Development Of Coffee Dehusker: Prospect Of Synthetic Rubber Beater Mechanism

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***Abstract*-Coffee is a global important economic crop, widely consumed as a beverage. Nigeria produces reasonable quantity of coffee, but below her potential due to lack of processing machines among others. A machine for dehusking dry coffee was developed using local materials. Performance test revealed that the machine has a good prospect, showing, average dehusking efficiency (51.3 – 67.8%), very low bean damage (0.5 – 0.8%) and high cleaning efficiency (72.9 – 96.7%). Detailed evaluation test will determine possible steps for improvement. Farmers' livelihood and coffee quality will be improved by adoption of the machine.**

Keywords—Coffee, Dehusker, Rubber beater, Bean damage, Investigating, Prospect, Efficiency

I. INTRODUCTION

Coffee is one of the major economic agricultural produce which serves as a mean of income to many nations and farmers worldwide. According to [1], only 25 countries out of 54 in Africa produce coffee which makes it a strategic crop. Coffee is the second traded commodity after oil and second consumed liquid after water; about 8.0MT of coffee is consumed globally every year [2]. Benefits from consumption of coffee include protection against some diseases, burning fat, making physically fit and smarter as added. It was also believed to contain essential nutrients such as potassium and Vitamins B2 and B12. Coffee came to Nigeria in 1859 with initial production of 5.5MT and potentials for increased production. Among 36 states in the country, 22 are producing one type of coffee or the others while 13 out of these states are on commercial production. Robusta (*coffea canephora*) and Arabica (*coffea arabica*) are the commonest grown among Nigerian farmers, based on the climatic conditions of the geographical zone. Robusta is commonly grown in relatively low altitude of the Southwest and North central, Arabica production is favoured by the cool weather of high altitude of the Northern part such as Plateau and Taraba states. Kaba is one of the major communities for commercial coffee production, particularly Robusta. Kaba coffee was once well recognized for good coffee production in the World before quality dropped due to poor processing which might have been caused by lack of appropriate machines. The potential of Nigeria to produce coffee on commercial level to support her economy and provide jobs for the teeming youths, especially at this period of dwindling prices of crude oil, cannot be overemphasized. Cocoa Research Institute of Nigeria (CRIN) has developed high yielding, coffee compatible clones which can increase berry production from existing 400 - 600 Kg/Ha to 1,360 Kg/Ha under Good Agricultural Practice (GAP) [2]. Reportedly, in Plateau state alone, 9 out of 17 LGAs are growing coffee with total cultivated area of 300 Ha which is very low compared to 20,000 Ha per LGA potential level of the state [3]. It was further stated that the state alone has potential of producing coffee worth 250 millions of Naira, all things being equal. Some major problems identified by National Coffee and Tea Association of Nigeria (NACOFTAN) and Inter Africa Coffee Organization (AICO) are lack of processing machines and market which had led to wastage of about 1,000 MT. Visit to farmers by and survey carried out by staffs of Cocoa Research Institute of Nigeria (CRIN) also supports this claim. This problem can adequately be addressed by development and production of relevant processing machines through appropriate technology that will boost quality bean production which can open up market, at both international and domestic levels. Coffee cherries/berries are harvested when most of them are fully ripped after which they are sorted and processed. It is appropriate for cherries to be harvested once the pulp is soft and easy to remove. Harvesting of coffee cherries is either done by strip picking method or selective picking method. Strip picking method which is the commonest among coffee farmers involves removal of all cherries from the clusters. In this practice, both ripe and unripe cherries are harvested together and later subjected the harvested fruits to further post-harvest processing. The selective picking method of harvest allowed picking of only ripe cherries, leaving unripe one until when fully ripe, making sorting easier. There are basically different types of coffee which are genetically and phenotypic different in term of taste, size and shape but are very similar in many respect. Generally, coffee fruit consists of exocarp (pulp), mesocarp (mucilage), endocarp (parchment or hull), spermoderm (testa or silver coat), endosperm (albumen) and embryo, made up of two cotyledons. The two most common methods of processing are wet and dry among others. The method adopted depends mostly on the quality desired, the type of coffee and local traditions. Dry method involves sun-drying fully ripe coffee berries at most 48 hours after harvesting to prevent Ochratoxin A and mould growth which will result in deteriorating beans quality. In Nigeria, dry method is usually employed for processing *C.canephora* (Robusta) which is most common as it thrives well in many lowland areas. Unfortunately, the method is not without the attendant poor quality and small quantity unreasonable for export. Among the major factors responsible for low coffee production in Africa is poor quality owing to poor coffee processing practices [4]. Lack of processing machines has been attributed to low production and poor quality of coffee in Africa. The use of pestle and mortar has been the common traditional way of removing pulp/husk from dried coffee berries in Nigeria as mechanical dehullers are relatively scarce. This approach is very laborious with attendant drudgery and time wastage. Appropriate mechanical dehusking will not only reduce drudgery, but bring about timely processing and improve quality of bean and its products. All these will culminate in increased production and utilization of local coffee. Production of relevant indigenous machines for coffee processing is therefore an integral part of proactive approach to explore high potential of Nigeria coffee production. Suitability of rubber strips mechanism for threshing/hulling tender crops with little or no grain damage had been reported by [5] and [6]. Reference [7] reported mean decortication efficiency and broken grain of 98.1% and 3.1% respectively for nutmeg using rubber lagged beaters. The role of both crop and machine parameters for effective and efficient performance had been stressed by various researchers. These parameters include moisture content, size, density, strength, feed rate, machine speed and clearance. Concave-drum clearance should be greater than mean axial dimensions of crop [5]. Several reports of previous studies also agreed on the importance of aerodynamic properties of crops, such as terminal velocity, drag coefficient and shape, for effective separation from foreign materials. The role played by amplitude and frequency of sieve oscillation in efficient crop separation was stated by [6]; amplitude of 20mm and frequency of 50Hz are commonly used for high feed rates and acceptable grain loss. However, better results could be achieved with larger amplitude and lower frequency. The aim of this study is to develop a machine for investigating the effectiveness of synthetic rubber beater for dehusking dry coffee berries.

II. MATERIALS AND METHODS

Relevant engineering and physical properties of the crop were studied to determine necessary parameters for the design and effective performance of the machine, using the methods of [8] and [9]. Dry Robusta coffee obtained from the stored berries, harvested from the plantation of CRIN, Ibadan in Southwest Nigeria, was used for the study of these properties using appropriate instruments such as BL 5002 Digital weighing balance and digital Vernier calipers, both with sensitivity of 0.01. Engineering theories and principles reported by previous work of other scientists were also applied. The properties which include axial dimensions, angle of repose, bulk and true densities were investigated as shown in Table I. The machine was tested using samples obtained from the same source described above. Samples were fed into the machine through the hopper; the products of the dehulling operation were collected through both the grain and screen outlets. These were manually sorted into pure beans, unshelled beans, damaged beans and chaffs. The unshelled beans were manually shelled and separated into pure beans and chaffs. Damaged beans were selected based on those having cracks or partly broken as described by [10], [6] and and [11]. The weight of each component separated was measured, using the scale described above, to evaluate the performance of the machine.

A. Machine description

The coffee dehuller was designed to consist of the following major units: the frame, the dehusking chamber, the cleaning unit and the power unit as shown in Fig. 1 with some major dimensions in Table II.

Dehusking chamber: The chamber employed the use of synthetic rubber beaters involving impact and shearing actions resulting from the centripetal force of the beaters, which removed husk from the beans through abrasion between the beater and the perforated fixed concave below the shelling drum. The hopper which was a trapezoidal frustum was placed directly on top of the dehusking chamber at one end while the chaff outlet was positioned at the other end.

Cleaning unit: Air-screen method was used to remove chaff and other foreign materials from the grain/MOG mixtures. Air current from a centrifugal fan and a screen were adopted for the cleaning system to achieve efficient cleaning of the beans. The fan was made of 4, 3mm thick blades, equally spaced around a 20mm diameter solid mild steel shaft. The screen which was fabricated from 3mm galvanized plate consists of 8mm diameter drilled holes throughout its surface area. The screen was position just below the concave while the fan was located under the screen. This was so arranged to minimize seed losses such that air current could cause initial separation of chaffs

TABLE I. ENGINEERING PROPERTIES OF DRY COFFEE BERRIES

Crop Properties	Means of replication (mm)
Major diameter	9.96 (0.50)
Intermediate diameter	6.68 (0.75)
Minor diameter	6.30 (0.39)
Geometric diameter	7.54 (0.42)
Aspect ratio	0.69 (0.07)
Bulk density	450.52 (12.71)
True density	1619.08 (76.19)
Angle of repose	26.51 (1.63)

[a.] Figures in parentheses are mean deviations

TABLE II. SPECIFICATIONS OF THE MACHINE COMPONENTS

Parameters	Dimensions (mm)
Concave Size	610 x 175 x 120
Drum outer diameter	132
Cleaning fan blade	475 x 100
Cleaning screen	600 x 52
Grain outlet	320 x 80 x 60
Chaff outlet	150 x 120 x 100
Frame	700 x 310 x 1020

Fig. 1. Photograph of the Dehusker

through suspension. The grain outlet was located below the cleaning chamber such that there could not be possible mixing from the chaffs blown towards the machine front.

Power unit: the drive consists of V-belt and pulleys with the power supplied through a 5 Hp 4-stroke engine with a throttle which provided mean of varying the speed.

The frame: this was constructed from 2 mm thick angled mild steel. It was constructed and arranged such that it could effectively support the weights of other components with good stability.

B. Mode of machine operation

Dried coffee berries were fed into the dehusking unit through the hopper after the prime mover had been put on and speed adjusted as necessary. The berries were dehusked through the impact force of the beaters and their abrasion action against the concave screen as they are conveyed towards the end of the machine. The repeated action of the beaters causes more berries to be shelled. Dehusked beans fell on the sieve through the concave holes while chaffs dropped through chaff outlet. Separation of pure beans from other materials (MOG) is achieved through the blowing fan and the agitating sieve. Separation was assisted by the initial segregation caused by rotation of the dehusking drum and variation in the specific gravities of the materials, especially at higher speeds. Pure beans including materials that were not removed at the cleaning unit were collected from the grain outlet, while un-dehusked berries and chaffs were collected from the chaff outlet and sieve outlet in front of the machine.

C. Design calculations

This analysis was necessary to determine important design factors such as strength, forces and sizes of materials in selecting machine components with a view to prevent failure due to fatigue during operation.

1) Determining shelling chamber parameter as expressed by [12] and [13]:

$q = qLM$ (1)

q – Feed rate of the sheller (kg/s)

q – permissible feed rate which is 0.4 - 0.6 kg/s

L – length of drum (m)

M – number of beaters

Beaters were arranged spirally around the drum to allow even application of forces on the berries. The berries would likely slide on engineering surfaces as the Aspect ratio of an average good dry coffee berry was earlier determined to be 0.69 (Table 1).

2) Concave design

Using the relationships stated by [5] to estimate least drum-concave clearance (C_T), concave diameter was determined (C_d):

$C_T = D_g + 3.04\sigma$ (2)

$C_d = d + 2L_p + C_T$ (3)

D_g – geometric diameter of coffee bean, σ – standard deviation of dimensions of coffee bean, d – diameter of the drum cylinder; large diameter cylinder worked better with available power [14], L_p – length of a beater. Reference [6] had reported D_g and σ.

Sphericity of 0.72 reported for coffee bean [6] indicated that it can be regarded a sphere [15] which would roll on a surface. The diameter of the concave holes and spacing were based on intermediate and major diameters of coffee beans respectively because of rolling possibility. This approach was to allow easy passage of shelled beans to avoid serious damage considering the nature of the bean as dicotyledonous.

Throughput capacity (T_c) was determined from gravimetric equation reported by [16]:

$T_c = V_c\rho_c$ (4)

$V_c = \pi(C_T/4)L$ (5)

V_c – Volumetric capacity, ρ_c – bulk density of coffee berries

Power (P_d) required due to weight of drum cylinder was estimated as stated by [17], [14] and [18]:

$P_d = 2\pi NT_d/60$ (6)

Torque (T_d) required was calculated from the weight of drum and beaters:

Weight of drum, $W_d = \rho_s g\pi L(\{d_0 - d_i\}^2 / 4)$ (7)

$d_i = d_0 - 2t_d$, d_0 – outside diameter, d_i - internal diameter, t_d – thickness of drum

Weight of beaters, $W_b = k(g\rho_b V_b)$ where k is number of beaters

$T_d = (W_d + W_b) \times (\{d_0 - d_i\}/2)$ (8)

Velocity of the dehusking drum is important as it determines the impact force generated to break the shell of coffee berries. Too high or low velocity of the drum would automatically affect the performance of the machine. The velocity, V_r, was determined from [13]:

$V_r = 2\pi rN/60$ (9)

N = Number of revolution per minute (rpm)

Power (P) required for shelling coffee berries was determined

According to the definition of power as the rate of doing work, and report of [14]:

$P = F\ V_r$ (10)

$F = F_i r_{i\ (i-----k)}$

i - k - number of beaters (11)

The centripetal force impacted by the beater was estimated from the equation stated by [13]:

$F = mr\omega^2$ (12)

$m = \rho_b V_b$

$\omega = 2\pi N/60$ (13)

m – mass of a beater, ω – angular velocity, ρ_b and V_b are beater density and volume respectively

3) Determination of pulley and belt parameters

The actual size of the belt to transfer power from the driving engine to the dehusker was determined through the nominal pitch length as in the following expression reported by [12], [19] and [15]:

$L_b = 2C + \pi/2(D_1 + D_2) + [(D_2 - D_1)^2/4C]$ (14)

$C = (D_1 + D_2/2C) + D_1$ (15)

The power transmitted by belts was evaluated by the expression reported by [15] and [13]:

$P = (T_1 - T_2)V_b$ (16)

P – power transmitted by belt (watts)

V_b – linear velocity of the belt (m/s)

$V_b = \pi N_1 D_1$, [13]

N_1 and D_1 are drive pulley speed and diameter respectively.

$T_1/T_2 = e^{\mu\Theta}$ [12] and [15] (17)

T^1 and T^2 are tensions at tight and slack sides of the belt respectively

μ = coefficient of friction = 0.25 [19]

Ө – angle of contact between pulleys (rads)

$\Theta = (180 - 2\alpha) \times \pi/180$, [19] and [13]

$\alpha = \sin^{-1}[(r_3 - r_2)/C]$ ([12] and [15])

Pulley dimensions were determined using speed ratios required as expressed in the equation:

$N_1 D_1 = N_2 D_2$ [13] (18)

N_2 and D_2 are driven pulley speed and diameter respectively.

r_3 and r_2 are radii of two matching pulleys respectively

4) Sieve design

Cleaning sieve factors were estimated using the reports of [20] and [21] as follows:

$C_0 = (3\pi/2) \times (D_s^2/\{D_s + D_o\}^2)$ (19)

C_0 – coefficient of screen (open area/total area) which varies between 0.4 - 0.45, D_s – distance between successive holes and D_0 - screen hole diameter which was selected to be a little greater than the geometric mean diameter of coffee beans.

5) Fan design

Centrifugal fan was preferred for this work because of its ability to produce air stream of considerably high volume and pressure at reasonably relative low speeds and reasonable power. Terminal velocity, the size and number of blades and shaft speed which are important determinants of the volume and speed of air stream produced were considered.

$Q_a = AV_a$ [17] and [22] (20)

$A = \pi d^2/4$

Q_a – Air volumetric flow rate (m^3/s), A – area swept by fan impeller (m^2), V_a – Air flow rate (m/s), d – diameter of fan blade.

Reference [6] determined terminal velocity of coffee bean as 12.9 m/s while [15] reported terminal velocity of tigernut, which has similar relevant physical properties of coffee bean, as 17.60 m/s. Terminal velocities of unwanted lighter materials in threshed crops, such as straws and chaffs were reported to range from 1.2 to 6 m/s. In order to achieve cleaning, velocity of air produced by the fan must be between 6 and 12.9 m/s, such that most of the foreign materials would be removed without coffee beans being blown away. Fan blade dimensions were selected such that large volume of air current would be produced at reasonable fan speed.

According to [15], the following relationships for centrifugal fan:

$D_{bh} = 1.5d$ (21)

$C_{bh} = 1.25W_{bh} + 0.1d$ (22)

D_{bh} = diameter of fan housing, C_{bh} – width of blower housing and W_{bh} – blade width.

Number of blades was estimated from the angle of blades using the equation of [23]:

$$r = R\left(1 + \frac{\theta}{360}\right) \quad (23)$$

r - Radius of fan case = D_{bh}, R - Distance from center of shaft to tip of blade = d/2, θ - Angle between blades

6) Hopper design

Hopper design was based on volumetric capacity, using the relationship by [20] and [15] below. Angle of repose of dry coffee (Table 1) was also considered as [5] recommended that the slope of hopper sides should be 8 - 10^0 greater than the angle of repose.

$V_{hp} = 1/3(A_1 + A_2 + \sqrt{A1} \times A2)h_p$ (24)

V_{hp} – hopper volume, h_p – depth of hopper, A_1 and A_2 are area of the top and bottom base respectively

7) Design of shafts

Diameter of dehusking drum shaft was determined against twisting base on rigidity theory according to [17] and [12]:

$\theta_T = 584M_tL_s/Gd_s^4$ (25)

$d_s = (584M_tL_s/G\ \theta_T)^{1/4}$

θ_T – angle of twist which was given as about 3^0 per metre for line shafting

G – torsional modulus (Nm^2) = = $80KN/mm^2$ by [17] and [19]

Mt – torsional moment (Nm), L_s – length of shaft (m) and d_s – diameter of shaft

Shafts driving the blowing fan and the sieve were designed against torsion using the equation reported by [14], [15] and [18]:

$$d = \sqrt[3]{16T/\pi\tau} \quad (26)$$

d = shaft diameter, T – torque and $\tau - allowable\ shear\ stress$ = 42N/mm^2 [17] and [18]

D. Machine Test

This test was carried out based on the reports of [10], [11] and [22]:

Dehusking efficiency = (Pure grain/ Total grain collected) x 100

Cleaning efficiency = (Chaff from chaff outlets/Total chaff collected) x 100

Bean damage = (Damaged beans/ Total beans) x 100

III. RESULTS AND DISCUSSION

The mean of data obtained from the machine test is represented in Table III. Percentage bean damage of 0.5 – 0.8 recorded in this study was relatively low and similar to those reported in previous works by [14], [12], [6] and [13]. The difference in bean damage was also marginal, implying that the rubber beater mechanism was versatile, considering bean damage at wide drum speeds. Beans that were either cracked or partly broken were regarded as being damaged. Damaged beans recovered were observed to have been affected by previous processing stage, prematurity and pest and/or disease. Considering broken bean as one that is less than half average bean according to [6], there was little or no damaged beans obtained from the machine test. Acceptable high cleaning efficiency range of 72.9 – 96.5% recorded compares with those obtained in previous studies, but was higher than those of 62.7%, 85.4% and 86.7% recorded by [12], [24] and [22]. The wide interval in the cleaning efficiency suggests that appreciable higher cleaning was achieved as the speed of the blower increased. Considerably high cleaning efficiency achieved at relatively low drum speed of 450 m/min, implies that the cleaning unit was very effective and well-synchronized with other related units of the machine. The dehusking efficiency of 67.8% recorded was higher than 59.7% for locust beans and 63.2% for millet reported by [16] and [12] respectively, and comparable with 69% for fonio [17] and 76.4% for guinea corn [24]. However, further detailed test can be carried out to better explore the potential of rubber beater mechanism for this purpose. The test may reveal appropriate steps to improve on the performance of the machine, particularly dehusking efficiency, to improve prospect of its adoption.

TABLE III. MEANS OF VALUES FROM PERFORMANCE EVALUATION

Drum speed (m/min)	Dehusking efficiency (%)	Cleaning efficiency (%)	Bean Damage (%)
550	67.8	96.5	0.8
500	60.5	83.4	0.6
450	51.3	72. 9	0.5

IV. CONCLUSIONS

The machine test has demonstrated a good prospect of rubber beater mechanism for dehusking dry coffee berries, considering its low bean damage at wide range drum speed, even when it was reasonably high. However, detailed test may reveal better performance or appropriate steps to improve on the potential of the machine. Generally, this development is promising for addressing farmers' and processors' problems as availability of an indigenous machine will be relatively affordable due to lack of involvement of high foreign exchange. Therefore, adoption of the machine will improve farmers' livelihood and coffee quality.

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