

Design, Fabrication and Testing of Cocoa Depodding Machine

Murtala O. Iyanda¹, Elijah A. Alhassan^{2*} and Timothy A. Adekanye²

¹Department of Agricultural and Biosystems Engineering
University of Ilorin
Ilorin, Nigeria

²Department of Agricultural and Biosystems Engineering
Landmark University
Omu Aran, Nigeria
*alhassan.elijah@lmu.edu.ng

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Abstract

Cocoa (Theobroma cacao) is an important cash crop that serves numerous food purposes. Removing the seed from the pod, or depodding is key to its vast applications. In an attempt to ease the bottleneck in breaking the pods to release the seeds for utilization, a cocoa depodding machine was developed to efficiently depod various sizes of cocoa. Fabrication was done using locally available materials to achieve reduction in production cost, stress and drudgery attributed to the manual methods of depodding. The essential components of the depodding machine are the hopper, the depodding unit, the frame and the power unit. Its design and operation are based on the engineering properties of the cocoa pod, and the machine utilizes impact and compression mechanism for depodding actions. Machine evaluation was conducted on four levels of speed resulting from different pulley diameter ratio (219, 278, 397 and 636 rpm) in order to establish the best operating speed for the machine. The results of which were 89.29%, 87.38%, 85.25% and 80.70% respectively. The best output of the depodding machine was obtained when operated at 219 rpm speed with a throughput capacity of 469.87 kg/h, a minimum bean damage of 10.71%, and a 2 hp electric motor as the prime mover.

Keywords: cocoa, depodding, agriculture, machine design, evaluation

1. Introduction

Cocoa tree thrives in hot and rainy tropical climates (20° north and south of the equator) and predominantly grows in Africa, Asia, Central and South America. It is a cash crop that has had its fair play in the Nigerian economy by taking the lead as an agricultural export commodity with huge foreign

exchange earnings for the country. The Nigerian cocoa economy has a rich historical documentation and its vast contributions to the nation's economic development have been reported by many Nigerian authors (Nkang, *et al.*, 2007; Adeoti and Olubamiwa, 2008).

Cocoa fruit (pod) comprises the husk, bean – being the most useful and valuable part – and placenta. Its usefulness is found in the industries of cosmetics, pharmaceuticals, beverages, soft drinks, flavoring agents and confectioneries. Cocoa husks can be used to produce fermentable sugar and cocoa cake as part of animal feed after the removal of theobromine. The shell (husk) is a good source of potassium and can be used in the production of potash fertilizer, local soap, biogas and particle board (Adzimah and Asiam, 2010; Aliu and Ebunilo, 2012; Oddoye, *et al.*, 2012).

Processing of cocoa involves breaking of pods, extraction, fermentation, drying, dehulling and winnowing of the beans and the production of valuable products from the bean. (Faborode and Oladosu, 1991; Ademosun, 1993; Adewumi, 1997; Adewumi and Fatusin, 2006). The process of breaking cocoa pods is traditionally manual by the use of wooden clubs, cutlasses and knives to hit the pods or by striking two pods against each other laterally. Cocoa depodding, a size reduction exercise and the primary process in the processing of cocoa, is stressful if done manually; hence, an apt mechanization attention is required (Adewumi and Fatusin, 2006; Aliu, 2012). Attempts have been made by researchers and engineers to mechanize the cocoa depodding process in Nigeria but the adoption and practice are not yet done intensively. The first cocoa pod breaker in Nigeria was constructed at the Cocoa Research Institute of Nigeria (CRIN). Based on design parameters, forces involved in mechanical breaking of cocoa pod could be impact, compressive and shearing, this depends on the type of machine, as well as the processes, and principles that machine designers and inventors have utilized in the various available designs of the machines (Audu, *et al.*, 2004; Vejesit and Salohkhe, 2004; Adewumi and Fatusin, 2006, Adzimah and Asiam, 2010; Vishwakarma, *et al.*, 2012). Although these machines have helped in reducing the drudgery involved in cocoa depodding, the efforts in operating some of them and percentage seed damage are high (Adewumi and Fatusin, 2006; Adzimah and Asiam, 2010; Aliu, 2012). This study design is worth looking at because it had a better seed damage percentage, required less input power and favorable output.

Promoting the value addition to agricultural commodities on semi-processed products rather than raw commodities will enhance their market values,

thereby resulting in economic empowerment for stakeholders in agricultural processing ventures. However, constraints in mechanizing the processing operations have hampered this and the efforts to meet the global market demand for cocoa. Therefore, the need for a mechanized way of depodding cocoa fruit and extraction of the beans to further expand the production capacity of cocoa seed should be advocated. In order to address the challenge of manual depodding of cocoa pod, a cocoa deppoder was designed, fabricated and evaluated using locally available materials. The development of the cocoa depodding machine, which works by impact and compressive mechanism to perform depodding actions, was undertaken based on the physical and engineering properties of Forastero cocoa fruit, the most common type of cocoa in Nigeria.

2. Methodology

The construction materials selected for the cocoa depodder were based on availability, strength and toughness. Materials such as angle iron, galvanized steel, mild steel, shaft, pulley, bearing, bolts and nuts, and consumables were used in the construction of the machine. Ripe Forastero cocoa fruits were obtained from a cocoa farm in Oke-Onigbin (8° 13' 0" N, 5° 0' 0" E), Kwara State. Hardness test was carried out using a Universal Testing Machine (UTM), model SF 300-2041 at the Department of Agricultural and Biosystems Engineering, University of Ilorin, to determine the force needed to break a cocoa pod. An electronic weighing balance and a measuring cylinder were used to determine the mass and volume of cocoa pod and seed samples respectively.

2.1 Design Consideration and Computation

The machine was designed based on engineering mechanics such as impact and compression forces acting on the machine during operation. The design was achieved using Autodesk tools with consideration given to material availability, cost, power requirement, safety, strength, durability and ease of operation of the machine in the fabrication process.

Significant physical and mechanical properties of the cocoa pod were used for designing the machine component parts. Cocoa pods are usually oval-shaped and vary in size depending on variety, an important factor in hopper design,

with their length ranges between 104 – 202 mm. Mature cocoa pods can be categorized into three major sizes based on the mid-diameter of the pod with large-sized diameter ranging 81 – 96 mm, the medium-sized diameter at 65 – 80 mm and the rare small-sized diameter at 50 – 64 mm (Adewumi and Fatusin, 2006; Aliu, 2012). Cocoa pod mass ranges 350 – 460 g except for the rare availability of pods with mass less than 350 g. Basic consideration was given to the design for capacity, shape and size, force to break the pod, volume of hopper, shaft, frame and power requirement (Figure 1).

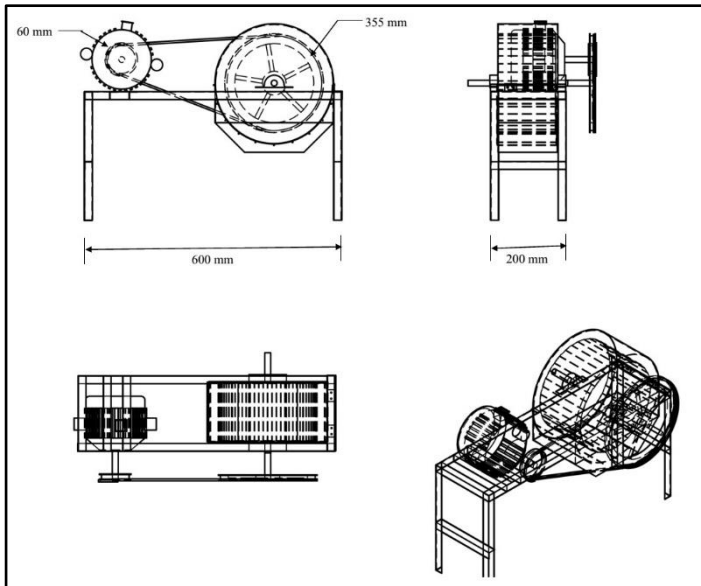


Figure 1. Orthographic projections of the machine

2.1.1 Volume of Hopper

The hopper is a truncated pyramid which appears as trapezoidal. The volume (V) of the hopper was determined using the expression (Gbado *et al.*, 2013):

$$V = \frac{1}{6}H(2L_1B_1 + L_1B_2 + L_2B_1 + 2L_2B_2) \quad (1)$$

where:

- H = height of the hopper, mm;
- L_1 = top length of the hopper, mm;
- B_1 = top breadth of the hopper, mm;
- L_2 = base length of the hopper, mm;
- B_2 = base breadth of the hopper, mm.

The designed capacity for the hopper can practically accommodate 10 medium sized pods.

Recall:

$$\rho = \frac{M}{V}$$

Mass of pod the hopper can accommodate = $\rho \times V$

where:

ρ = density of cocoa pod, kg/m³

V = volume of the hopper, m³

2.1.2 Force at the Depodding Unit

Required force at the depodding unit was obtained using the expressions by Khurmi and Gupta (2005):

$$F = ma \quad (2)$$

$$a = \omega^2 r \quad (3)$$

where:

m = mass of cocoa pod

a = angular acceleration of the beater

2.1.3 Shaft Design

The shaft, a major part of the process unit of the machine, is acted upon by the weights of cocoa pod being processed, the belt, the pulley, the beater and the seeds. Power generated from the prime mover is transmitted to the shaft by pulley and belt arrangement that rotate the depodding drum. A mild steel rod of diameter 25 mm was selected based on the design calculation for the machine and material toughness (Khurmi and Gupta, 2005).

$$d = \sqrt[3]{\frac{16T}{\pi\tau}} \quad (4)$$

where:

$$\tau = 0.27 \text{ } \Upsilon_s.$$

d = diameter of the solid shaft;

T = Torque transmitted by the shaft;

τ = Torsional shear stress;

Υ_s = yield stress

2.1.4 Power Requirement of the Machine

The power required to operate the machine was designed based on the force needed to break the pod and velocity of the rotational shaft as expressed in equations 5 and 6 (Khurmi and Gupta, 2006):

$$P = Fv \quad (5)$$

$$v = \omega$$

$$P = (F_c + W_p) v \quad (6)$$

where:

F_c = force at the depodding unit for crushing the pods, N

W_p = force required to press the seeds through the screen, N

ω = angular speed of the shaft, rad/s

r = shaft radius, m

v = velocity of shaft rotation, m/s

Based on the design calculation, a 2 hp electric motor was used.

2.1.5 Pulley and Belt Design

The maximum permissible ratio for the pulley in order to prevent the slipping of the A-type V-belt from the sheave is 10:1. The belt is for power transmission from the motor to the shaft. It requires relatively close spacing and precise center distance. The center distance between the motor and shaft was made adjustable. Using the expressions given by Khurmi and Gupta, 2006, the belt and pulley was designed.

$$V = \frac{\pi ND}{60}$$

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (7)$$

where:

D_1 = Diameter of motor pulley, mm;

D_2 = Diameter of shaft pulley, mm;

N_1 = Motor speed, rpm;

N_2 = Depodding drum speed, rpm.

A pulley diameter of 355 mm was selected based on the design calculation.

For the center distance and the length of belt, the following equations apply:

$$C = \frac{D_1 + D_2}{2} + D_1 \quad (8)$$

$$L = \frac{\pi(D_1 + D_2)}{2} + 2C + \frac{(D_2 - D_1)^2}{4C} \quad (9)$$

2.1.6 Stationary and Rotating Drum

The stationary drum is a cylindrical drum with dimension 300 mm diameter and length 200 mm. It was fixed to an outer casing rectangular in shape such that the lower half of the drum is a screen through which the broken pods are discharged with ensured pulverization. The dimension was chosen based on the average size of a cocoa pod as determined in the laboratory.

The rotating drum was designed with diameter 180 mm and length 180 mm such that two discs were connected by rods so as to enhance rotation of the pods against the walls of the stationary drum and to also generate an impact on the pods. They were made from galvanized steel of thickness 2 mm. The semi-circular drum protrude to form the discharge chute. The rotating drum inside the screen is shown in Figure 2.

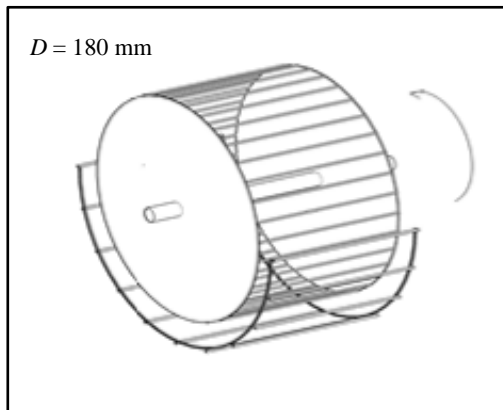


Figure 2. Rotating drum and screen

2.2 Description of the Cocoa Seed Depodder

The machine consists of the hopper, the depodding unit and the frame. The hopper is trapezoidal in shape and made from mild steel. To provide adequate strength and rigidity for the machine, an angle iron of dimension 30 x 30 x 3 mm was selected for the frame design. The frame is 600 x 600 mm in height and length. Upper (semi-circular) and lower (screen) layers formed the depodding unit where pod breakage takes place.

Four pulley sizes of diameters 55, 70, 100 and 160 mm were used for the driver (electric motor) for the four levels of speed investigated and 355 mm was selected based on design for the driven (machine) shaft with a 2 hp electric motor to supply the needed power for the operation (Figure 3).

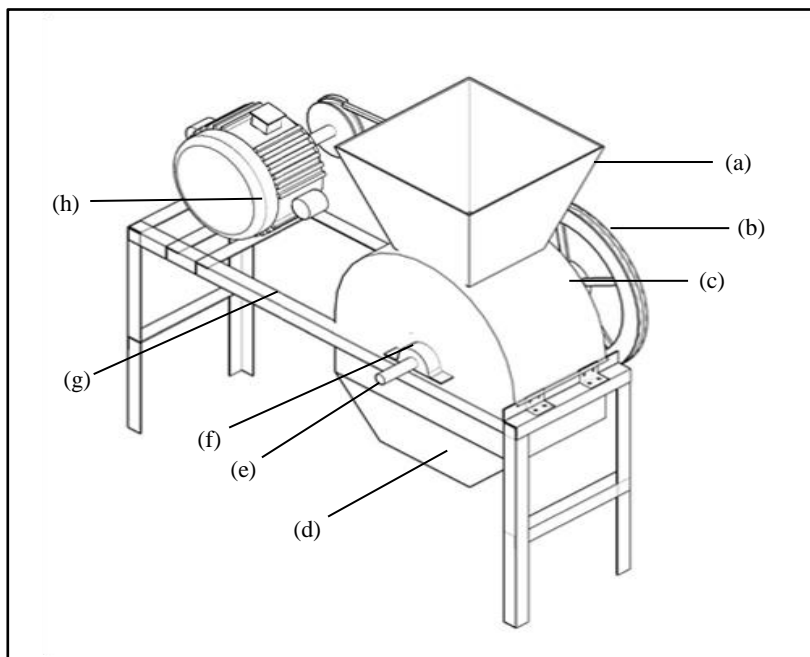


Figure 3. Isometric view of the machine: a) hopper, b) belt and pulley, c) depodding drum, d) discharge chute, e) shaft, f) bearing, g) frame and h) electric motor

2.3 Working Principle of the Machine

The machine works by converting electrical energy to mechanical energy that supplies both the impact and compressive forces needed for the depodding actions. Ripe harvested cocoa pod were fed manually into the hopper which fall by gravity into the depodding unit where the action of impact and compression bring about the size reduction and separation of the seed from the husk. The pods fall on a rotating drum which throws them against the wall of the stationary drum. The depodding unit is divided into two layers, the upper layer (semicircle) and the lower layer (screen). The upper layer allows the pods to fall into the drum, then breaks them by impact and the broken pods further reduced at the lower layer where the broken pods and the beans are forced out by compression with further breaking taking place as they pass through the screen for an efficient size reduction of the pods (Figure 3). The pictorial view of the cocoa depodder machine is as shown in Figure 4.



Figure 4. Pictorial view of the cocoa depodding machine

2.4 Machine Testing and Performance Evaluation

The machine was run empty to ascertain smooth functioning of the various component parts. The speed of operation was varied at four levels (219, 278, 397 and 636 rpm) to establish machine efficiency, capacity and best operating speed for depodding operation. Speed variation was achieved by varying the driver (motor) pulley diameter (55, 70, 100 and 160 mm), while the driven pulley diameter (355 mm) was kept constant.

The 24 kg of cocoa pod used for testing was divided into twelve (2 kg each) for the three replicates of the four levels of speed used in the evaluation. By the manual filling of the hopper, the machine was run at the desired level of speed and the time taken for depodding was recorded using a digital stop watch while the weights of both the depodded and the damaged beans were obtained using a weighing balance.

The resulting depodded samples were collected and the machine was evaluated in terms of percentage mass of bean damaged, throughput capacity (kg/h) and efficiency in terms of bean integrity.

2.4.1 Performance Indices

The machine performance indices in terms of throughput capacity, machine efficiency and percentage seed damage were evaluated using equations (10) - (12), following the procedures used by Adewumi and Fatusin (2006) and Ghafari *et al.* (2011).

Throughput (C): The throughput of the cocoa depodder (C) was evaluated using the following equation:

$$C = \frac{M_t \times 3600}{T} \text{ kg/h} \quad (10)$$

where:

M_t = mass of sample before depodding, kg

T = time used in depodding, hr

Machine efficiency (η): The machine efficiency was estimated in terms of percentage mass of beans damaged using the expression:

$$\eta = 100 - \% \text{ mass of bean damage} \quad (11)$$

$$\eta = 100 - \left(\frac{M_{bd}}{M_t} \times 100 \right) \%$$

$$\% \text{ mass of bean damaged} = \frac{Mbd}{Mt} \times 100\% \quad (12)$$

where:

Mbd = mass of bean damage

Mt = total mass of sample

3. Results and Discussion

3.1 Force Required to Break a Cocoa Pod

The result of the compression test for ten Forastero cocoa pod variety of cocoa pod using UTM is as presented in Table 1. The minimum force required to break a pod was 343.33 N while a maximum of 759.7 N was obtained. An average major and minor diameter, mass, volume, and maximum breaking force of 158.81 mm, 73.59 mm, 370.85 g, 388.06 cm³ and 614.30 N respectively was obtained from the laboratory evaluation.

Table 1. Force required to break a cocoa pod

S/N.	Major Diameter (Length) mm	Minor Diameter (Width) mm	Mass, g	Volume, cm ³	Maximum Breaking Force, N
1	172.80	80.00	447.80	410.00	544.40
2	163.50	76.50	459.23	412.80	508.40
3	154.20	73.30	329.00	385.00	343.33
4	159.00	73.50	427.94	408.00	759.70
5	149.80	74.00	326.72	383.80	609.20
6	171.50	78.80	418.14	402.00	725.30
7	159.50	72.00	338.18	390.00	651.80
8	151.20	69.50	302.37	378.00	711.10
9	202.00	75.80	451.65	411.00	588.80
10	104.60	62.50	207.47	300.00	700.84
Average	158.81	73.59	370.85	388.06	614.30

3.2 Effects of Machine Speed on Performance Indices Investigated

The results obtained from the machine performance evaluation are as presented in the Figure 5 and the sample depodded cocoa is shown in Figure 6. Graphical representation shows the influence of machine speed on machine efficiency, percentage bean damage and throughput capacity.

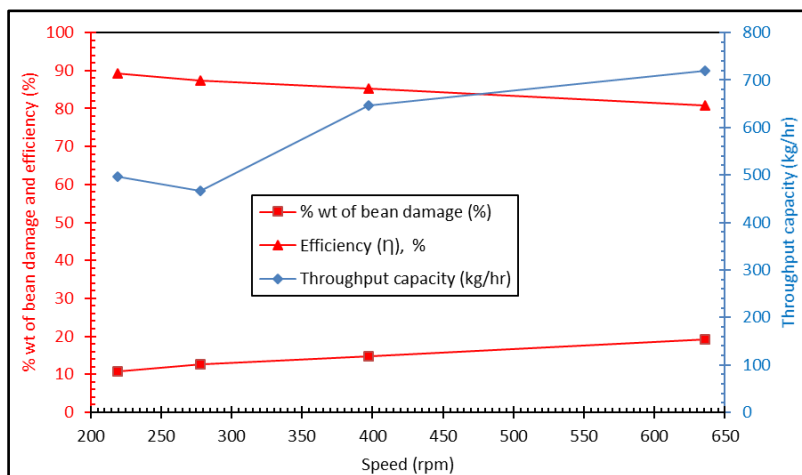


Figure 5. Graph showing the change in machine capacity, percentage weight of bean damage and machine efficiency with respect to change in machine speed



Figure 6. Samples of cocoa before and after depodding

Investigation shows that machine speed has an effect on the performance indices investigated. Operating the machine at 219 rpm produced the highest efficiency of 89.29% with throughput capacity of 469.87 kg/h and bean damage of 0.037 kg. At 636 rpm the highest throughput capacity of 718.92 kg/hr was obtained but the quantity of damaged beans was also the highest (0.0667 kg) as this speed resulted in the lowest efficiency of 80.70%. Efficiency tends to reduce as operating speed increases and there is an increase in the percentage seed damage as the operating speed increases. Hence, there exist an inverse relationship between efficiency and speed and a direct

relationship between the percentage seed damage and operating speed. It was also observed that as the operating speed increases, the depodding time reduces. This is because more energy is available for agitation of the cocoa pods, thereby striking them more effectively against the stationary drum for breakage. The recommended speed for efficient and smooth running of the machine was found to be 219 rpm.

4. Conclusions and Recommendation

A cocoa depodding machine was developed based on the physical and engineering properties of cocoa pods using locally available materials. Peasant farmers were the target recipient; hence, the machine was designed to be user-friendly and at an affordable price. Its operation was on the principle of impact and compression mechanism for depodding action. Four levels of speed were achieved by varying the pulley diameter of the driver. It was observed that machine speed has an effect on the performance parameters of the machine throughput capacity, efficiency and percentage bean damaged. Operating the machine at 219 rpm produced the highest efficiency of 89.29%, throughput capacity of 469.87 kg/h and bean damage of 0.037 kg.

There is a need for improvement on the machine in reducing the percentage of seed damage. Incorporating a separating mechanism in the machine design for the separation of the broken husks from the bean and a cover for the hopper to prevent throw up of cocoa pods from the machine for a safe and smooth operation should be also considered.

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