



## Design, Fabrication and Performance Evaluation of a Reciprocating Cocoa Pod Breaking Machine

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### A B S T R A C T

#### Keywords:

Cocoa Pod,  
Breaking Machine,  
Fabrication,  
Performance  
Evaluation

*After harvesting ripped cocoa pods during primary processing the next operation is the extraction of the wet seeds from their pods before fermentation. This operation of wet seed extraction is commonly performed manually using cutlass for cutting into two and using of hands for the extraction of the set seeds. This caused drudgery, low extraction rate and atimes incised wounds from cutlass used. Hence an electrically or fueled reciprocating engine powered cocoa pods breaking machine was designed, fabricated and evaluated. It has a crushing chamber of 0.054m<sup>3</sup>, hammer mass of 15.38 kg, applied force of 150.92 N for breaking pods, rated power of the prime mover (electric motor or fueled engine) is 1.22 kW, diameter of hammer's shaft is 28.0 mm, the angle of hopper is 210 using mild steel of 5 mm gauge with friction coefficient of 0.32, total mass of the machine is 145 kg with attached accessories and its geometric dimension is (1060 x 690 x 460) mm. It's crushing capacity per hour based on size of pods are 7,600, 5,400 and 3,600 for small, medium and large pods respectively. It's efficiency based on the pod classifications are: small pods 92.5%, medium pods 87% while the large size is 86.25%. The cost of the machine considering: material, machining, bought out goods, non – machining and labour costs amount to five hundred and twenty four US dollar US \$524:00.*

### 1. Introduction

Cocoa is a prominent tree crop in Nigeria and is one of the main cash crops exported in the country. The proportion of the impact of cocoa exportation in terms of socio economic income is less than 2%. About 30000 households in Nigeria depend on the cocoa economy for their livelihood (COPAL, 2006). According to Adewumi (1997), the exported cocoa beans are processed abroad and the required products are imported to Nigeria at a relatively high cost.

Over the years, from the time of discovery of the cocoa tree, man has been trying to simplify and modify the procedures of planting, harvesting and processing the crop through the use of wood in breaking the pods. The process of breaking of cocoa pods manually required a lot of manpower as well as time (Opeke, 1987). The efficiency of this method depends on the variety of the crops and worker's attitude. There is therefore a need to improve efficiency in order to aid profits and reduce losses.

The uses of cocoa are numerous, such as beverage, wine chocolate, cream lotions, body cosmetics, cheap feeds for poultry and pigs, potash fertilizers, local soap, biogas, particle boards, etc. The cocoa tree is thought to have originated in the foothills of the Andes in the Amazon

and Orinoco basins of South America (ICCO, 2006). According to ICCO (2006), there are three main varieties of cocoa tree amongst many others.. The most common is the Forastero which accounts for 90% of the cocoa beans produced in the world. It is mostly found in West Africa and Brazil. The second group is the Criollo which produces fine flavor beans, mostly grown in parts of the Carribean, Venezuela, Papua New Guinea, the West Indies, Sri Lanka, East Timor and Java. Finally there is Trintario variety, which is a cross from the Criollo and the Forastero. The trees are susceptible to varying diseases. The cocoa tree has a distinctive gray brown bark and grows to a height of 4.572 to 7.62 m. It needs a warm and humid environment, with temperature range of 18 to 35 degrees with relative humidity approaching 100%. It requires an annual rainfall of at least 1270 mm for good growth. The fully grown cocoa pod reaches up to 15.24cm and 30 cm in length and 7.62 cm to 10.16 cm thick at the centre, containing about 30 to 40 seeds (Maduoka and Faborode, 1991). The cocoa pods take a period of about 5 – 6 months to ripe. Yields vary tremendously from as low as 90.72 kg per acre to 226.8 kg per acre (UNCTAD, 2006). Cocoa pod is a berry which varies in size, shape and color. Maduoka and Faborode (1991), identified three distinct parts of the cocoa pod as the pod wall (Husk, 56%), the wet beans (Seeds; 42%), and the placenta (the mucilaginous pulp; 2%) by weight.

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Mature cocoa pods are harvested from the trees by machetes, or by a similar knife attached to a long pole (sickle) for the higher branches. Adewumi (1997) identified five processes involved before the cocoa bean is available in the market. These include: pod breaking and bean extraction, fermentation of the beans, drying of the beans, dehulling and winnowing of the beans, production of cocoa butter, beverage and cake. Other processes include the grinding, roasting, pressing, extraction and deoxidizing of cocoa butter products. A properly dried husk will make cracking sound when rubbed in the hand and the two halves of the beans separate easily. Further processing after drying is not common in the developing nations since they market the beans most times after drying. After harvesting of matured ripe cocoa pods, the first processing operations are pod breaking and bean extraction (Faborode and Oladosun, 1991). Pods are usually opened by carefully cutting them, such that knife do not touch the beans and then twisting them, thereby breaking of a portion of the pod (Wood, 1975). While this is the most common method of pod opening, the use of knife can result in some damage to the seeds, which may rise to as high as 5% of seeds with a cut testa. Ademosun, (1993) and Akinnuli et al., (2013) described the necessary considerations that must be put in place before the development of any agriculture processing machine. Some are: physical characteristics of the produce, moisture content and others. The first cocoa pod breaker in Nigeria was constructed by Jabagun and was tested at the Cocoa Research Institute of Nigeria (CRIN) in 1965. Two people are required to operate the machine; one feeds the cocoa pods into the machine while the other collects the beans. It breaks the pod by means of a crushing principle using a revolving ribbed wooden cone mounted vertically inside a ribbed cylindrical metal drum. The pods fed into the Hooper move to the shelling sections by gravity. The beans pass through the meshes into the collecting wooden box, while the shell fragments drop out the open end of the rotary sieve. Another earlier machine, the Zinke Machine uses several rotary jaws or toothed rollers (Faborode and Oladosun, 1991). These machines have the problem of crushing the husk a further into tiny portions which mix with the beans and this poses a problem during separation. Faborode and Oladosun (1991) designed and tested a machine to break cocoa pods and extract wet beans. These machines consist of a hopper, meter plate, hammer and reciprocating sieve. The pods are broken by the hammer. The husk is separated by the vibrating sieve. The beans are then collected through the discharge chute. This also is characterized with low efficiency and bulkiness. There is therefore a need for an electrically or fueled reciprocating engine powered cocoa pods breaking machine that is portable, with high efficiency and ergonomically compliant which is the focus of this study.

## 2. Materials and Methods

The methodology used involved design considerations and conceptualization, design analysis of component parts, selection of materials for its components, assembling of the produced components and evaluation of the performance of the developed cocoa pod breaking machine.

### 2.1 Design Theory

The following factors were put into consideration for ease of fabrication of the machine. The shape of the hammer was made to be rectangular in shape, the material used was mild steel to minimize cost; the resisting force of the cocoa pods considering the size, shape, hardness and geometry of the cocoa pods were considered. This assist in the selection of the appropriate weight that will not cause seed damage, the power requirement was made to march the speed of the pulley transmitting the motion to the shaft carrying the hammer. Anthropometric parameters of 5th and 95th percentile of both male and female Nigerian population were used for the height and handle to make the developed machine ergonomically compliant.

### 2.2 Impact Load Determination

This was obtained by breaking 32 cocoa pods by impact forces caused by free fall hammer from selected heights. Cocoa pods were grouped into four of eight pods per group. This gave total number of pods used to be 32 cocoa pods. The energy required to break the pod is a function of the product of the weight of the hammer used and the density.

$$U = M_a g h \quad 1$$

Where U is the net energy required to break one pods;  $m_a$  is the mass of hammer; g is acceleration due to gravity,  $(m/s^2)h$  is the height of fall, (m);  $\rho$ , is the density of mild steel.

But;

$$\rho_s = \frac{M_a}{V_h} \quad 2$$

Hence,

$$U = \rho_s V_h g h \quad 3$$

Where,  $V_h$  is the volume of hammer

The weight of the hammer was determined from the product of the hammer's density and its volume as in equation (4)

$$M_h = \rho V_h \quad 4$$

and the mass was calculated to be 12.53 kg. The shaft that carries the hammer is made of solid mild steel and this contributed to the weight of the hammer. The mass of the shaft is obtained using equation (5).

$$M_s = \rho V_s \quad 5$$

Where;  $M_s$  is the mass of the shaft,  $\rho_s$  is the density of mild steel shaft and  $V_s$  is volume of shaft. The mass of the shaft is therefore 0.8860 kg. Equation (6) gives the total mass of the hammer ( $M_{th}$ ) is the addition of the hammer mass and shaft mass.

$$M_{Th} = M_h + M_s \quad 6$$

The total mass of hammer is  $(12.5286 + 0.8860)$  kg is 13.4146 kg and the weight of the hammer in Newton (N) is 131.59 N

### Belt Drive

The belt drive was designed considering the following:

$$\text{Belt Speed, } S = \pi d n \quad 7$$

Where, d is the small pulley diameter, n is the speed of

**Table 1: Physical Properties of Whole Cocoa Pods ( $\pm$  Standard Error)**

S/NO	PHYSICAL PROPERTY	VARIETY		
		Amelonado	Criollo	Trinitario
1.	Angle of Response (o)	15.5 $\pm$ 1.0	16.1 $\pm$ 1.4	20.1 $\pm$ 1.3
2.	Bulk Density (kg/m <sup>3</sup> )	389.9 $\pm$ 8.9	464.5 $\pm$ 7.8	470.3 $\pm$ 8.0
3.	Volume (cm <sup>3</sup> )	397.9 $\pm$ 22.7	710.5 $\pm$ 57.2	599.5 $\pm$ 4.4
4.	Coefficient of Friction			
	(i) On Wood	0.38 $\pm$ 0.01	0.25 $\pm$ 0.02	0.25 $\pm$ 0.03
	(ii) On Galvanized Steel	0.32 $\pm$ 0.02	0.25 $\pm$ 0.02	0.25 $\pm$ 0.03
5.	Gravimetric Composition			
	(i) Pod Husk (%)	68.6 $\pm$ 0.84	78.3 $\pm$ 1.0	76.5 $\pm$ 1.2
	(ii) Wet Beans (%)	28.5 $\pm$ 0.76	18.7 $\pm$ 0.8	20.2 $\pm$ 1.2
	(iii) Placenta (%)	2.93 $\pm$ 0.21	3.07 $\pm$ 0.24	3.31 $\pm$ 0.3

**Table 2: Physical Properties of Cocoa Wet Beans and Pod Husk**

S/N	PHYSICAL PROPERTY	Wet Beans			Pod Husk		
		Amelonado	Criollo	Trinitario	Amelonado	Criollo	Trinitario
1.	Angle of Response (o)	21.0 $\pm$ 0.1	22.7 $\pm$ 1.3	21.8 $\pm$ 0.6	52.3 $\pm$ 1.4	48.6 $\pm$ 2.4	$\pm$ 2.9
2.	Coefficient of Friction						
	On Wood	0.47 $\pm$ 0.02	0.62 $\pm$	0.64 $\pm$	0.39 $\pm$ 0.03	0.48 $\pm$	0.57 $\pm$ 0.07
	On Galvanized Steel	0.32 $\pm$ 0.01	0.04	0.04	0.24 $\pm$ 0.01	0.06	0.55 $\pm$ 0.01
	Plate		0.53 $\pm$	0.57 $\pm$		0.44 $\pm$	
			0.02	0.03		0.06	

small pulley and this gave result of 6.6m/s.

The speed ratio was determined to be 0.98 while the revolution of the bigger pulley diameter, N is 457.33 rpm.

The minimum and the maximum centre distance were calculated thus:

$$C_{min} = 0.55(D+d) + T \quad (8)$$

$$C_{max} = 2(D+d) \quad (9)$$

Where, Cmin is the minimum centre distance, (mm), D is the larger pulley diameter, d is the small diameter, T is the nominal belt thickness, the value of Cmin and Cmax therefore are 206 mm and 706 mm respectively.

The actual centre distance "C" is determined to be 226 mm using equations (10)–(12)

$$C = A + \sqrt{A^2 - B} \quad (10)$$

Where

$$A = L / (A - \pi(D+d)) / 8 \quad (11)$$

$$B = (D-d)^2 / 8 \quad (12)$$

The V – belt rating is kilowatt for belt speed of 6.6 m/s and equivalent pitch diameter of 102.6 mm is 1.39 kW. The number of belts required for the device is determined using equation (13) to be 1

$$\text{Belt Number} = \frac{P \times F_a}{(K_w \times F_c \times F_d)} \quad (13)$$

Where, P is maximum power is kilowatt,  $F_a$  is correction factor for industrial services,  $K_w$  V – belt rating power,  $F_c$  is correction factor for pitch length L and  $F_d$  is correction factor for arc of contact.

The shaft diameter was determined by using equation (14) to be 24.90 mm

$$d_s^3 = \frac{16}{\pi S_s} \left[ (M_b K_b)^2 + (M_t K_t)^2 \right]^{1/2} \quad (14)$$

Where, d is shaft diameter,  $K_b$  is combined shock and fatigue factor applied to bending moment,  $K_t$  is combined shock and fatigue factor applied to torsional moment,  $S_s$  is allowable stress for shaft.

### 2.3 Machine Description and Construction Details

The developed cocoa pod breaking machine is shown in Figure 1. The machine was designed to work having its hopper side way to the vertical reciprocating flat hammer, which crush the cocoa pods against the angle bar directly set under the crushing hammer. Under these angle bars is a receptor to receive the crushed pots.

The angle of repose selected from data available for the hopper is 27o while that of the receptor is 21o. The physical properties extracted from the work of Maduake and Faborode (1991) (Tables 1-2).

The fuel generator (petrol or diesel) or electric motor may be used to power this machine. Summation of the shafts designed power and the factor of safety made the total power required to be 1.22 kW. Salient features of the machine include the hammer, the feeding hopper and the receptor (collector). The machine's isometric drawing and orthogonal views are as shown in figure 1 and 2 respectively.



### 2.3 Determination of the Machine Efficiency

The efficiency of the machine was determined comparing the total pods broken per hour to the total number of pods loaded into the hopper per hour for each size (small, medium and big) using equation (15).

$$\xi = \frac{N_{cb}}{N_{cc}} \times 100 \quad 15$$

Where,  $\xi$  is the machine functional efficiency,  $N_{cb}$  is number of cocoa pods broken per hour and  $N_{cc}$  is number of cocoa pods loaded per hour. The efficiency of the machine for each size is as stated thus: small size is 92.5%, medium size is 87% and the large size is 86.25%.

The machine's performance was also compared with the present manual method of cocoa bean extraction using cutlass or club. The manual braking of cocoa pods was carried out to know the number of pods that can be broken per hour and results shows that 190, 162 and 135 pods were broken and their beans extracted for small, medium and large pods respectively. This makes manual breaking efficiency of small pods to be 2.5%; the medium size 3% while that of large size is 3.75%.

### 3. Results and Discussion

The developed machine was designed to have crushing chamber of 0.054 m<sup>3</sup>, using hammer of mass 15.38 kg capable of applying 150.92 N force for breaking cocoa pods. It required primary mover (electric motor or fueled engine) of 1.22 kW power

rating. The Geometric dimension of the machine is (1060 x 690 x 460) mm. driving shaft of the hammer was designed to be a solid shaft of mild steel with 25.00 mm diameter. The feeding hopper as well as the discharged orifice duct was at repose angle of 210 and 220 respectively. Coefficient of friction selected was 0.32 for galvanized sheet metal used for the fabrication.

While the net mass (with the attached accessories) when weighted on the "Weigh Bridge" is 145 kg. Its crushing capacities per hour based on the size of pods are: 7600, 5400 and 3600 for small, medium and large sizes respectively. It's efficiencies based on these classifications are: 92.5% for small pods; 87% for medium pods while that of large pods is 86.25%. The production cost of this machine considering; materials and labour costs amounted to Ninety Seven thousand Naira (N97, 000.00) only. This is equivalent of five hundred and twenty four US dollars \$524 at the exchange rate of N185 per dollar as at the time of this project.

### 4. Conclusion

Cocoa pod breaking machine was designed, constructed with locally sourced materials and its performance evaluated. The test results showed that the machine will be useful in breaking cocoa pods hence reduce the drudgery of the cocoa farmers in pods breaking before extraction, there will be high productivity on cocoa bean processing in order to extract their butter and get their cake for foreign exchange.

### References

- Ademosun, C. O. (1993): Performance Evaluation of a Medium scale Dehulling and Wining Machine Mechanization in Asia, Africa and Latin America, 24(2):57–60.
- Adewumi, B. A. (1997): Cocoa Bean Processing and Drying Equipment for Small and Medium Scale Industries. A paper presented at a Conference Titled "The Role of Science and Technology in the Development of Small/Medium Scale Industries in Nigeria Organized by the Centre for Research and Development, Ondo State University, Ado-Ekiti.
- Akinuli, B. O., Abadariki, S. O. and Fasan J. O. (2013): Design, Fabrication and Performance evaluation of an Indigenous Honey Extractor. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) Vol. 4(1), Pp. 1–6.
- Aliu, S. A. and Ebunilo, P. O. (2004): Development and Performance Evaluation of a Cocoa Pod Breaking Machine. Advance Material Research Trans Tech. Publication, Vol. 367 (2012), Pp. 725–730.
- Cocoa Producers Alliance, (COPAL) (2006): The Cocoa Economy of Nigeria. Conference of Cocoa Research. All Paper on Cocoa Productivity, Quantity Profitability, Human Health and Environment.
- Faborode, M. O. and Oladosun, G. A. (1991): Development of a Cocoa Pod Processing Machine. The Nigerian Engineers, 26(4):26–31.
- International Cocoa Organization, (ICCO), (2006): Chocolate from A – Z Paper by Khodorowsky, K. and Henry R. at Barry Callebaut.
- Jabagun J. A. (1965): A Mechanized Cocoa Pod Sheller. The Nigeria Aquaculture Journal 2(1): 44–45.
- Maduako, J. N., and Faborode, M. O. (1991): Some Physical Properties of Cocoa Pods in Relation to Primary Processing, Ife. Journal of Technology 2(1), Pg. 4–5.
- Opeke, L. K. (1987): Tropical Tree Crops. John and Sons Clichester, Pp. 108–119.
- United National Conference on Trade and Development (UNCTAD), (2006): Prospects for the World Cocoa Market Until the year 2007. Paper by John N. A.
- Wood, G. A. R. (1975): Experiment on Cocoa Drying in Cameroun, Tropical Agriculture, Longman Publishers, London.