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Development of a Palm Fruit Bunch Chopper and Spikelet Stripper

Ademola K. Aremu[1], Oluwatoosin A. Alade[2*]
[1,2]Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.

Abstract: *The inadequacy of processing technology involved in the palm fruit processing has been attributed to the manual method and individualized processing machinery. This imposes the need to develop an all-in-one machine to increase efficiency, reduce time, space and drudgery. The palm fruit bunch chopper and spikelet machine comprise of the frame, chopping, stripping and cleaning chambers and the outlets (fruitlets, spikelet and dirt). Evaluation of the machine was varied on the level of ripeness of fresh palm fruit bunch, fermentation time of 24, 48, and 72hours, shafts speed (stripper shaft 320, 350, 500rpm and blower shaft 1300, 1500, 2100rpm). The stripping and quality performance efficiency with output capacity of stripping increased with level of ripeness, shafts speed and fermentation time from 15.949 – 94.015%, 12.843 – 79.943% and 59.208 – 249.056kg/hr respectively. The optimum chopping, stripping, quality performance and cleaning efficiency was obtained from the over-ripe fresh fruit bunch, 72hours fermentation time, 500rpm shafts speed and moisture content of 46.16% (db). The cost of producing one unit of the combined palm fruit bunch processor as at the time of fabrication was estimated to be ₦85,000 not including the cost of electric motor and the power required when operated with electric motor of 5.5hp.*

Keywords: *palm fruit bunch chopper, palm fruit spikelet stripper, quality performance efficiency, stripping efficiency.*

I. Introduction

The oil palm, (*Elaeis guineensis* Jacq.*)* is a perennial tree crop of the *Arecaceae* family [9] and was said to be native to the countries bordering the Gulf of Guinea [1], with the main belts running through the southern latitudes of Cameroon, Ivory Coast, Ghana, Liberia, Nigeria, Sierra Leone and into the equatorial region of Angola [2; 3; 4; 5; 6; 7). The oil palm is categorized as a major tropical tree crop in Nigeria and is cultivated mostly in the Southern part and some parts of the Middle belt of the country [4]. The oil palm produces its fruit in bunches varying in weight from 5-40kg consisting of several oval-shaped drupe fruits of 6-20 grammes and fresh fruits of an average length, width and thickness of 35.96 mm, 20.15 mm and 17.11 mm respectively [4; 7; 8]. The types of oil palm fruit occurs in two forms, termed *dura* (with a large kernel) and *pisifera* (having no shell and yet sterile) while *tenera* is a hybrid form of *dura* and *pisifera*, and the most cultivated variety because it produces fruits with higher oil content [9].

The processing of palm fruits begins with harvesting the palm fruit bunches, chopping and stripping, sterilization, digestion, palm oil extraction, palm kernel cracking and oil extraction and ends with storing the oils, each using different methods and machines [3; 6; 10; 7). [11] concluded that improved technologies that meet both growth and sustainability goals can be effectively used by oil palm processors. However, most technologies are designed for developed rather than developing countries. [12] stated that Nigeria has enormous potential to increase her production of palm oil and palm kernel primarily through application of improved processing techniques.

Though the technology of palm oil production has advanced in recent years with new technological innovation to produce palm oil, survey results showed that 80 percent of Nigerians oil palm resource exist in smallholders [13] who uses manual/traditional processing techniques and equipment for palm fruit by processing [2]. Thus the nation's oil palm industry is still subsistent with very few large estate plantations that make large mills and imported mills relatively expensive and unaffordable by most farmers, thereby making the traditional method to predominate [13]. The chopping of palm fruit bunch becomes imperative so as to remove the fruitlets located in the inner layer of the bunch and mechanical stripping which eliminates the use of human labor and work related injury to their fingers and bodies. However, this research work is geared to reducing time and drudgery in the chopping and stripping of palm fruits by designing and fabricating a machine that incorporates the two process into one unit using locally available materials suitable to both small and medium scale palm oil processors and also conserving space in their palm mills. The main objective is to design and fabricate a palm fruit bunch chopper, spikelet stripper and cleaning of palm fruitlets.

Figure 1: Harvested palm fruit bunches at Gilgal farms

II. Materials And Methods

Machine Description and Operation

The palm fruit bunch chopper and spikelet stripper consists of five basic units: the chopping chamber, stripping, separating, drive mechanism and the discharge outlets. The whole palm fruit bunch is manually placed and arranged for chopping the bunch into spikelet and fed directly into the spikelet stripper chamber where the fruitlets are being detached from the spikelet and convey the empty spikelet for discharge. The drive mechanism which consists of shafts, belt and pulley is used to operate the stripping and separating units. The received fruitlets are sieved into the separating chamber which utilizes pneumatic for the separation of cleaned palm fruitlets for discharge.

The solid isometric and exploded view of the palm fruit bunch chopper and spikelet stripper are shown in figure 2 and 3 are shown below.

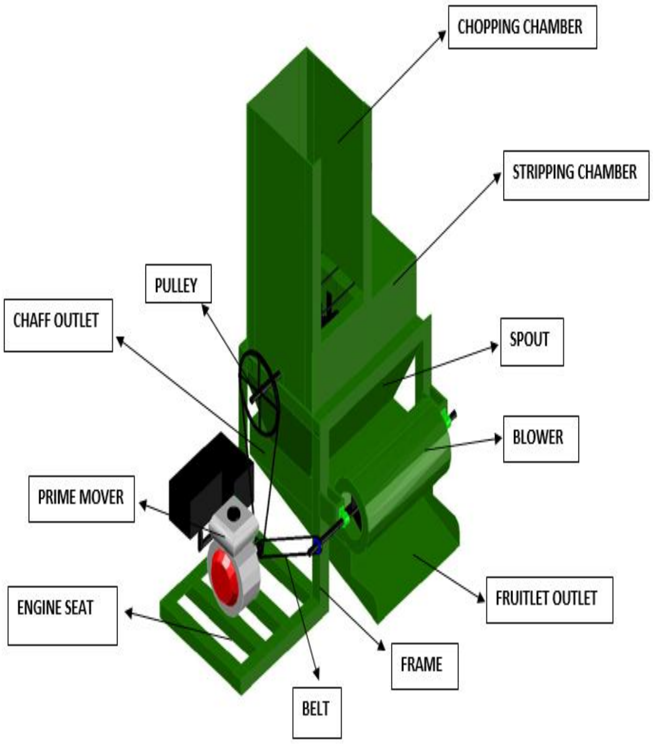
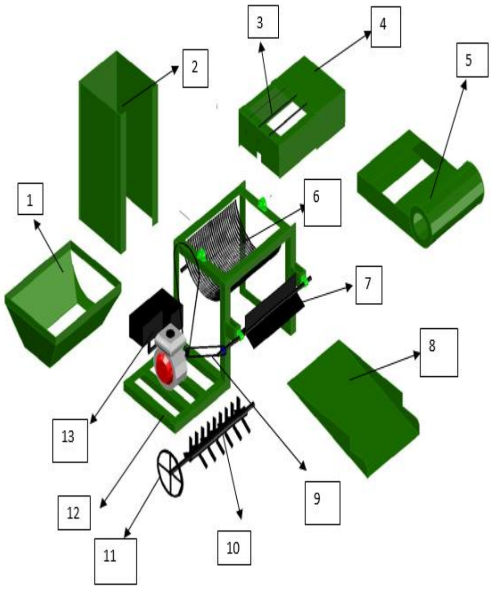


Figure 2: Isometric view of the Palm fruit bunch chopper and spikelet stripper



1- SPOUT	8- FRUITLET OUTLET
2- CHOPPING CHAMBER	9- BELT
3- BUNCH SEAT	10-STRIPPERS
4- STRIPPING COVER	11- PULLEY
5- BLOWER CASING	12-ENGINE SEAT
6- CONCAVE SIEVE	13-PRIME MOVER
7- BLOWER	

Figure 3: Exploded view of the Palm fruit bunch chopper and spikelet stripper

Design Considerations

Some of the factors considered while designing the palm fruit chopper, spikelet stripper and cleaning of the palm fruitlets are as described:

Reliability and performance of the various components

Factors such as rigidity, deflection, wear, corrosion, vibration and stability were considered in the selection of appropriate material, sizing and shaping of the various machine components. Also, in order to take into account a number of uncertainties such as variation in material properties, effect of environment in which the machine is expected to operate, and the overall concern for human safety, provisions were made through the use of factor of safety stipulated by standard and experience.

Availability of materials

The machine was constructed of locally available materials so as to enhance the possibility of replacing damaged parts with less expensive but equivalently satisfactory parts that are locally available.

Simplicity

The ease of design and fabrication of machine for productivity were considered, bearing in mind the need of dismantling to carry out routine cleaning and maintenance of the machine when necessary so as to maintain higher level of performance and also for the possibility of conveying the machine from one point of use to the other whenever the need arises.

Effectiveness

Meeting the farmers general requirements with minimum loss of oil that may arise from oil being absorbed and carried off by the stalks of the stripped bunches or loss due to unstripped fruits still attached to the bunches. And also the need to have a fruit discharge outlet that is different from the stripped bunch discharge outlet for optimum separation.

Cost

The reduction of cost was taken into account through critical value analysis on the phases of design, material selection, production and maintenance of the machine which at the end make it affordable by farmers and other intending users.

Design Analysis

This machine was designed by taking cognizance of the geometric properties (length, width, thickness, geometric mean diameter, and sphericity), gravimetric properties (including true density, bulk density and porosity) and frictional properties (angle of repose and static coefficient of friction) of palm fruit bunch, spikelet and fruitlets in other to ensure an acceptable efficiency.

Driven pulley speed

This was done in order to know the equivalent ratio between size of the motor pulley and that of shaft pulley. The allowable diameter of the pulley was calculated using the equation 1 as described by [14].

Neglecting belt thickness:

$$\mathbf{N_1 D_1 = N_2 D_2} \qquad \textbf{(1)}$$

$\mathrm{N_1}$ = speed of the prime mover (rpm)

$\mathrm{N_2}$ = speed of the cracking shaft (rpm)

$\mathrm{D_1}$ = pulley diameter of the prime mover (mm)

$\mathrm{D_2}$ = pulley diameter of the cracker machine (mm)

Therefore, the speed needed for stripping of palm kernel spikelet seed is 428.6rpm

Shaft Speed of the electric motor

The speed of the belt, $\mathbf{V_1}$, was determined according to the expression described by [15] as shown in equation 2:

$$\boldsymbol{V_1} = \frac{\boldsymbol{\pi N_1 D_1}}{\mathbf{60}} \qquad \textbf{(2)}$$

Where;

$\mathrm{N_1}$ = speed of the prime mover (rpm),

$\mathrm{D_1}$ = pulley diameter of the prime mover (mm).

Shaft Speed of the palm fruit strippers

The speed of the belt, V_2 was determined according the expression described by [15]:

$$\boldsymbol{V_2} = \frac{\boldsymbol{\pi N_2 D_2}}{\mathbf{60}} \qquad \textbf{(3)}$$

where:

$\mathrm{N_2}$ = speed of the shaft of the machine (rpm),

$\mathrm{D_2}$ = pulley diameter of the machine (mm).

Power required by the shaft

The power requirement (Ps) was divided into three parts. [15] reported the power requirement (Ps) for the palm spikelet stripper.

i. Power required to drive shaft:

The power requirement of the shaft was determined with the equation 4:

$$\boldsymbol{Ps = Ws \times Rs} \qquad \textbf{(4)}$$

where: $\mathbf{R_s}$: Radius of shaft (m),

$\boldsymbol{W_s}$: Weight of the shaft (N),

ii. Power required for striping the spikelet:

The power requirement for striping the spikelet was determined with the equation 5:

$$\boldsymbol{P_{st} = \tau \times \omega} \qquad \textbf{(5)}$$

where: $\mathbf{P_{st}}$ – Power requirement for striping (kW)

$\boldsymbol{\omega}$ – Angular speed of the shaft (rad/s)

$\boldsymbol{\tau}$ – Torque of the shaft (Nm)

iii. Power required for driving the pulley:

The power required for driving the pulley was determined with the equation 6:

$$\boldsymbol{P_p = W_p \times R_p} \qquad \textbf{(6)}$$

where: $\mathbf{P_p}$ – Power requirement for pulley (kW)

$\mathbf{W_p}$ – Weight of the pulley (N)

$\mathbf{R_p}$ – Radius of Pulley (m)

However, the total power requirement of the shaft ($\boldsymbol{P_t}$) is expressed in equation 7:

$$\boldsymbol{P_t = P_s + P_{st} + P_p} \qquad \textbf{(7)}$$

= 0.00103 + 1.616 + 1.483 = 3.10 kW

Hence, a 5.5hp petrol engine was used for the design.

Belt Length

The length of the belt from the electric motor to the palm kernel spikelet stripper was determined by the relationship given by [16] as shown in equation 8:

$$\mathbf{L = 2C + \frac{\pi}{2}(D_1 + D_2) - \frac{D_2}{4C} - \frac{D_1}{4C}} \quad \textbf{(8)}$$

Where;

$C = \left(\frac{D_2}{2} + \frac{D_1}{2}\right) + D_1 =$ centre distance (mm),

D_1 = pitch diameter of the larger pulley(mm)

D_2 = pitch diameter of the larger pulley(mm)

Thus, the calculated belt length is given as approximately 1360mm.

Shaft Diameter

The shaft for the palm fruit spikelet was designed on the basis of strength, rigidity and stiffness. When designing the shaft, it was considered that it may be subjected to twisting and bending moments. [14] and [15], reported that the formulae used for shaft design is as shown in equation 9 – 11:

$$\boldsymbol{\sigma = \frac{16\tau}{\pi d^3}} \quad \textbf{(9)}$$

$$\mathbf{d = \sqrt[3]{\frac{16\tau}{\sigma\pi}}} \quad \textbf{(10)}$$

$$\mathbf{d^3 = \frac{16}{\pi\, \tau_s}\sqrt{M_b K_b{}^2 + M_t K_t{}^2}} \quad \textbf{(11)}$$

where at the section under consideration:

d = shaft diameter (mm),

$\boldsymbol{\tau}$ = torque of the shaft (Nm),

$\boldsymbol{\sigma}$ = Maximum permissible work stress (N/m).

$\boldsymbol{\tau_s}$ = allowable shear stress for bending and torsion, (N/mm^2)

$\mathbf{K_B}$ = combined shock and fatigue factor applied to bending moment = 2.0 for minor shock

$\mathbf{K_T}$ = combined shock and fatigue factor applied to torsional moment =1.5 for minor shock

$\mathbf{M_B}$ = maximum bending moment, (N/m)

$\mathbf{M_T}$ = torsional/twisting moment, (N/m)

The diameter of the shaft was calculated to be 32.6mm. However, 30mm diameter was chosen for the design of the stripper by standard.

Blower

The blower was designed with respect to the terminal velocity of the palm fruitlets in a way that the air produce was less than the terminal velocity of the palm fruitlets and greater than the terminal velocity of the chaff so that it will not be able to blow off the fruitlets during its separation using a centrifugal blower.

III. Test Procedure

In other to evaluate the performance of the machine, an experiment is designed such that the machine is tested by categorizing the palm fruit bunches into three maturity levels (under-ripe, ripe, and over-ripe), fermentation time (24, 48 and 72 hours), moisture content of fruit spikelet, speed of stripper (320, 350 and 500 rpm) and blower shafts (1300, 1500, 2100 rpm) respectively.

In all the tests which was replicated three times (a, b and c), the weight of the palm fruit bunches are measured using the Salter weighing Scale (50kg, ±0.1) and the time taken (seconds) to chop and strip each sample are measured using a stop watch. The machine is powered by 5.5 horse power (h.p) petrol engine prime mover. The revolution per minute (rpm) of the beater and pneumatic shaft are measured with hand-held digital tachometer and the wind speed with the digital anemometer according to Philippine Agricultural Engineering Standards PAES 241:2010 and PAES 305:2000. After each operation the chopped palm fruit bunch, stripped and unstripped palm fruit spikelet and cleaned and un-cleaned fruitlets from its outlets are carefully sorted out and weighed.

Further analysis of the results of the experiment is carried out using Response Surface Methodology (RSM) software (*Design Expert version 6.06*).

Performance Evaluation

Samples were taken from each of the sub-plot, where parameters such as weight of stripped and unstripped fruitlets with weight of stripped spikelet and unstripped spikelet etc., were used for the computation of the machine stripping efficiency, cleaning efficiency, quality performance efficiency etc. This was done in accordance with the Philippine Agricultural Engineering Standards PAES 255:2011 for Abaca stripper.

The following formulas were used in the computations:

1. Stripping efficiency, E_s

$$E_s = \left({W_{sf}}/{W_{cf}} \right) \times 100 \tag{12}$$

where: $\mathbf{W_{sf}}$ = total weight of stripped palm fruits
$\mathbf{W_{cf}}$ = total weight of palm fruits in the chopped bunches.

2. Cleaning efficiency, E_a

$$E_a = \left({W_{db}}/{W_d} \right) \times 100 \tag{13}$$

where: $\mathbf{W_{db}}$ = total weight of dirt blown
$\mathbf{W_d}$ = total weight of dirt.

3. Chopping efficiency, CHE,

$$CHE = \left({W_{pf}}/{W_{tb}} \right) \times 100 \tag{14}$$

where: $\mathbf{W_{pf}}$ = Weight of chopped palm fruit
$\mathbf{W_{tb}}$ = Total Weight palm fruit bunch

These terms and nomenclature were further adopted in the analysis of the performance of the palm fruit stripper by [5] and [8]

1. Output Capacity for stripping, C_o, (Kg/hr) =

$$C_o = \frac{W_{fs}+W_{fb}}{T_s} \tag{15}$$

where:

$\mathbf{W_{fs}}$ = Weight of palm fruit stripped
$\mathbf{W_{fb}}$ = Weight of empty spikelets
$\mathbf{T_s}$ = Time of stripping

2. Determination of Quality performance efficiency, Q_{PE}, %

$$Q_{PE} = \left[\frac{Wfs}{Wfp+Wfb}\right] \tag{16}$$

where: $\mathbf{W_{fp}}$ – Potential palm fruitlets in spikelet

3. Feed Rate

IV. Results And Discussion

The result of the performance evaluation test of the palm fruit bunch chopper and spikelet stripper was carried out for 81 experimental feedings with the average of the three runs (27 experimental feedings) was computed and observed response values are as shown in Table 1.

The moisture content of the palm fruit spikelet at three fermentation time (24, 48 and 72 hrs) after oven drying showed the highest moisture content as 46.16 % (db) over-ripe FFB at 72 hrs fermentation time while the lowest moisture content is 45.71 % (db) under-ripe FFb at 24 hrs fermentation time.

V. Conclusions And Recommendation

The performance assessment of the machine has a high feeding rate of 472.038 kg/hr and average chopping efficiency of about 98%; stripping and quality performance efficiency of stripping as 94.015%, 79.943% respectively. The output capacity of the stripper and the effectiveness of the cleaning chamber make the machine useful for palm fruit processors. The combination of two processes (chopping and stripping) as an all-in-one machine, its local content for fabrication costing ₦85,000.00 (eighty-five thousand naira only), less maintenance and durability of structure gives the palm fruit bunch chopper and spikelet stripper a high edge and advantage among other technologies in oil palm processing business.

The palm fruit bunch chopper and spikelet stripper is hereby recommended for small and medium scale oil palm fruit processing centers. This research work could be a step to automation of the chopping and stripping process of palm fruit processing all-in-one machine targeted at small and medium scale palm fruit processors.

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Table 1: Design Factors and Responses as Influenced by Treatments of level of ripeness of Oil palm fruit FFB

RUNS	SPEED (rpm)	Ripeness	FT (HR)	MC (%)	FEED RATE (KG/HR)	E_S (%)	C_O (Kg/hr)	CE (%)	QP (%)	CHE (%)
1	320	0	24	45.71	290.789	15.949	59.208	50	12.843	98.114
2	320	0	48	45.75	327.682	25.846	87.091	50	20.529	98.497
3	320	0	72	45.94	295.964	27.786	78.021	50	21.988	98.303
4	350	0	24	45.71	357.333	25.852	100.135	66.667	21.321	97.286
5	350	0	48	45.75	326.811	31.709	93.507	55.556	24.731	98.43
6	350	0	72	45.94	354.319	40.461	123.431	66.667	32.464	97.153
7	500	0	24	45.71	289.094	54.433	116.036	50	44.367	98.103
8	500	0	48	45.75	322.127	61.187	150.847	50	49.582	98.443
9	500	0	72	45.94	290.399	65.115	141.962	50	53.441	98.265
10	320	1	24	45.74	310.376	30.47	87.145	55.556	24.938	98.399
11	320	1	48	45.79	311.323	36.39	97.464	50	29.031	98.274
12	320	1	72	45.97	286.006	43.582	99.091	50	35.618	98.212
13	350	1	24	45.74	325.336	36.917	104.631	61.111	30.272	97.437
14	350	1	48	45.79	317.604	51.727	154.587	50	43.484	98.335
15	350	1	72	45.97	457.464	68.598	249.056	55.556	54.591	98.172
16	500	1	24	45.74	309.546	66.133	152.2	50	54.093	98.377
17	500	1	48	45.79	296.078	71.531	152.175	50	58.377	98.119
18	500	1	72	45.97	287.601	80.982	163.452	50	66.356	98.189
19	320	2	24	45.77	318.906	49.229	122.377	55.556	40.145	97.625
20	320	2	48	46.01	334.549	63.397	148.27	50	50.838	98.118
21	320	2	72	46.16	322.289	79.201	174.955	50	67.209	98.072
22	350	2	24	45.77	472.038	54.077	212.595	46.667	44.291	98.397
23	350	2	48	46.01	426.262	81.558	246.913	55.556	64.904	98.094
24	350	2	72	46.16	371.572	92.039	228.474	55.556	76.362	97.532
25	500	2	24	45.77	336.949	76.955	184.676	50	63.719	98.289
26	500	2	48	46.01	344.943	91.982	214.177	50	77.129	98.193
27	500	2	72	46.16	358.938	94.015	236.909	50	79.143	98.133

KEY:
Level of ripeness
0 – Under-ripe FFB,
1 – Ripe FFB,
2 – Over-ripe FFB,
MC – Moisture Content
$\mathbf{C_O}$ – Output Capacity for stripping
$\mathbf{E_s}$ – Stripping Efficiency
CE – Cleaning Efficiency,
QP – Quality performance efficiency,
CHE – Chopping efficiency,
FT – Fermentation time,