Design, Fabrication and Testing of an Impact-Type Hand Operated Cocoa Pod Breaker

B. A. Adewumi*[1] and A. B. Fatusin

Department of Food Science and Technology, Federal University of Technology

Akure, Nigeria

*Present Address of Corresponding Author: Department of Grain Science and Technology,

Central Food Technological Research Institute, Mysore 570 020, India.

[1]Email: babatunde_adewumi@yahoo.com

ABSTRACT

A manually operated impact-type machine for breaking cocoa pods was designed, fabricated and tested. The major components of the machine include a frame, rail, hammer, pulley, bearings and rope. The machine requires rope tension, tensile stress and cross sectional area of 128.7 N, 728 kN/m^2, 1.77 x 10^{-4} m^2 respectively. Impact energy of 30.9 J is required to break one pod while 78.6 J is required for five pods at a time. Hammer speed was determined to be 3.13 m/s. The total load on the pulley shaft was 143.52 N. The machine requires a shaft diameter of 14.6 mm and a shaft of 15 mm was used. The machine has a power requirement of 201.6 W.

The pods used for testing the performance of the machine were classified into small (5.00 – 6.40 cm), medium (6.50 – 8.00 cm) and big (8.10 – 9.60 cm) sizes according to the dimension of their mid-diameters. The machine was tested using 1 to 4 pods per loading. The parameters measured for testing the performance of the machine include the average number of hammer drops/falls required to break the specified number of pods, time required to break the pods, number of broken pods per operation, machine capacity, percentage bean damage and machine functional efficiency. The machine had less than 1% seed damage with its efficiency and capacity ranging from 93 to 100% and 377 to 738 kg^{-1} respectively. The best results of 0.34% seed damage, 738 kgh^{-1} capacity and 100% efficiency were recorded for two big pods of cocoa loaded at once. It is affordable to peasant cocoa farmers with the production cost less than ten thousand Naira (₦ 10,000.00), less than one hundred dollars ($100.00).

Keywords: Cocoa, machine, capacity, efficiency, bean damage

1. INTRODUCTION

Cocoa is a prominent commercial cash crop in West Africa. It is one of the economy cash crops produced in Ekiti and Ondo States of Nigeria in a large quantity. The most useful and valueable part of the crop is the bean. The highest percentage of cocoa bean produced in the developing countries is exported. The exported beans are processed abroad and the end products are imported back to the developing countries at a relatively high cost (Adewumi, 1997a).

The processing of cocoa includes the breaking of the pods; extraction, fermentation, drying, dehulling and winnowing of the beans; and production of cocoa butter, beverage and cake (Adewumi, 1997a; Ademosun, 1993; Faborode and Oladosun, 1991). Traditionally, the process of breaking cocoa pods is done manually using wood and cutlass. This is an arduous task, apart from the large labour requirement and time consumed during the operation. The cutlass used damages the beans, resulting in damage to the beans. This makes some of the beans unsuitable for fermentation causing losses (Bamgboye, 2003). Also, the man-hours required for this manual operation vary and depend on crop factors such as variety and workers attitude and supervision (Opeke, 1987).

The breaking of pods is a size reduction process, which aims at extracting the beans from the pod. The forces involved in breaking the cocoa pods could be compressive, impact or shearing forces depending on the type of machine and process (Audu et al., 2004; Vejesit and Salohkhe, 2004; Adewumi et al., 2006). The first cocoa pod breaker in Nigeria was constructed at the Cocoa Research Institute of Nigeria (CRIN) as reported in Jabagun (1965). A similar machine built by Messers Christy and Norris Limited of England was tested at Cadbury Brothers Cocoa Plantation at Ikiliwindi, Cameroon (Are and Gwynee-Jone, 1974). 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 mean of a revolving ribbed wooden cone mounted vertically inside a ribbed cylindrical metal drum. The pods fed into the hopper move to the shelling section by gravity. The beans pass through the meshes into a collecting wooden box, while the shell fragments drop out at the open end of the rotary sieve.

Another earlier machine, the Zinke machine, uses several rotary jaws or toothed rollers (Faborode and Oladosun, 1991). This machine has the problem of crushing the husks further into tiny portions, which mix with the wet beans, and this poses a problem during separation. Faborode and Oladosun (1991) designed, fabricated and tested a machine to break cocoa pods and extract the wet beans. It consists of hopper, meter plate, hammer and reciprocating sieve. The hammer breaks the pods while the vibrating sieve separates the husk. The bean is collected through the discharge chute.

Cocoa beans contain about 50 % fat. It is useful in the production of lightning oil, ointments, candles, soaps and medicines (Opeke, 1987). Cocoa butter, made from the fat extracted from the beans, is a stable fat used in the production of cosmetics and pharmaceutical products. The beans are ground into powder for making beverages, chocolates, ice cream, soft drinks, cakes, biscuits, flavouring agents and other confectionaries. Cocoa husks can be hydrolysed to produce fermentable sugar. Cocoa cake is used as part of feed ingredients for poultry, pig, sheep, goat, cattle and fish after removing the theobramine (Adeyanju et al, 1975). The shell (pod) is a good source of potassium and can be used in the production of potash fertilizer, local soap, for biogas and particle boards (Adeyanju et al, 1975; Opeke, 1987). Considering all these benefits, cocoa production and processing must be mechanized and properly improved to aid profits and reduce losses. The objectives of this study therefore is to design, fabricate and test a simple, hand operated and low cost impact type cocoa pod-breaking machine for the peasant farmers in the rural area where there is no electrical source of power.

2. MATERIAL AND METHODS

2.1 Machine Description

Fig. 1 shows the photograph of the machine. Its components include the frame, the hammer, shafts, rope, bearings, pulleys, rail, catch tray or collector and covers. The frame holds other major components in position. It is made of 38 x 38 x 3mm angle iron welded together. The hammer is a suared solid iron of 380 x 380 x 10mm dimension. Bearings of diameter 30 mm are fitted on the shafts and the shafts are permanently placed on the hammers edges to aid the linear motion of the hammer via the guide or slot. An anchor is provided at the center of the hammer for the rope to fit in. Pulleys of diameter 80 mm are aligned on two parallel shafts at the top of the machine.

Fig. 1: Manually operated cocoa depodding machine

A rope is tied to the hammer and runs over the pulleys. It has adequate contact with the pulley. This allows easy sliding and pulling up of the hammer. The rail is made of well-arranged flat bars. It assists in the breaking the pods and serves as sieve for the broken materials. The collecting tray is made of sheet metal and it is inclined at 55º, equivalent to the angle of repose of the material. The body of the machine is covered with sheet metal.

2.2 Pre-design Experiments

Prior to the design, some preliminary experiments were conducted to determine some basic design parameters to enhance the design of the machine. These include the maximum length and diameter of bean; the impact energy required to break the pods; the rail distance; the average number of hammer drops/ falls required to break specific number of pods; time required to break the pods and the angle of repose of the broken pods.

Fifty whole pods of ripe cocoa beans were randomly selected, and the maximum length and mid-diameter were determined using calipers. The summary of the results are shown in Table 1. The height of hammer drops was measured with meter rule to one decimal. The time required to break the pods was measured with stop watch. The average number of hammer drops/falls required to break the specified number of pods were derived through trial experiments. The impact energy required to break the pods was determined as a variable of the height of drop of hammer and the number of pod(s). A fixed weight of hammer (13.12 kg) was dropped at various reasonable heights (22 to 68 cm) at which the whole pods were broken under impact. Various quantities (1 to 5) of whole cocoa pods were used. Each of the experiments was repeated ten times. Table 2 shows the result of the average height of hammer required to break 1 to 5 pods of cocoa.

Table 1: Size of whole pod of cocoa

Parameter	Pod Maximum Diameter	Pod Length
Frequency	50	50
Range (cm)	6.16 – 9.60	11.25 – 20.20
Mean (cm)	7.83	16.04
Standard Deviation	1.07	2.40

Table 2: Height of hammer drop(s) required to break the pod

No. of Pods Used	Frequency	Heights of drop of hammer (cm) Range	Average Height	Standard Deviation
1	10	20-26	24.0	1.73
2	10	30-36	33.7	2.15
3	10	35-46	41.9	4.04
4	10	45-54	50.3	2.97
5	10	54-68	61.1	4.11

The impact energy (E_i) required to break the pods is equivalent to the potential (E_p) stored in the hammer. It is the product of the weight of the hammer used and the height of fall as shown in equations 1 and 2.

$$E_i = E_p \quad (1)$$

$$E_p = Mgh = \rho_s V_h gh \quad (2)$$

Table 3 shows the calculated average impact energy required to break the specified number of pods at the various heights of the hammer as obtained from the experiments. The rail distance is needed to determine the arrays of flat bars through which the pods shall pass when the hammer falls on the pods and break them. The rail distance was taken to be equivalent to the average mid radius of the pods. Hence, the gap between the rails is taken to be half of the average pod diameter.

Table 3: Calculated energy required to break cocoa pods

No. of Pods Used	Calculated Average Energy Required (J)
1.	30.9
2.	43.4
3.	53.9
4.	64.6
5.	78.6

A device utilizing the trigonometric method was used for the measurement of the angle of repose as described in Adewumi (1997b), and Adewumi and Ayodele (1997). It was found to be 55º on galvanized sheet metal.

2.3 Design of Machine Components

The parameters designed for include the shaft diameter, belt tension, tensile load on rope, velocity of the hammer and machine power requirement. Equations 3 to 9 were used to calculate some of the parameters for the various components (Allen et al., 1988).

$$\sigma = T/ A_r \qquad (3)$$

$$A_r = \pi D_r^2/4 \qquad (4)$$

$$V_h = (2E_p/M)^{1/2} \qquad (5)$$

$$P = F_i V \qquad (6)$$

$$M_R = \sqrt{(M_v)^2 + (M_h)^2} \qquad (7)$$

$$M_t = 9550 \text{ x } P(kw)/N \qquad (8)$$

$$d^3 = (16/\pi\sigma s).\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \qquad (9)$$

From the design calculations, the machine is capable of breaking up to five (5) pods at once on raising the hammer to an average height of 61.1 cm (Table 2). Rope tension, tensile stress and cross sectional area of 128.7 N, 728 kN/m^2, 1.77 x 10^{-4} m^2 respectively are required. Average impart energy of 30.9 J is required to break one pod while 78.6 J is required for five pods at a time (Table 3). Hammer speed was determined to be 3.13 m/s. The total load on the pulley shaft was 143.52 N. The machine has a power requirement of 201.6 W. It requires a shaft diameter of 14.6 mm and a shaft of 15 mm, obtainable in the market, was used during fabrication. It was however fabricated using a drop height of 50.3 cm. The choice of 50.3 cm drop height was adjudged optimum for the machine performance from the preliminary and trial experiments conducted. This drop height is also adequate for ergonomic considerations.

2.4 Performance Test Procedure

Ripe cocoa pods were obtained from the farm and categorized, depending on the mid diameter, as big (8.10 – 9.60 cm), medium (6.50 – 8.00 cm) and small (5.00 – 6.40 cm) sizes. The machine was tested using a maximum of four (4) pods. It was observed during the experiment that single drop of hammer may not adequately break the pods, especially when more than one pod was loaded. The number of hammer drop and the time required to effectively break the pods were recorded.

The pods were weighed and loaded on depodding platform of the machine and the hammer released to break the pods. The beans were examined for any damage and as such classified as damage and whole beans. Each experiment was replicated five times. The parameters determined during the test include the average number of hammer drops/falls required to break the specified number of pods, time required to break the pods, number of broken pods per operation, machine capacity, percentage bean damage and machine functional efficiency.

The machine capacity (C) in kg/h, percentage beans damage (B), and functional efficiency (f) were determined using the relationships in eqns. 10, 11 and 12 respectively as adapted from Adewumi (2000).

$$C = M_p/T \qquad (10)$$

$$B = N_{bd}/N_{bf} \times 100 \qquad (11)$$

$$f = N_p/N_t \times 100 \qquad (12)$$

In order to accommodate the time lag, during the period of loading of the pods which was estimated to be 40% of the operation, a factor of 0.6 was introduced to eqn 10. Hence, the practicable machine capacity was determined using eqn 13.

$$C = 0.6M_p/T \qquad (13)$$

3. RESULTS AND DISCUSSION

Table 4 shows summary of the size classification of the cocoa pods used for the experiments. Table 5 shows the summary of the mean of the number of drop of the hammers required to break the pod(s), time required to break the pod(s), number of pod broken, % seed damage, machine efficiency and machine capacity.

Table 4: Size Classification of cocoa pods (mid diameter)

Category	Size Range(cm)	No. of Sample	Mean	Std. Deviation
Big	8.10 – 9.60	50	8.76	0.42
Medium	6.50 – 8.00	50	7.24	0.47
Small	5.00 – 6.40	50	5.80	0.41

Table 5: Summary of the average data obtained during machine testing for small, medium and big pods

Parameters	No. of Pods	Small Pods	Medium Pods	Big Pods
No of Hammer Drops	1	1	1	1.2
	2	2	2.2	2.4
	3	3	3.2	3.8
	4	3	4.2	4.6
Seed Damage (%)	1	0	0	0
	2	0	0.49	0.34
	3	0.37	0.65	0.39
	4	0.57	0.48	0.48
Time Required to Break Pods (sec)	1	1.26	1.28	1.56
	2	2.56	2.90	3.22
	3	3.90	4.02	4.78
	4	3.90	5.38	6.06
No of Pods Broken	1	1	1	1
	2	2	2	2
	3	2.8	2.8	2.8
	4	3.4	3.6	3.8
Machine Efficiency (%)	1	100	100	100
	2	100	100	100
	3	93	93	93
	4	85	90	95
Machine Capacity (kgh^{-1})	1	377	455	720
	2	422	402	738
	3	404	435	655
	4	581	437	713

It is evident that irrespective of the size of the pods, the average hammer drop, percentage seed damage, pod breaking time and the number of broken pods increased as the number of pods increased from 1 to 4 (Table 5). Also, irrespective of the number of pods used, machine capacity, number of broken pods and number of hammer drops increased as the pod size increased (Table 5).

The size of the pods did not have effect on the number of hammer drops required to break the pods. However, the number of pods loaded on the machine affected the number of hammer drops (Table 5). As the number of pods increased, the number of hammer drop increased proportionately for a fixed height of drop of 50.3 cm.

Result showed the total time required to effect the breaking of the pods is relatively low, with a maximum record of 6.06 seconds. Therefore, it should be preferable to use the 13.12 kg hammer and drop the hammer several times versus increasing its weight and reducing the depodding time. This is essential to minimize the percentage seed damage. The seed damage recorded during the machine testing was less than 1%, which is advantageous to the subsequent processes and the quality of the final product (Ademosun, 1993). Increasing the hammer height or weight is likely to increase the impact on the pods and seeds. Consequently, the percentage seed damage will increase. Therefore, it seems appropriate and recommendable to use a hammer height and weight of 50.3 cm and 13.12 kg respectively for impact cocoa pod breaker. Equally, the size of pods did not affect the number of pods broken. This is likely because the hammer, with a square surface, is a uniformly distributed load. It exhibited a uniform impact on the pods.

Size classification of the pods is essential because it has been reported that it has effects on machine performance (Adewumi, 2000). Unfortunately, previous reports found in literatures have not given attention to the effects of pod size on the performance of depodders. The results of this study showed that the classification of the pods into uniform size range also assisted the uniformity of the impact exerted on them, thereby enhancing the effective breaking of the pods. It is therefore appropriate to grade the pods for the machine to perform effectively as recommended for processing systems (Adewumi, 1998; Ademosun, 1993).

The efficiency of the machine ranged between 85 and 100%. For 1 and 2 pods, irrespective of the size of the pods, the efficiency was 100%. But, for 3 and 4 pods, the efficiency was reduced. Therefore, reducing the number of pods translates to very high efficiency. Machine capacity generally increased with the number of pods loaded. Also, the big pods generally recorded the highest machine capacity, irrespective of the number of pods loaded. Table 5 showed that the best result was obtained the when the number of big pods was 2 which had a record of 0.34% seed damage, 100% efficiency and 738 kg^{-1}capacity. A capacity of 500 pods per hour was considered adequate for cocoa depodder such as this (Decabossage, 2006). The unit cost of the machine is less than ten thousand naira (₦ 10,000.00), that is about eighty dollar ($80.00). This is not beyond the purchasing power of an average cocoa farmer in Nigeria. It is equally easy to transport. For a normal 8 hours working day, the machine could handle up to 5 tons of cocoa pods per day. It is recommended for use in cocoa farms in Nigeria.

4. CONCLUSION

The machine developed during the study is simple and easy to maintain. It was fabricated using materials sourced locally. It is cheap and affordable. The drudgery and much time involved in the process of breaking the cocoa pod with hands could be overcome with the help of the machine.

5. REFERENCES

Ademosun, O.C. 1993. Performance evaluation of a medium scale dehulling and winnowing machine. Agricultural Mechanization in Asia, Africa and Latin America. 24(2): 57-60.

Adewumi, B.A. 1997a. 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. 17pp.

Adewumi, B. A. 1997b. Relationship between the angle of repose and related parameters for granulated agriculture materials. *Applied Tropical Agric* 2 (2): 114 - 119.

Adewumi, B. A. 1998. Status of cocoa processing industry in Nigeria. Proceeding of the 20th Annual Conference and General Meeting of the Nigerian Society of Agricultural Engineer, Lagos Nigeria. 20:175-187.

Adewumi, B. A. 2000 . Design and testing of a manually operated cashew decorticator. *Nigerian Journal of Tree Crop Research* 4(2): 10-17.

Adewumi, B. A, Ademosun, O. C. and Ogunlowo, A. S. 2006. Design, fabrication and preliminary testing of a thresher-cleaner for legume. Journal of Food Science and Technology, India 44(3) - In Press.

Adewumi, B. A. and Ayodele, O.R. 1997. Design and construction of a device for the determination of static and dynamic angle of repose of granular agricultural materials. Nigerian Journal of Tech. Education 24(1): 101- 106.

Adeyanju, S. A., Oguntuga, D. B. A., Ilori, J. O. and Adegbola A.A. 1975. Cocoa husk in maintenance rations for sheep and goats in the tropic. Nutrition Report International II, pg 351 – 357.

Allen, S. H., Alfred, R. H. and Hernan, G. L. 1988. Theory and problems of machine design. S. I. (Metric) Edition. Schaum's Outline Series, McGraw Hill Book Company, New York.

Are, L. A and Gwynne Jonnes, D.P.G. 1974. Cocoa in West African. Oxford University Press London. pg 102 – 103.

Audu, I., A. O. Oloso and B. Umar. 2004. Development of a concentric cylinder locust dehuller. CIGR-Ejournal PM 04 003 Vol VI, August, 2004.

Bamgboye, A. I. 2003. Effect of some physical properties of cocoa bean on post harvest delay on its compressive and impact rupture. Discovery and Innovations 15(3): 137-141.

Decabossage. 2006. Pod breaking, pod splitting. www.proz.com/kudoz/1238555.

Faborode, M. O. and Oladosun, G. A. 1991. Development of a cocoa pod processing machine. The Nigerian Engineers. 26(4): 26-31.

Jabagun, J. A. 1965. A mechanised cocoa pod sheller. The Nigeria Aquaculture Journal 2(1): 44-45.

Opeke, L. K. 1987. Tropical Tree Crops. John and Sons, Clichester, Pg 108 – 119.

Urguhart, D. N. 1962. Cocoa. Longman Green and Co, London, U.K. Second Edition.

Vejesit, A. and V. Salokhe. 2004. Studies on machine-crop parameters of an axial flow thresher for threshing soy bean. CIGR-Ejournal Vol VI, July, 2004.

Nomenclature

A_r = cross sectional area of rope, m^2

D_r = diameter of the rope, m

E_i = impact energy required to break the pod, J

E_p = potential energy required to break the pod, J

F = impact force, N

g = acceleration due to gravity, m/s^2

h = height of fall, of the hammer, m

K.E = Kinetic energy required to break a pod, J

k_b = combined shock and fatigue factor applied to bending moment, 1.5

K_t = combined shock and fatigue factor applied to torsional moment, 1.5

M= mass of the hammer, kg.

M_h = Maximum horizontal moment, Nm

M_p = mass of pod fed into the machine, kg

M_R = resultant bending moment of the shaft, Nm

M_v = Maximum vertical moment, Nm

M_t = tortional moment of the shaft, Nm

N = shaft speed, rpm

N_{bd} = No. of beans damage

N_{bf} = Total No. of beans loaded.

N_p = number of pods broken

N_t = number of pods loaded

P = power required by the falling hammer to break the pod(s), W

T = time taken to depod, sec

T = Tension on the rope, N

V = velocity of drop of hammer, m/s

V_h = volume of the hammer, m^3.

σ = tensile stress on rope, N/m^2

σ_s = allowable stress for shaft with key way, 40 MN/m^2

ρ_s = density of mild steel, kg/m^3