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Design, development and performance evaluation of a portable cocoa seed extractor

Damilola Victoria Awe [1, *], Victoria Adebisi Alao [2], Peter Efosa Ohenhen [3], Olusegun Abiodun Balogun [4], Zolani Ndlovu [5] and Asafa Tesleem Babatunde [6]

[1] *Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.*
[2] *Department of Mechanical Engineering, University of Ilorin, Kwara, Nigeria.*
[3] *Department of Mechanical Engineering, University of Nebraska-Lincoln, USA.*
[4] *Department of Mechanical Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.*
[5] *Department of Mechanical Engineering, Pan African University institute for basic Science, Technology and innovation, Nairobi Kenya.*

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Abstract

Even though cash crops like cocoa, cotton and rubber are a major source of revenue for the nation, the unavailability of affordable and easily accessible post-harvest process machines has made it impossible to generate maximum income from these crops. A cocoa seed extractor was produced to increase the productivity of cocoa farmers and reduce the stress and dangers they are exposed to in the process of splitting the cocoa pods and separating the cocoa beans from the pods. The machine has two major chambers: A cocoa seed extractor was produced to increase the productivity of cocoa farmers and reduce the stress and dangers they are exposed to in the process of splitting the cocoa pods and separating the cocoa beans from the cocoa pods, fed into it by the conveyor belt, to crack the pods as they are forced through the centre of rotation. The sprout then conveys the cracked pod to the separating chamber where a rotating beater beats the pod, forcing the cocoa seeds out of it. The seeds then pass through the 16mm sieve in the chamber and are collected at the cocoa seed outlet while the pod is collected at the pods outlet. The machine is powered by a 3 horse power and a 0.74 horse power electric motor. The materials used in its fabrication are locally sourced. A performance evaluation of the machine reveals that it works at an efficiency of 87.5% in terms of the number of cocoa pods processed per day, and at 75% efficiency in terms of the number of cocoa seeds processed without damage. The throughput of the machine is 250kg/hr. Thus, the cocoa seed extractor can process 8,228pods/day compared to about 400pods/day that can be processed by an average person.

Keywords: Cash crops; Cocoa pods; Cocoa seeds; Extractor; Cracking chamber; Separating chamber

1. Introduction

Agricultural mechanization plays a significant economic role by increasing agricultural production and reducing the cost of cultivation. It is the application of technology through the use of modern machines to enhance agricultural production. The introduction of agricultural machinery results in increased productivity, thus, leading to higher efficiency of the inputs and quality of the produce (Basi et al. 2021).

According to research on the green revolution, irrigation, improved seed, and fertilizer, all work together to increase productivity, and mechanization is at the heart of agricultural success. (Wessel et al. 2015). A survey of the number of farms in the world indicates a figure of over 500 million family farms. These farms tend to occupy at most 80 % of farmland and the world's food production value depends on them (Sims et al. 2017).

* Corresponding author: Damilola Victoria Awe.

In West Africa, the largest producers of cocoa are Ghana and Cote d'Ivoire, followed by Cameroon and Nigeria. Cocoa is a prominent commercial cash crop in West Africa. Furthermore, Wessel et al. (2015), stated that cocoa is mostly farmed by smallholders in West Africa, who originally planted it at random under thinly shaded forest cover. This low-input agriculture approach utilizes forest soil fertility and existing shade. Most high-quality cocoa in the world today is from West Africa. Likewise, most peasant farmers depend on cocoa farming as their means of livelihood (Fapohunda et al. 2012). The shell of the cocoa pod is an excellent source of potassium and can be used to make potash fertilizer and locally produced soap. The cocoa beans are processed into powder for producing beverages, soft drinks, ice creams, biscuits, and cocoa butter used in the production of cosmetics (Kiran et al. 2020).

The first step after harvesting cocoa is to shatter the pods. Today, even in many manufacturing zones, each cocoa pod is manually cut with a machete or a piece of wood. It is risky and unproductive, and sometimes the cocoa seeds are destroyed or chopped. Because the rupture force is not well understood, modelling this force is important for cocoa pod breaker designers (Josue et al. 2019).

2. Literature Review

There are mainly three varieties of cocoa, namely amezonia, amelonado and the hybrid of the two. The cocoa fruit comprises of the pod or shell, beans or seeds, husk, placenta and mucilaginous pulp. Generally, cocoa pods are oval-shaped and vary in size. The length is normally between 20 and 32cm (Asiam, 2010). It varies in color from yellow or green to crimson or violet. In most situations, the surface texture is warty, deep furrowed, or practically smooth. The husks are noticeably thick. Each bean is encircled by mucilaginous pulp. The quantity of beans per pod is typically between 30 and 40. Each bean is made up of two twisted cotyledons that are contained in the testa. The cotyledon ranges in hue from white to purple. Figure 1 depicts the cocoa fruit, the beans with the pulp, and the pod or husk (Asiam 2010).

The cocoa pod breaking is a size reduction method that removes the beans from the pod. The pressures involved in breaking the cocoa pods could be compressive, impactive, or shearing forces depending on the type of machine and method (Audu, 2004; Vejesit, 2004; Fatusin, 2006). Adewumi et al. (2006) explained that the first cocoa pod splitting machine was fabricated in Nigeria at the Cocoa Research Institute of Nigeria (CRIN) another was tested in Cameroon and utilized by Messers Christy and Norris Limited of England. These machines are operated by two people, one feeds the cocoa pods into the hopper while the other collects the beans.

In a paper by Josue et al. (2019), the machine was fabricated using stainless steel with a capacity of 3.5 tons per day, approximately 8 hours. Physical and chemical compositions of the cocoa pods were taken into consideration while the compression force was a major factor considered in the selected components of the machine. The gap between the blades and the sieve determined the efficiency of the machine. Another work by Iyanda et al. (2018) with the use of mild steel as the major material resulted in the fabrication of a cocoa depodding machine. The evaluation of the machine was conducted at four different speeds with the best output being obtained at 219 revolutions per minute and throughput of 469.87 kg/hr.

A convenient cocoa bean separation machine fabricated by Kiran et al. (2020) using locally available materials was evaluated in five trials. The average time taken for splitting the pods was approximately 35 seconds but the machine could accommodate only one pod at a time.

3. Design Methodology

To overcome the numerous limitations of existing machines for the removal of cocoa seeds from the pods, the design of the cocoa seed's extractor was generated using practical knowledge of the process, information gathered from literature and the relevant design equations. The cocoa seeds extractor has three major parts. They are;

3.1. The conveyor belts

The conveyor belt is in the uppermost part of the machine. The cocoa pods are usually placed in this part and the rotating conveyor belt transports them to the grabber wheels.

3.2. Cracking chamber

The actual cracking of the pod takes place in this part of the machine. The cracking chamber has two grabber wheels rotating at the same speed but in opposite directions. The grabber wheels are arranged such that the space between them is not sufficient to allow a cocoa pod to pass through it. This constraint, together with the rotational speed of the wheels, creates a compressional force which is sufficient to crack the cocoa pods as they are forced down the cracking chamber.

3.3. Separating chamber

This is the part of the machine where the cocoa pods will be separated from the beans. It consists of an inlet which has a hopper opening to receive split cocoa. Also in the separating chamber is a stationary perforated net–like plate (sieve) which has holes that can accommodate cocoa beans, enabling them to fall through into a passage that leads to the cocoa beans outlet where they are collected while the pods, which cannot pass through the holes are collected via the pod outlet which is designed for this purpose. Another important component of the separating chamber is the beater which rotates at a high speed. The beater beats the pod, forcing the cocoa seeds out of it.

4. Materials Selection

4.1. Belt and Pulley Selection

A V-belt is usually used to transmit a great amount of power from one pulley to another when the two pulleys are very near to each other. It also operates better at high speed than other type of power transmission mechanism. Therefore, a V-belt was selected.

Similarly, a V-grooved pulley is used for transmitting the power. A rectangular keyway was cut on the shafts as well as on the pulleys for tight griping to avoid wearing out of the pulley on the shaft thereby giving effective power transmission.

4.1.1. Belt and pulley analysis

The separator has a 0.74hp electric motor rotating at 1350rpm and has a power of 550Watt connected to it via a belt and pulley. Speed of the separator;

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{1350}{N_2} = \frac{165}{78} \quad (1)$$

$$N_2 = \frac{1350 \times 78}{165} = 638.2 \text{ rpm}$$

4.1.2. Evaluation of belt and pulleys

$$V = \frac{\pi DN}{60} = \frac{\pi \times 0.165 \times 1350}{60} = 11.66 \text{ m/s} \quad (2)$$

$$L = \pi(r_1 - r_2) + 2x + \frac{(r_1 - r_2)^2}{x} = \pi\,(0.034 + 0.0825) + 2(0.15) + \frac{(0.034 - 0.0825)^2}{0.15}$$

$$L = 0.365 + 0.3 + 0.015 = 0.68\text{m}$$

4.1.3. Angle of contact between the belt and the pulley:

$$\sin\alpha = \frac{r_1 - r_2}{x} = \frac{0.034 - 0.0825}{0.15} = -0.323 \quad (3)$$

$$\alpha = -18.86$$

$$\theta = (180 - 2\,\alpha)\,\frac{\pi}{180}\,rad = 180 - 2(-18.86)\,\frac{\pi}{180} = 3.78\,rad \quad (4)$$

$$2.3 \log\left[\frac{T_1}{T_2}\right] = \mu\theta = 0.2 \times 3.78 = 0.756 \quad (5)$$

$$\log\left[\frac{T_1}{T_2}\right] = \frac{0.756}{2.3} = 2.13$$

$$\frac{T_1}{T_2} = 2.13$$

$P = (T_1 - T_2)V$ (6)

$550 = (T_1 - T_2)\ 11.66 = T_1 - T_2 = \frac{550}{11.66} = 47.17$ N

$T_1 = 2.13\ T_2$

$2.13\ T_2 - T_2 = 47.17 = 1.13 T_2 = 47.17$

$= T_2 = 2.13 T_2$

$= T_1 = 89$N

Tension on the tight side T_1 = 89N;

Tension on the slack side T_2 = 42N

4.2. Chain Selection

In this design, chain drives are employed to transmit rotary motion to the grabber wheels in an efficient manner such that the problem of slipping associated with belt drive which leads to loss of power and disparity in the speed of rotation of the wheels is eradicated. Chain Analysis:

To determine the velocity ratio of the conveyor belt and grabber wheels;

where, N_1 = speed of rotation of the sprocket on the roller shaft attached to the electric motor,

N_2= speed of rotation of the sprocket on the grabber wheel shaft,

T_1=number of teeth on the sprocket on the roller shaft attached to the electric motor,

T_2 = number of teeth on the sprocket on the grabber wheel

$\frac{N_1}{N_2} = \frac{T_2}{T_1} = \frac{1420}{N_2} = \frac{18}{18}$ (7)

$$\frac{1420 \times 18}{18} = 1420\ rpm$$

The conveyor roller and the sprocket on the shaft of the first grabber wheel are both rotating

at 1420 rpm.

The velocity ratio of the chain drive between the shaft of the first grabber wheel and the shaft below it is given by;

Where N_3 = speed of rotation of the sprocket on the grabber wheel shaft

N_4 = speed of rotation of the sprocket on the shaft below it

T_3=number of teeth on the sprocket on the grabber wheel shaft

T_4 = number of teeth on the sprocket on the shaft below it

The velocity ratio of the chain drive between the shaft below it and the second grabber wheel is given;

where, N_5 = speed of rotation of the sprocket on the shaft below it,

N_6 = speed of rotation of the sprocket on the second grabber wheel,

T_5 = number of teeth on the sprocket of the shaft below it,

T_6 = number of teeth on the sprocket of the second grabber wheel.

$\frac{N_5}{N_6} = \frac{T_6}{T_5} = \frac{1420}{N_6} = \frac{18}{18}$

$$\frac{1420 \times 18}{18} = 1420\ rpm$$

The length of the chain (L) must be equal to the product of the number of chain links (K) and the pitch of the chain (p).

Mathematically;

$$L = Kp \quad (8)$$

The number of chain links may be obtained from this expression,

$$K = \frac{T_1 + T_2}{x} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2x}\right]^2 \frac{p}{x} \quad (9)$$

The centre distance is given by;

$$x = \frac{p}{4}\left[K - \frac{T_1 + T_2}{2} + \sqrt{\left(K - \frac{T_1 + T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2x}\right)^2}\right] \quad (10)$$

The two grabber wheels rotation is at the same speed so the force at which the pod is drawn through the grabber wheels is given as;

$$F = \frac{mv^2}{r} \quad (11)$$

4.3. Gears

The gear and the pinion are designed to ensure that the two grabber wheels rotate at the same speed.

4.3.1. Evaluation of gear:

Gear ratio=1:1; Centre distance = 100mm

To get the speed of the pinion;

Where, D_P = Diameter of the pinion; D_g = Diameter of the gear; N_g = Speed rotation of the gear; N_p = Speed of rotation of the pinion

$\frac{D_P}{D_g} = \frac{N_g}{N_p}$

$= \frac{40}{40} = \frac{1420}{N_p}$

$N_p = \frac{40 \times 1420}{40} = 1420\ rpm$

4.4. Electric Motor

A 3hp electric motor was selected for driving the conveyor and grabber wheel. The electric motor has a power of 2,238W and its speed of rotation speed of 1,420rpm.

The torque of the electric motor is calculated as:

$$T = \frac{60 \times P}{2\pi \times 1420} = \frac{60 \times 2238}{2\pi \times 1420} = \frac{134280}{8922.12} = 15.05\ Nm$$

5. Results and discussion

One piece of the cocoa pod was used at a time for testing. The average longitudinal and transverse lengths of the pod and the average weight were measured. The pods were fed into the machine and the time at which pods were broken totally and came out of the spout was recorded. The number of damaged and undamaged seeds was computed and analysed. The test was repeated ten times. The results and detailed calculations are presented in the table below:

Average splitting time per pod = 3.5 ± 0.52 sec/pod

Average number of collected seeds per pod = 34.3 ± 4.47 seeds/pod

The average number of seeds per pod remaining in the chamber = 4.9 ± 1.66 seeds/pod

Average total number of seeds per pod = 39.2 ± 4.89 seeds/pod

Average weight of pod = 294.43g = 0.29443kg/pod

Number of pods split per hour = $\frac{1 \times 3600}{3.5}$ = 1028.5 pods/hour

Assuming 8 working hours per day,

Number of processed pods per day = 1028.5 pods/hour ×8 hours/day = 8,228 pods/day

The capacity of the machine = number of pods cut per day × average weight of pods

= $\frac{8228 \times 0.29443}{1000}$ = 2.42 Tons per day

Average number of seeds per pod = $\frac{392}{10}$ = 39.2 seeds/pod

Separating efficiency = $\frac{Total\ no.of\ collected\ seeds}{Total\ no.of\ seeds} = \frac{343}{392} \times 100\% = 87.5\%$

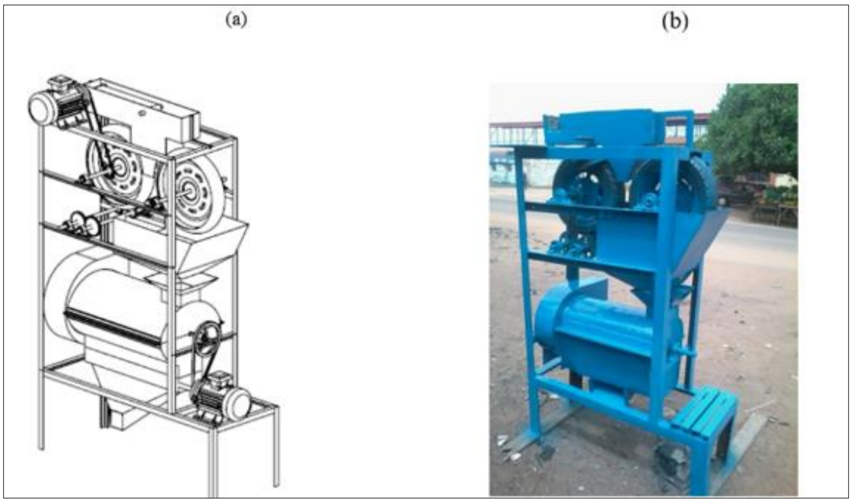

Figure 1 (a) An isomeric drawing of the cocoa seeds extracting machine **(b):** The actual cocoa seeds extracting machine

Figures 1(a) and (b) show the isomeric drawing of the cocoa seeds extracting machine and the actual machine that was fabricated. The results show that the average longitudinal size ranges between 14-18cm, the transverse size ranges between 6-10cm and the average weight is 294.43g for the sample used. The average number of beans in each pod is

39. With feeding one pod at a time, it was realized that the capacity of the machine is 2.42 Tons per day which is equivalent to 8,228 pods per day. It was revealed, from the survey, that a laborer splits 400 pods per day manually. Comparing the output of the machine with maximum capacity using manual operation, it is deduced that a minimum number of 20 laborers are required to match the maximum capacity of the machine. The separating efficiency of the machine was computed using the total number of undamaged seeds released from the spout with respect to the total number of seeds, and it was found to be 87.5%. Given the sticking property of wet cocoa seeds, this value is exceptional.

6. Conclusion

After testing the cocoa pod extractor with a 3hp electric motor which has a speed of 1420rpm for the splitter and also a 0.74hp electric motor which has a speed of 1,350 rpm for the extractor, the conclusions are as follows:

The machine is able to break 8,228 pods per day with one operator. This is equivalent to 24.23 tons per day assuming 8 working hours. Invariably, a day's work on the machine is equivalent to hiring 20 labourers.

The separating efficiency of the machine is found to be 87.5%. The efficiency is based on the number of seeds that were discharged through the sprout and the total number of seeds in the pods including the remaining seeds in the separator. Continuous feeding of the machine leads to fewer deposits of seed in the chamber which brings about decreased efficiency.

Recommendation

The following recommendations are made from the design, construction and evaluation of the extractor with a view to improving its efficiency, capacity and uses:

In the process of splitting, the motion of the cocoa through the rotating grabber wheels is sufficient to crack open the cocoa pod without the use of blades.

In the process of separation, the beater rotates at a very high speed thereby damaging the cocoa seeds and also beating the pods to a very tiny size which enables them to pass through the perforations designed for the seeds alone. Therefore, the speed of the beater should be reduced to an appropriate and minimal speed via speed-reduction gears.

The holes on the sieve in the separation chamber should be enlarged so as to allow seeds to pass either longitudinally or transversely.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to disclosed.

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