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Development of a Dual Stripping and Screening Machine for Separating Oil Palm Fruit Bunch

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Abstract: *The purpose of this study was to design, fabricate, and evaluate a dual stripping and screening machine for oil palm fruits in Nigeria, with the aim of improving efficiency, reducing damage to the fruits, and minimizing injuries to processors. The study involved the design and fabrication of a machine that could easily handle palm fruit bunches (PFB), separate the fruits from the chaff, and minimize damage to the fruits. The evaluation was conducted using a 3×3×3 factorial experiment, with three levels of PFB sizes, three levels of operating speed, and three replications. The evaluation results showed that the optimal operating speed for the machine was 1000 rpm. At this speed, the machine achieved a stripping efficiency of 98.6% for small PFB sizes, 89.93% for medium PFB sizes, and 85.68% for large PFB sizes. The screening efficiency was 98.62%, 96.23%, and 95.68% for small, medium, and large PFB sizes, respectively. The percentage of damage to the fruits was 2.25%, 2.11%, and 2.55% for small, medium, and large PFB sizes, respectively. The output capacity of the machine was 131.25 kg, 139.30 kg, and 165.36 kg for small, medium, and large PFB sizes, respectively. This study presents a novel dual stripping and screening machine for oil palm fruits, addressing the time-consuming and labor-intensive manual post-harvest operations associated with the local method. The machine's design and evaluation provide valuable insights for improving efficiency and reducing damage in oil palm industries in Nigeria.*

Keywords: *Palm Fruit Bunch (PFB), Stripping, Screening, Calyx, Oil Palm Fruit Seeds.*

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1. INTRODUCTION

Oil palm cultivation in Nigeria, especially in Edo State, holds significant economic value [1]. Challenges to palm oil production in Nigeria are not only many sided but also extend beyond the global placement that is anchored on quantity and quality. Research effort in the oil palm production has been very poor, therefore limiting how far the industry could go [2] [3]. However, the quality of palm oil produced by small and medium scale processors is poor and production costs are high owing to the technology which depends largely on manual labor that is used previously. The prevailing dismal situation can only be rectified with a view of improving efficiency using better technologies and machines for extracting palm oil as established in [4] [5]. By optimizing processing techniques, Nigeria can potentially boost the quality and quantity of its palm oil output, thereby increasing its competitiveness in the global market.

The process of producing crude palm oil involves a series of steps that can range from traditional manual methods to modern automated machinery [6]. Traditionally, harvested palm fruit bunches are left to ferment, making it easier to detach the fruits by striking them with a stick [7]. The fresh fruit bunch comprises fruits within spikelets attached to a main stem, which are manually stripped by cutting the fruit-laden spikelets with tools like an axe or machete and then separating the fruit from the spikelets by hand [8]. This manual labor is often carried out by individuals in villages, including children and the elderly, who work as casual laborers at the processing site to earn income [9]. Additionally, advancements in technology, such as automated detection systems, have been developed to improve the efficiency of palm oil harvest management [10].

In addition to its labor-intensive nature, time-consuming process, and significant labor demand, the manual threshing of oil palm fresh fruit from bunches can lead to injuries, damage to the fruits, and subpar oil quality due to the accumulation of Free Fatty Acids (FFAs) during the fermentation process [11]. Therefore, it is imperative to develop an efficient mechanical oil palm stripper/screener to eliminate the injuries, discomforts, time wastage, and energy consumption associated with the manual method of oil palm fruit separation. The objective of this research is to develop a machine for the stripping and screening of oil palm fruit that is suitable for adoption by small and medium scale oil palm processors. The development of the oil palm fruit bunch stripper and screener is aimed to ensure the efficient threshing or stripping of oil palm fruit at the cottage level.

2. MATERIALS AND METHODS

2.1 Design Considerations

The design and development of the oil palm fruit bunch stripper/screener were based on a set of general considerations such as the availability of locally sourced materials to reduce production costs, the type of force exerted on the materials, the intended tasks they were expected to perform, and the environmental conditions to which the machine would be exposed [12].

The design of the stripping housing unit was devised in a manner that allows for easy passage of stripped fruits and calyx, while preventing empty bunches from passing through. The base of the stripping unit facilitates the free fall and rolling motion of the fruits from the stripping unit to the screening unit. The screening unit was designed in such a way that only the calyx would be able to pass through, while the clean fruits would be recovered at the fruits outlet.

2.2 Specific Design Considerations

Specific design factors considered in designing and fabricating of oil palm fruit stripper/screener are:

i. Power requirement
ii. Machine capacity
iii. Speed of the machine
iv. The size of the bunch
v. Stripping rate
vi. Screening rate
vii. Fruit damage rate
viii. Cost of Machine

2.3. Design of Machine Elements

2.3.1 Determination of machine power requirements

The machine power requirement was determined using the expression

$$P = \frac{2\pi NT}{60} \tag{1}$$

Where;

P = Power requirement
N = Beater shaft speed
T = Torque required to turn the shaft (Nm)

2.3.2 Determination of impact energy required for stripping of the fruits

The impact energy required by a spike to remove the fruit from the bunch was determined as a function of velocity of the shaft.

$$E = 0.5\,(R + 0.5H)^2 + \omega^2 \tag{2}$$

Where,

E = impact energy required
R = rotor radius (mm) =70mm
H = height of the impact survace (mm) =300 mm
ω = shaft velocity (rpm)= 219.94 rpm

2.3.3 Determination of bending stress of the spikes

For spikes to be safe, the maximum allowable moment should be greater than or less equal the actual maximum moment. The two moments were determined using the following expressions.

$$maximum\ moment = p \times H_h w/2 \tag{3}$$

$$p = w(h + y) \tag{4}$$

Where,

p = the equivalent static force (Nmm)
w = impact force (N)
h = height of fall of the fruit bunch (mm)
y = deflection (mm)

$$Maximum\ allowable\ moment = C_S \times LZ^2 \times 2/12 \tag{5}$$

Where,

C_S = allowable stress (N/mm^2) 200 N/mm^2
L = length of spike (mm) = 110 mm
Z = thickness of the spike (mm)= 30 mm

2.3.4 Determination of weight of a spike

The weight of the spike was determined using the expression

$$W_s = m_s g \quad (6)$$

W_s = weight of spike (N) =15.5 N
m_s = mass of a spike (kg)= 1.55 kg
g = acceleration deu to gravity (m/s^2)

2.3.5 Determination of torque and power transmitted to the shaft

The power transmitted to the shaft was determine by

$$P = (T_1 - T_2)V \quad (7)$$

The torque of the shaft was determine by

$$T = (T_1 - T_2)R \quad (8)$$

2.3.6 Pulley and belt drive

The speed required by the machine is driven through the v-belts and pulley.

$$S = \pi dN \quad (9)$$

$$S = 3.142 \times 0.05 \times 1400$$
$$= 219.94\ rpm$$

Where d = diameter of driving pulley (m)
N = speed of driving pulley (rpm)

The length of the belt was determine using

$$L = \frac{\pi}{2}(D_1 + D_2) + 2c + \frac{(D_1 - D_2)^2}{4c} \quad (10)$$

The diameter of the pulley that were used, were determined by:

$$\frac{D}{d} = \left(\frac{n_1}{n_2}\right) \quad (11)$$

Where: D = Diameter of the driven pulley
d = diameter of driving pulley
n_1= speed of driving pulley
n_2= speed of driven pulley
c = center distance between the *pullies*

2.3.7 Determination of shaft diameter

The shaft diameter was determined using ASME code equation expressed by Mubeen (2007) as:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \quad (12)$$

Where d = shaft diameter (m)
m_b = Maximum bending moment (Nm)
k_b = Combined shock and fatigue factor applied to bending moment = 1.5 (assumed)
k_t = Combined shock and fatigue factor applied to torsion moment = 1.5 (assumed)
S_s = Ultimate stress of mild steel
The pictorial view of the new machine is presented in Figure 1

2.4 Machine Description and Operation

The stripper/screener is a single machine that carries out two distinct operations: threshing and screening of oil palm fruits. This apparatus is composed of seven fundamental components, namely the feeding unit, stripping unit, drive mechanism, linkage point connecting the stripping unit to the screening unit, outlet for empty bunches, screening unit, and clean fruits discharge unit. The striping unit of this machine encompasses a shaft that supports several beaters made from flat bars with a thickness of 150mm. The drive mechanism and outlet for empty fruit bunches are also part of the striping unit. On the other hand, the screening unit comprises a perforated cage, outlets for oil palm fruits and calyx. The entire system is firmly held in place by a frame made of angle iron measuring 45mm x 45mm.

The feeding unit of this apparatus is equipped with a hopper through which oil palm fruit bunches are introduced into the stripper unit. The stripper unit, which has a cylindrical shape, is horizontally positioned on the supportive frame. During the operation of the machine, the fruit bunches are fed into the stripping unit through the hopper. As the shaft rotates, the beaters on the shaft exert energy on the oil palm fruit bunches. The continuous impact of the beaters on the materials results in a force that causes the fruit bunches to detach from the bunch. The loosened fruits, along with the calyx, fall into the screening unit by gravity due to the inclined base. Within the screening unit, the fruits are separated from debris and calyx by employing the principle of centripetal force. A pictorial view of the machine is shown in Figure 1.

(a) Front view (b) Screening unit (c) Side view

Figures 1: Pictorial views showing the front view, screening unit and side view of the machine

2.5. Performance Evaluation

2.5.1 Sample preparation

The palm fruit bunches (Figure 2) used for the evaluation of the machine was purchase from a farmer in Ikabigbo, Etsako-west Local Government area of Edo State. The palm fruit bunches after purchase were sorted into three categories of big, medium and small based on their sizes and weight.

Figure 2: Pictorial view showing different categories of arrangement of the palm fruits bunches used for the evaluation.

2.5.2. Measurement and calculations

The parameters considered in evaluating the machine are:

i. Stripping efficiency (E_{St})

$$E_{St} = \frac{weight\ of\ stripped\ fruits}{total\ weight\ of\ the\ fruits\ in\ a\ bunch} \times 100 \quad (13)$$

ii. Screening efficiency (E_{Sc})

$$E_{Sc} = \frac{weight\ of\ cleaned\ fruits}{total\ weight\ of\ the\ fruits\ in\ a\ bunch} \times 100 \quad (14)$$

iii. Percentage damage to the fruits (%Damage)

$$\%Damage = \frac{weight\ of\ bruized\ fruits}{total\ weight\ of\ the\ stripped\ fruits} \times 100 \quad (15)$$

iv. Output capacity (C_P)

$$C_P = \frac{total\ weight\ of stripped\ fruits\ (kg)}{total\ time\ taken\ (h)} \quad (16)$$

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis

The data derived from the computed average values of the stripping efficacy, screening efficacy, percentage of damage, and output capacity for various sizes of palm fruit bunches at three levels of speed were illustrated in Table 1.

Table 1: Effects of palm fruit bunch size and machine speed on the stripping efficiency, screening efficiency, percentage damage to the fruits and output capacity of the machine

Items	Size of the Palm Fruit Bunch (kg)	Speed (rpm)		
		900	1000	1100
Stripping Efficiency (%)	Small	97.08±0.85	98.60±1.20	95.12±1.66
	Medium	85.20±0.91	89.93±1.75	84.96±1.36
	Large	83.23±1.25	85.68±0.95	83.89±1.23
Screening efficiency (%)	Small	98.61±0.45	98.62±0.52	96.22±0.25
	Medium	95.22±0.82	96.23±0.25	94.96±1.36
	Large	93.13±0.25	95.68±0.65	93.06±0.23
Damage to the fruits (%)	Small	2.36±0.26	2.25±0.12	2.58±0.21
	Medium	2.21±0.35	2.11±0.24	3.21±0.13
	Large	2.65±0.25	2.55±0.21	4.34±0.32
Output capacity (kg/h)	Small	128.42±0.21	131.25±0.66	129.14±0.54
	Medium	132.52±0.83	139.30±0.62	133.24±0.52
	Large	164.35±0.53	165.36±0.66	165.12±0.52

Each value is the mean of triplicate ± standard deviation; (small ranges from 1-4kg, medium from 5-9kg and large 10-15kg)

3.2 Effects of Speed and Palm Fruit Bunch (PFB) Sizes on the Stripping Efficiency of the Machine

The effect of speed and palm fruit bunch sizes on the stripping efficacy of the machine is elucidated in Figure 3. It can be inferred from the graph that the stripping efficacy of the machine diminishes as the size of the PFB increases. Furthermore, regardless of the size of PFB, the highest stripping efficacy was achieved at an operational speed of 1000 rpm.

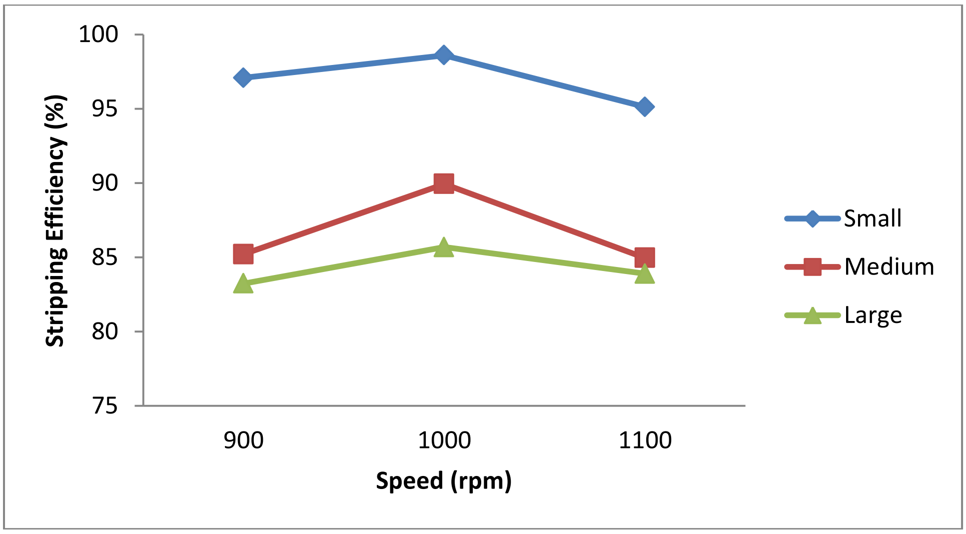

Figure 3: Effects of speed and palm fruit bunch sizes on the stripping efficiency of the machine

3.3 Effects of Speed and Palm Fruit Bunch (PFB) Sizes on the Screening Efficiency of the Machine

Figure 4 exhibits the effects of speed and palm fruit bunch sizes on the screening efficacy of the machine. The figure discloses that the screening efficacy of the apparatus also declines as the size of the PFB increases, and the smaller size of PFB exhibits the highest screening efficacy, followed by medium and large sizes.

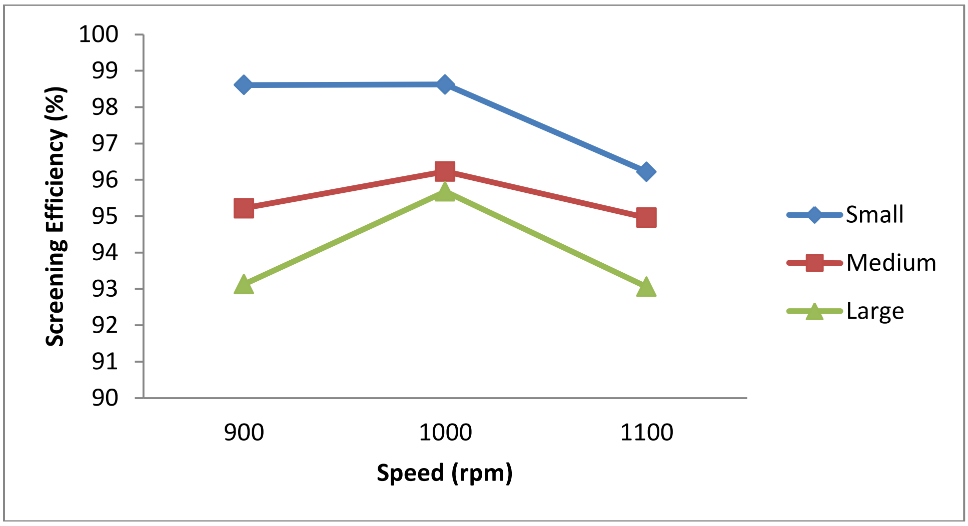

Figure 4: Effects of speed and palm fruit bunch sizes on the screening efficiency of the machine

3.4 Effects of Speed and Palm Fruit Bunch (PFB) Sizes on the Percentage Damage to the Fruits

Figure 5 shows the effects of speed and palm fruit bunch sizes on the percentage of damage to the fruits. The figure revealed that the percentage of damage to the fruits is minimal with no significant difference at 900 and 1000rpm operating speed but higher at 1100rpm irrespective of the PFB sizes.

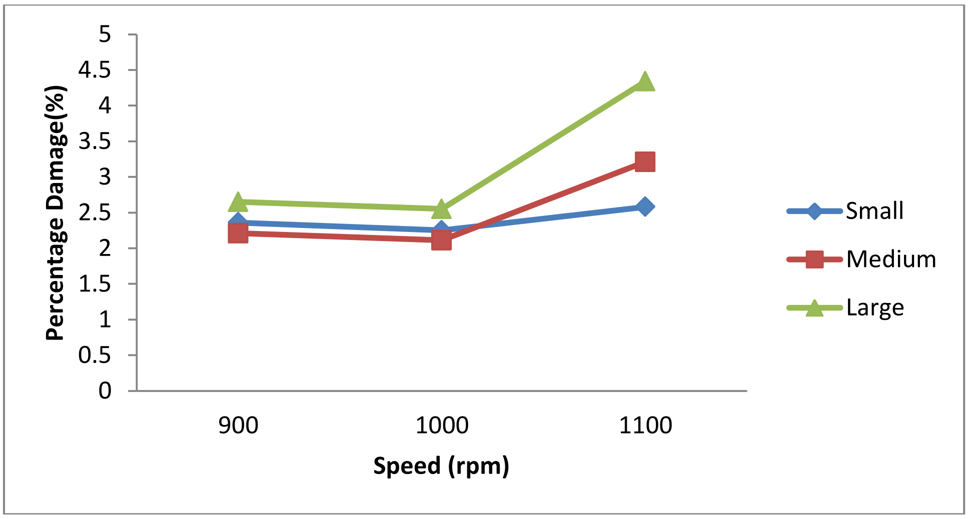

Figure 5: Effects of speed and palm fruit bunch (pfb) sizes on the percentage damage to the fruits

3.5 Effects of Speed and Palm Fruit Bunch (PFB) Sizes on the Output Capacity of the Machine

Figure 5 reflect the effects of varying speed and palm fruit bunch sizes on the proportion of damage inflicted upon the fruits. The figure signifies that the level of damage experienced by the fruits is minimal when the operating speed is set at either 900 or 1000rpm, with no notable disparity between the two. However, at a speed of 1100rpm, regardless of the size of the palm fruit bunch, the percentage of damage to the fruits is noticeably higher.

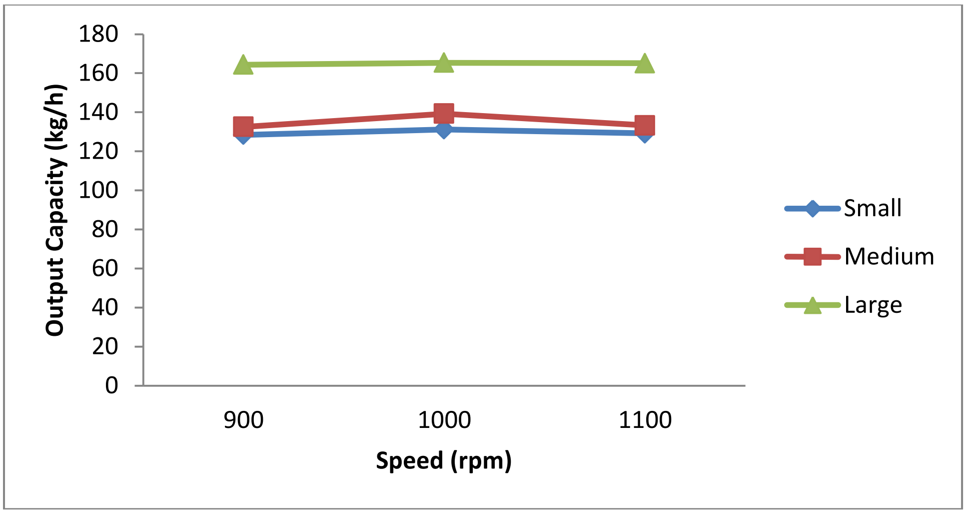

Figure 6: Effects of speed and palm fruit bunch (pfb) sizes on the output capacity of the machine

4. CONCLUSION

In this study, a stripping and screening machine for oil palm fruit bunches was designed, fabricated and evaluated for performance. The results indicate that the efficiency of machines, fruit damage percentage and output capacity are significantly affected by the size of the fruit bunches and machine speed. Larger bunches had lower stripping efficiency and higher fruit damage, while smaller bunches showed the reverse trend: more efficient operations with less added fruit extract. If machine speed is increased, it will have the possible benefits of improving efficiency and capacity while increasing the extent of fruit damage. It is imperative to strike a balance between speed and efficiency. Further research also may evaluate how the correlation between fruit bunch size, maturity, moisture content, and machine performance to enhance machine design and operation.

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