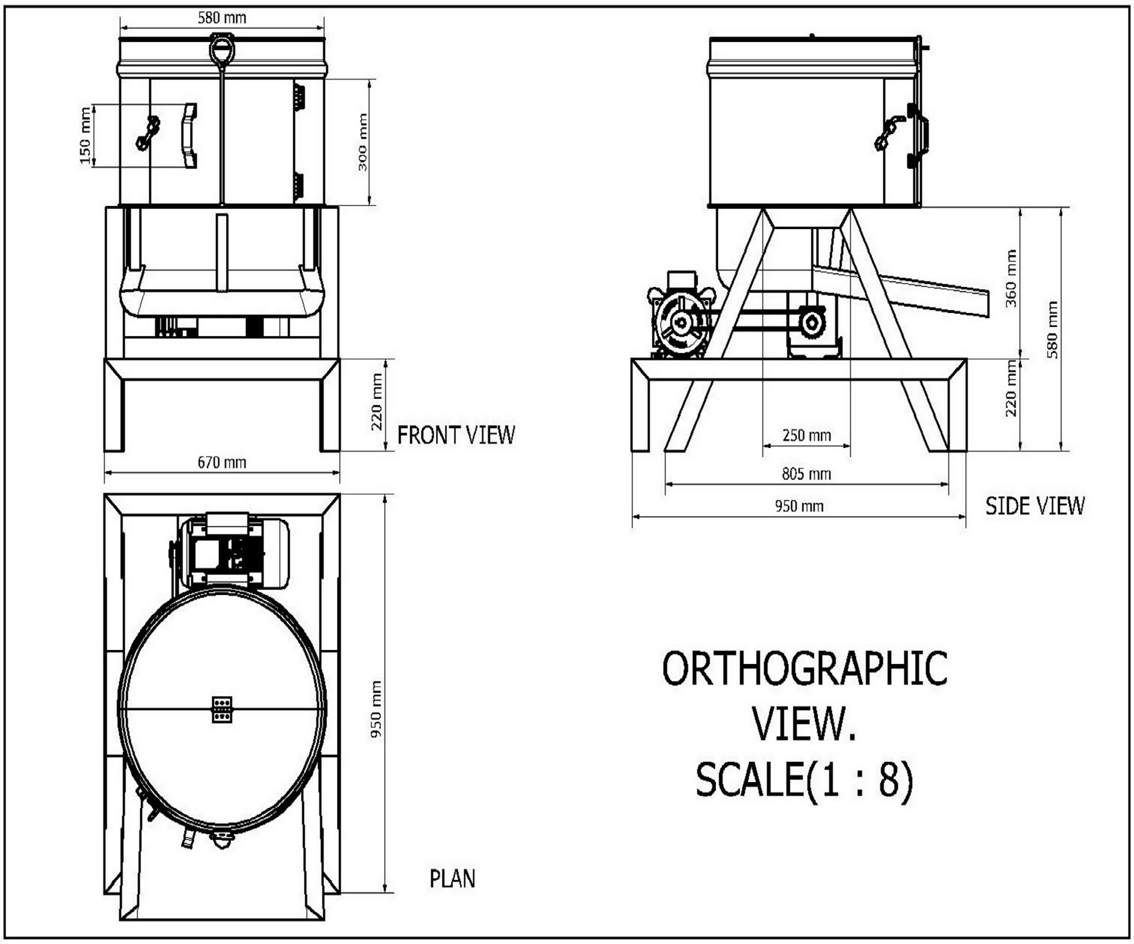

Figure 1: The orthographic view of the palm fruit stripper

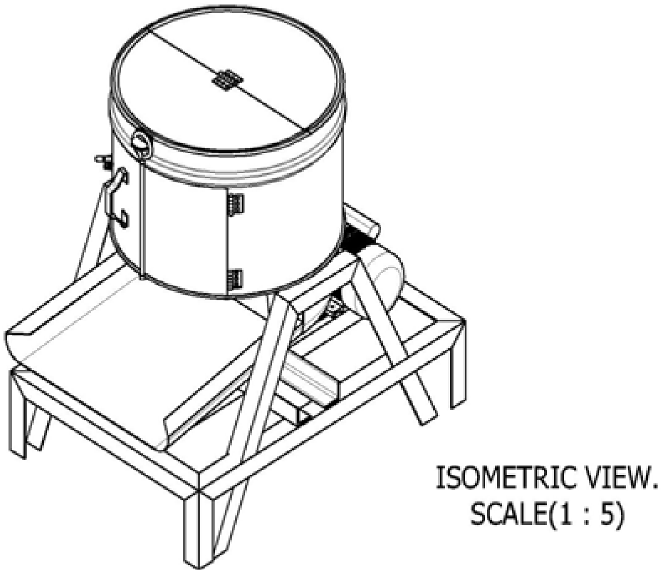

Figure 2a: The isometric view of the palm fruit stripper

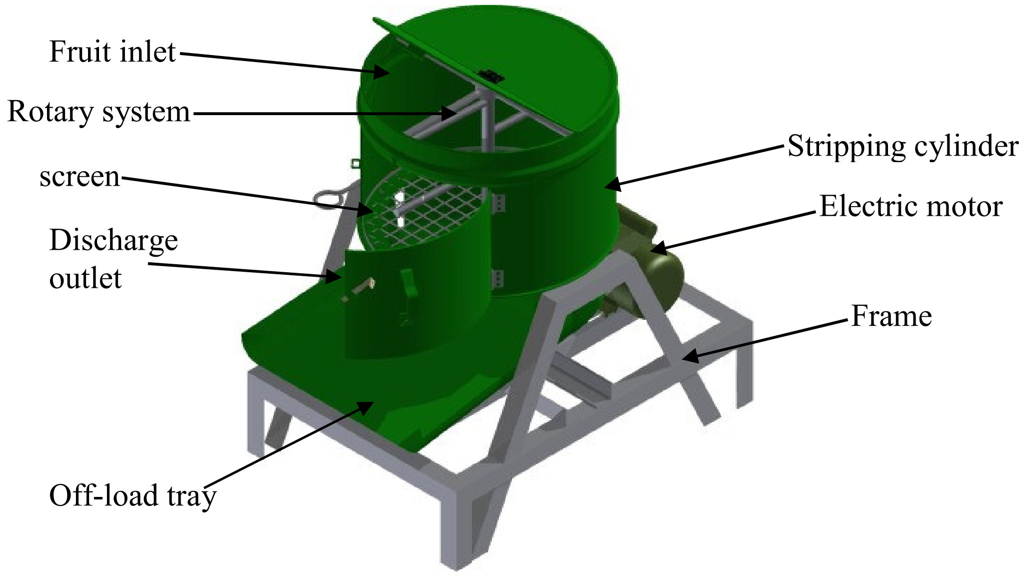

Figure 2b: The isometric view of the palm fruit stripper

2.2 Design considerations for the improved palm fruit stripper

Some factors were considered in the design of palm fruit stripping machine in order to produce high quality and quantity of oil. The factors considered are as follows:

- The availability and cost of materials required (relatively cheaper than imported ones)
- Ease of operation (feeding and discharging of materials)
- The stripping chamber is a batch type
- Can be operated by one person
- Size and weight of the machine
- Ease of Maintenance
- Safety

Component parts of the improved fruit stripper

The new stripper consists of the following parts as shown in the exploded view of the machine as presented in Figure 3;

- Enlarged machine frame
- Rotary Assembly
- Enlarged stripping cylindrical chamber
- Enlarged discharged (fruitlet and bunch) outlets
- New electric motor

2.3 Description, Construction and Analysis of the Stripper

The modified palm stripper, shown in Figure 2, consists of a frame, the loading, the stripping and discharge units as follows;

The frame support

The palm fruit stripping machine has a support frame which was constructed of mild steel angle iron with dimension of 45 mm x 45 mm x 5mm, thick. It has four vertical and two V- shape support stands. The frame holds the whole system firmly and in a rigid position.

The loading unit

The fresh fruit bunches are usually stored for 36 hours under closed system to allow for easy loosening of fruitlets. The sterilized bunches are fed into the stripping unit through the stripper opening or cover.

The stripping unit

This stripping unit consists of a stripping chamber and rotary assembly where processing of the fruit is carried out as shown in Figures 3 and 4. The stripping chamber was constructed with mild steel and made in a cylindrical form. The cylinder was measured to be 580 mm diameter and 465 mm height and vertically erected on the frame. The cylinder has a perforated bottom screen through which stripped fruitlets pass to the outlet. The rotary assembly consists of a paddle made of iron rod of 50 mm diameter and the distance between the paddle and shaft tip is 10 mm. The paddle is driven by a gear system that is powered by a 5.5 hp water cooling diesel engine. The rotary assembly, is mounted at the bottom center part of the stripping cylinder, which contains four beaters (for thorough stripping of the fruits) that are inclined against the inside wall of the cylinder.

The discharge unit

The discharge unit consists of fruitlet and bunch outlets as presented in Figures 3. The fruitlet outlet is made of 3 mm diameter rod of 20 mm x 20 mm squared hole that connected to the mesh and extends from the rear bottom part of the cylinder to the front at an inclined angle for easy rolling of the fruitlets into a collector. The bunch outlet is designed for emptying the fruit bunches after stripping. It has an opening on the side of cylinder which is covered by a guard for safety and ease of handling.

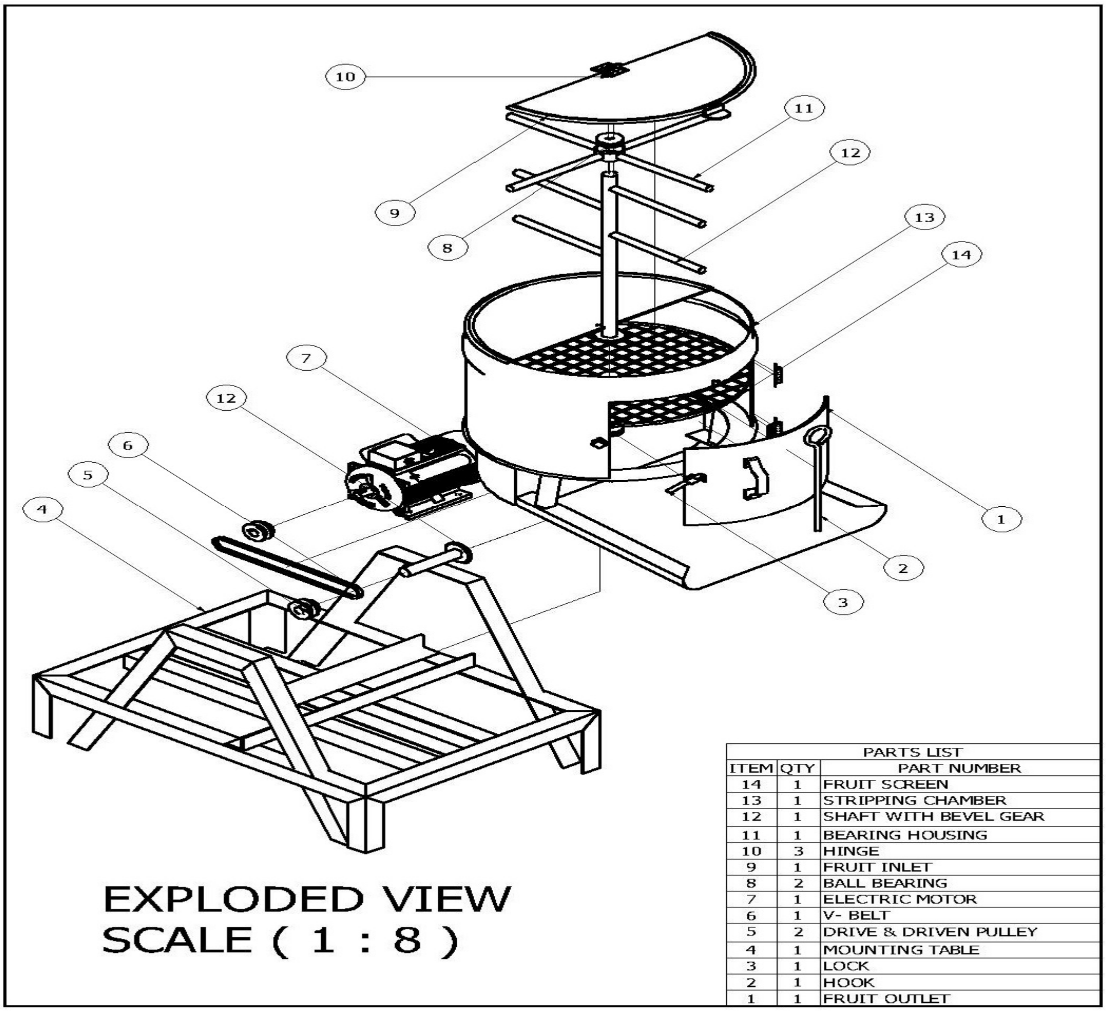

Figure 3: The exploded view orthographic view of the palm fruit stripper

Figure 4: The pictorial view of the palm fruit stripper

2.4 Design Analysis

In the design of this machine, relevant physical and mechanical properties of oil palm fruits were considered as a basic design input for the determination of the mesh size for the drum sieves and power requirement. Other factors considered include availability of materials, cost of materials, durability, and the ease of feeding and discharging of palm fruit bunches, and the condition of palm fruit bunches before stripping.

- ***Stripping Chamber***

The stripping chamber is cylindrical in shape with diameter of 0.580 m. The circumference of the circular section of the cylinder is given in equation1as suggested by Balogun *et al.* (2009):

$$C_{sc} = \pi D \qquad (1)$$

Where;
C_{sc} = circumference of the circular section of the cylinder (m)
D = diameter of the cylinder = 0.58 m

- ***Volume of the Stripping Unit (C_v)***

The mathematical expression given by Balogun *et al.* (2009) was adopted to determine the volume of the stripping unit.

$$C_V = \pi r^2 h \qquad (2)$$

Where;
h = height of the stripping unit (m)
r = radius of the stripping unit (m)

- ***Gear Speed of the Stripper***

Gear speed of the stripper was determined by equation 3 as recommended by Khurmi and Gupta , 2005.

$$\frac{Tg}{Tp} = \frac{Np}{Ng} \qquad (3)$$

Where;
Tg = number of teeth of the gear
Tp= number of teeth of the pinion
Ng = speed of the gear
Np = speed of the pinion

- ***Shaft Diameter***

Shaft diameter was obtained from the following expression given by Khurmi and Gupta (2005).

$$d^3 = 16 \sqrt{(K_b M_b)^2} + \sqrt{(K_t M_t)^2} \; /IISS \qquad (4)$$

Where;
d = shaft diameter (mm)
K_b = combined shock and fatigue factor for bending moment = 1.5
K_t = combined shock and fatigue factor for torsion moment = 1.5
M_b = Maximum bending moment (Nm)
M_t = Maximum torsional moment (Nm)
SS = allowable shear stress of mild steel = 450/mm^2.

- ***Selection of Pulley Speed***

The type of pulley selected was determined using by equation 5 as stated by Onifade (2016); Stephen and

Emmanuel (2009).

$$N_1 D_1 = N_2 D_2 \quad (5)$$

Where;
N_1 = speed of the driving pulley (rpm)
D_1 = diameter of driving pulley (mm)
N_2 = speed of the driven pulley (rpm)
D_2 = diameter of the driven pulley (mm)

- ***Centre Distance and Belt Length***

The center distance between the two adjacent pulleys and belt length were calculated using equation 8 as determined by Khurmi and Gupta (2005); Akande and Onifade (2015).

$$C = \frac{D_2 + D_2}{2} + D_1 \quad (6)$$

for belt length;

$$L = \frac{\pi}{2}\left(D_2 + D_2\right) + 2C + (D_2 - D_2)^2/4C \quad (7)$$

Where;
C = center distance

- ***Angle of Wrap***

The angle of wrap was calculated using the following expression as stated by Khurmi and Gupta (2005):

$$\theta_w = \Pi - 2\sin^{-1}(d_1 + d_2)/2x \quad (8)$$

Where,
θ_w = angle of wrap

- ***Tension in Belt***

Tension in belt was obtained using the expression below as given by Khurmi and Gupta (2005); Akande and Onifade (2015).

$$T_1 / T_2 = e^{\mu\theta} \quad (9)$$

Where,
T_1 = tension in the tight side of the belt, N
T_2 = tension in the slack side of the belt, N
θ = angle of wrap in rad
μ = co-efficient of friction between belt and pulley

- ***Power Requirement***

A change in speed of any fan in operation will predictably change the pressure rise and power necessary to operate under a predictable set of laws concerning its speed, power and pressure (Ojomo *et al.,* 2010). The law can be applied to agricultural equipment that uses shaft as a power take off. One of the equations from these laws is given as:

$$K_{W1}/K_{W2} = (N_1/N_2)^2 \quad (10)$$

Where,
K_{w1} = power from the motor, kW
K_{w2} = power required by the gear shaft, kW
N_1 = speed of the gear shaft, rpm
N_2 = speed of the motor, rpm

Performance Evaluation of the Machine

A preliminary test was conducted using a sterilized bunch to ascertain the machine performance before the experiment. The palm fruit bunch consists of several fruits attached on a main bunch. The fresh fruit bunches are usually stored for 36 hours under closed system to allow for easy loosening of fruitlets. The sterilized bunches are fed into the stripping unit through the opening. The stripping speed was determined using a digital Tachometer, PCE-DT 65. Six fresh palm fruit bunches were used as the test samples and each sample was weighed using electronic digital balance (Compact, BL 30002) with an accuracy of 0.01 g. Each sample was fed into the machine one after the other.

As the rotor assembly rotates, the whole bunches rotate with it and hit against the beaters by imposed force or action. This in turn causes loosening and detachment of fruitlets from bunches. Hence, the loosened fruitlets pass through the sieve mesh at the bottom of the cylinder to its outlet and eventually clean fruits are collected and the chaff are filtered out and finally, the guard is then opened to allow empty bunch to be removed out of the machine through the bunch outlet. The stripped fruitlets, unstrapped fruit lets and empty bunches were collected and weighed after each experiment. The test parameters of the machine performance were determined from the data obtained during testing (Ojomo *et al.,* 2010) and (Suryanto and Bardaie, 1996). Thus, stripping efficiency, clean fruit recovery, input and output capacities were calculated as follows as stated by Ojomo *et al.* (2010) and Suryanto and Bardaie (1996):

- **Stripping Efficiency or Strippability (%)**

The stripping efficiency, (%) of the machine was determined using equation 11.

$$\eta_S = \frac{N_{SF}}{N_{TF}} \times 100 \quad (11)$$

$N_{TF} = N_{SF} + N_{UF}$
η_S = stripping efficiency
N_{SF} = number of stripped fruitlets
N_{UF} = number of unstrapped fruitlets
N_{TF} = total number of fruitlets in the bunch

- **Input capacity (kg/h)**

The input capacity was calculated using equation 12

$$I_C = W_{AB}/T \quad (12)$$

I_C = Input Capacity, kg/h
W_{AB}= weight of whole bunch to be stripped, kg
T = time of stripping, h

- **Output capacity (kg/h)**

The output capacity was calculated using equation 13

$$O_C = W_{SF}/T \quad (13)$$

O_C = Output capacity, kg/h
W_{SF} = weight of stripped fruitlet, kg
T = time of stripping, h

- **Clean Fruit Recovery (%)**

$$C_{FR} = \frac{W_{SF}}{W_{FB}} \times 100 \quad (14)$$

W_{SF} = weight of stripped fruitlet, kg
W_{FB} = total weight of fruitlet in each bunch, kg

- **Operating capacity**

The operating capacity, C, was calculated using equation 15 as stated by Najeem *et al.* (2015) and Khurmi and Gupta, (2010):

$$C = \frac{w}{t} \quad (15)$$

Where;
w = total weight of fruit in bunch (g)
t = total stripping time (s)

3 RESULTS AND DISCUSSIONS

Results from design analysis showed that axial and radial forces required for stripping a fruitlet is averagely 0.4 N and 0.12 N, respectively. The angular speed of rotating disc is 220 rad/s. A 375 mm length of belt was used for transmitting power from electric motor to the rotary system inside the stripping cylinder. Tables 1 and 2 presented the summary of the performance test and output parameters obtained such as the output capacity, input capacity, stripping efficiency and clean fruit recovery. Results revealed that the stripper has stripping efficiency of 98.91 %. This means that the more the sterilization of the fresh fruit bunch, the more the weakening of bond between the fruits and the stalks, and thus making detachment of the fruits from bunches relatively easier. According to Madya (2003) sterilization prevents further rise in free fatty acids due to enzymatic lipolysis, conditions the bunch and facilitating subsequent processing. There is an increase in output capacity and clean fruit recovery from 227.47 kg/h to 275.78 kg/h and 91.13 % to 99.23 %, respectively. This indicated that very few of the fruitlets was lost during stripping operation. The feed rate of the stripper ranges between 341.40 kg/h and 369.02 kg/h showing that the stripper will be able to handle more than one ton of oil palm fruit bunches in 8hrs/day which makes it suitable for small medium scale oil palm fruit processing industries.

The stripping time for a bunch of raw palm fruit was between 47 to 160 seconds, compare to manual and other existing machine which takes between 60 to 260 seconds to strip a bunch of palm fruit depending on the weight of bunch ranging from 4.5 to 15.40 kg and fruits on each bunch 3.96 to 10.25 kg. The average time taken to strip 6.325 kg of weight of whole fruits on the bunch was 89.67 secs. Results showed that six bunches of palm fruit were weighed to be 52.20 kg, the weights of the whole fruits on the bunch, fruitlets and empty bunch were 37.95 kg, 37.35 kg and 15.57 kg, respectively. Also, 4752 palm fruitlets were produced by six bunches of palm fruit and 4704 fruitlets were stripped out of 4752 fruitlets indicated 98.98 % while 49.8 unstripped fruitlets gave 1.05 %. During operation, the machine was noise free and no vibration was observed. The rotary system rotated without wobbling, the output of motorized stripper was quite encouraging and saved time. This is an indication that the ability of the machine to strip efficiently depends on the mass of the fruit and the power rating of electric motor. This indicated that the machine's functional requirement was achieved.

Table 1: Performance Test Conducted on the Bunch Stripping Machine

S/N	W_{AB} (kg)	N_{SF}	N_{UF}	N_{TF}	W_{FB} (kg)	W_{EB} (kg)	W_{WFB} (kg)	T (sec)
A	8.8	956	6	962	6.5	2.80	6.55	90
B	8.4	918	4	922	5.7	2.50	5.84	85
C	15.4	1150	15	1165	10.1	5.10	10.25	160
D	4.5	345	5	350	3.6	0.98	3.96	47
E	5.5	355	5	360	4.46	0.99	4.86	58
F	9.8	980	15	993	6.99	3.2	6.49	98
Av.	8.7	784	8.3	792	6.225	2.595	6.325	89.67

Av. =average values
W_{AB}= Total weight of bunches, kg
N_{SF} = Number of fruitlets stripped
N_{UF} = Number of fruitlets unstripped
N_{TF} = Total number of fruitlets
W_{FB} = Weight of fruitlets removed from each bunch, kg
W_{EB} = Weight of empty bunch, kg
W_{WFB} = Weight of the whole fruit in each bunch, kg
T = stripping time, sec

Table 2: Results Obtained on the Output Parameters

S/N	Total weight of bunches (kg)	Time taken (sec)	Strippability η_s %	Input capacity kg/h	Output capacity, kg/h	Clean fruit recovery, %
A	8.8	90	99.30	352.00	265.00	99.23
B	8.4	85	99.56	355.98	241.52	97.60
C	15.4	160	98.71	346.84	227.47	98.52
D	4.5	47	98.60	344.82	275.78	91.13
E	5.5	58	98.61	341.40	273.74	91.76
F	9.8	98	98.69	360.02	256.79	97.99
	8.7	89.67	98.91	350.18	256.72	96.03

- **Benefits of the improved stripper**

The benefits of the improved stripper are based on the results of the test obtained, the machine proved to be a better design in the following ways;

i. The stripping time of palm fruits reduced since new rotary assembly and four beaters were provided.
ii. Cheap maintenance since the machine can be easily assembled and disassembled and required lubrication of moving parts only.
iii. Cheap and locally available materials were used for the construction of the machine.
iv. Operation of the machine does not require special skill though two persons are preferred.
v. Energy for unloading is reduced since discharge outlets are enlarged.
vi. All rotating parts are shielded and electric motor casing is insulated to ensure safety.

4 CONCLUSIONS

The palm fruit stripping machine was designed, fabricated and evaluated. With this new palm fruit stripper, the problems of safety, quality and quantity of sliced plantain associated with manual slicing and other existing slicer has been eliminated. The palm fruit stripper is environmental and user friendly and does not require any special skill to operate though it can be operated by two persons. The stripping efficiency and operating capacity of the machine had been determined to be 98.89 % and 70.54 g/s. In addition, the equipment is required to be properly maintained and kept clean to provide a more reliable and longer service life. This plantain slicer is recommended for small and medium scale production.

5 RECOMMENDATIONS

The effect of bunch ripeness and sterilization time on the performance of the machine should be determined. Also, the material for constructing the stripping (cylinder) chamber can be changed to stainless steel for durability of the machine and prevent contamination of products.

ACKNOWLEDGEMENTS
Acknowledgement is hereby accorded to Engr. Oyebanire D.O. for their support and contributions towards the success of project and Adebayo Tobi for designing the diagrams.

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