British Journal of Applied Science & Technology
8(1): 35-45, 2015, Article no.BJAST.2015.184
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

Design Concepts towards Cocoa Winnowing Mechanization for Nibs Production in Manufacturing Industries

B. O. Akinnuli[1*], O. S. Bekunmi[1] and C. O. Osueke[2]

[1]Department of Mechanical Engineering, Federal University of Technology, P.M.B.704, Akure, Ondo State, Nigeria.
[2]Department of Mechanical Engineering, Landmark University Omu-Aran, Kwara State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/16161
Editor(s):
(1) Elena Lanchares Sancho, Department of Mechanical Engineering, University of Zaragoza, Zaragoza, Spain.
Reviewers:
(1) Anonymous, Poland.
(2) Shihao Liu, Hainan University, China.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1069&id=5&aid=8538

Original Research Article

Received 13th January 2015
Accepted 13th February 2015
Published 20th March 2015

ABSTRACT

Cocoa beans processing for human consumption is growing into different products from time to time. Demand for it's processing equipment is also at increase and costly to purchase. One of the processing workstations that needs urgent attention is the winnowing section, where the shell (seed coat) is removed from the cocoa beans and retains the broken cotyledons(Nibs). The mechanization of this process is capital intensive and all cocoa processing industries in Nigeria have no local substitute that can render same service at lower cost. Hence, the design of a winnower that can be produced locally at low cost and capable of producinghigh qualityproducts. The required components were identified, each of these components was designed and the designed values were used for the proposed machine drawings. The production cost was estimated, each machine component/unitmaterial required for their production were suggested for the proposed machine development in this design concept. The mechanical system was designed to have: centrifugal force of 4.8 N, motor power rating of 1.5 kW, speed of 500 rpm and process capacity of 2 tonnes per hour. It's total estimated production cost is ₦470,000 which is equivalent to US$2904.32 at the current exchange rate of ₦162/$.

**Corresponding author: E-mail: ifembola@yahoo.com;*

Keywords: Design concepts; winnower; cocoa nibs; drawings; cost estimate; local content.

NOMENCLATURE

Symbol	*Meaning*	*Units*
F_s	Strength of bevel gear	Newton(N)
σ_{av}	Safe allowable stress	MN/m^2
P_c	Centre pitch	mm
F_d	Correction factor for arc of length	Nil
K_v	Load factor	Nil
K_s	Service factor	Nil
K_m	Load distribution factor	Nil
F_t	Force tangential to pitch circle	Newton(N)
f_a	Correction factor for industrial service	Nil
Y	Deflection	kgM/N
F_d	Dynamic load	Newton(N)
Y	Form factor	Nil
d_p	Pitch diameter of the driver pulley	mm
d_e	Equivalent pitch diameter	mm
F_b	Small diameter factor	mm
C	Centre distance	mm
R	Radius of shaft	mm
L	Nominal pitch length of belt	mm
T	Torque or twisting moment	Nm
J	Polar moment of inertia	Nm
θ	Angle of twist	Degree
L	Length of the shaft	mm
N_g	Number of teeth of the gear	Nil
N_p	Number of teeth of the pinion	Nil
N_v	Formative number of teeth	Nil
α	Pitch angle of pinion	Degree
β	Pitch angle of gear	Degree
A	Addendum	Degree
d_{op}	Outside diameter of pinion	mm
d_{og}	Outside diameter of gear	mm
d_m	Mean diameter	mm
M_m	Mean module	mm
F_w	Wear load	Newton(N)
K	Stress fatique factor	Nil
F_x	Radial force on pinion	Newton(N)
F_y	Radial load on gear and thrust on bearing	Newton(N)
D_{motor}	Diameter of motor	mm
D_{fan}	Diameter of fan	mm
S_s	Shear stress	N/m^2
Rpm_{motor}	Speed of motor	Rpm
Rpm_{fan}	Speed of fan	Rpm
λ_p	Face angle of pinion	Degree
λ_g	Face angle of gear	Degree
φg	Root angle of gear	Degree
φ_p	Root angle of pinion	Degree
δ_a	Addendum angle	Degree
ρ	Density of material	N/m^2
v	Volume	m^3
m	Mass	kg
w	Weight	N

1. INTRODUCTION

Cocoa is best known for its derived products, especially chocolates, rather than its original botanical form i.e. fruits and beans. These products are consumed in great demand worldwide due to its unique flavour and aroma that cannot be replaced by other plant products [Wood and Lass, [1]. *Theobroma cacao* is the name given to cocoa tree and belongs to the family *sterculiaceae*. Cocoa tree are found wild in the rainforest of the western hemisphere from 18°N to 15°S, which is from Mexico to the southern edge of the Amazon forests. *Theobroma cacao* is the only species cultivated commercially in major producing countries such as Ivory coast, Ghana, Nigeria, Cameroon, Brazil, Ecuador, Indonesia and Malaysia [Barnigboye [2], Cocoa beans contain about 50% fat. It is useful in the production of: lightening oil, ointments, candles, soaps and medicine [3]. Cocoa butter, made from the fat extracted from the beans, is a stable fat used in the production of cosmetics and pharmaceutical products. Are and Gwynce [4], Dotse and Boating [5], and Donahue et al. [6]. The beans are ground into powder for the production of beverages, chocolates, ice creams, soft drinks, cakes, biscuits, flavouring agents and other confectionaries. The shell is a good source of potassium and can be used in the production of potassium fertilizer, local soap, biogas and particle boards [3]. Dried cocoa beans physical appearance is as shown in Plate 1.

The processing of cocoa includes the breaking of the pods, extraction of beans, fermentation of beans, drying, dehulling and winnowing of the beans. The beans are then processed into cocoa butter, beverage and cake [7,8,9].

Winnowing is the process of removing the outer shell from the cocoa beans. The basic process of winnowing involves an initial crack of the beans. During this step, it is important not to crack the bean too vigorously because it can lead to the formation of fine particles. Overly fine shell and nib particles can’t be used for fine chocolate because it is too difficult for the winnower to separate between the two. The goal of a good crack is to keep the nibs as large as possible while simultaneously separating the shells and removing the dirts. The basic principle behind winnowing is that the shell is less dense than the nib, so if the correct velocity of air flow is used, then the shell should blow away, leaving the nib behind [10]. The only way this could be accomplished for thousand of years was tossing the beans and shells up into the air on a windy day. The wind blew the shells away while letting the nibs fall into a container that was resting on the ground. This was then good way to get rid of shells. It is still practiced in some parts of the world today. Winnowing machines were introduced in the late 1910s [11]. These portable, engine-driven contraptions could achieve around 80% purity in sifting out gum chips this is a big improvement over winnowing by hand. These two machines were used at Ahipara between 1910 and 1919, see Plate 2 below:

Plate 1. Cocoa beans [12]

Sometime during the 19th Century; some genius decided that there had to be a better way to deal with this onerous task. The solution was to invent a device called a winnowing machine.This machine is used in the removal of outer shell from the cocoa beans. And this winnowing machine which is the major aspect of this study, is made up of some important components used in achieving the winnowing process, they are: blower, suction fan, vibrator, hopper, crusher, reciprocating sieve, electric motorand others.

In Nigeria, the first cocoa pod breaker was constructed at the Cocoa Research Institute of Nigeria (CRIN) as reported in Jabagun [14] Pandaya [15].

Similar machine to the above was designed and built by Messrs Christy and Norris Limited of England, was tested by Cadbury Brothers Cocoa Plantation at Ikiliwindi, Cameroon according to Are and Gwynee-jove [4] Kashayap and Pandaya [16].

Another earlier machine, the Zinke Machine, use several rotary jaws or toothed rollers but it has the problem of crushing the husks further into tiny portions, which mix with the wet beans and this poses a problem during separation according to [9,17].

Plate 2. Ancient winnowing machine [13]

2. METHODOLOGY

The methodology to this research took care of the design analysis of the winnower, material selection for each component designed, operating description of the system, engineering drawings, required system assembly and its production cost.

2.1 Identified Components to be Designed for Production

The components identified and designed were listed as follows: inlet hopper, loading hopper or receptor, conveyor drive, beans silo, auger shaft, bevel gears, crushing unit, separating or sieving unit, suction fan, electric motor and blowing unit.

2.2 Material Selection

In the context of product design, the main goal of material selection is to minimise cost as well as selecting the appropriate material to be used for each component considering engineering factors as well as environmental factors so that the components used will be able to perform properly with high degree of reliability. The material selection is summarised in Table 1 as well as the reasons for their selection.

Table 1. Proposed material for components production before Assembly

S/no	Component	Selected material	Reason for selection
1	Frame	Mild still	Strength to withstand the impact load of crusher.
2	Crusher	Mild steel	Tensile strength and heat resistance.
3	Shell separator/vibrating screen	Stainless steel	It is a corrosion resistant steel, strength and hardness.
4	Pulley	Mild steel	Strength.
5	Vee belt/conveyor belt	Leather	Power transmission/ It is flexible and can withstand considerable wear under suitable condition.
6	Duct hoses	Synthetic rubber	Elasticity
7	Vibrator housing	Mild steel	Ability to resist shear stress and vibrate(shake)
8	Spring	High carbon steel 0.8 – 1.0% c	Property of low damping ratio and resilience.
9	Bevel gear	Cast iron	Strength, heat resistance and wear resistance to corrosion.
10	Silo	Mild steel	Strength and hardness, ability to withstand high temperature.
11	Blower	Aluminium	Lightness of the metal and wear resistant property.

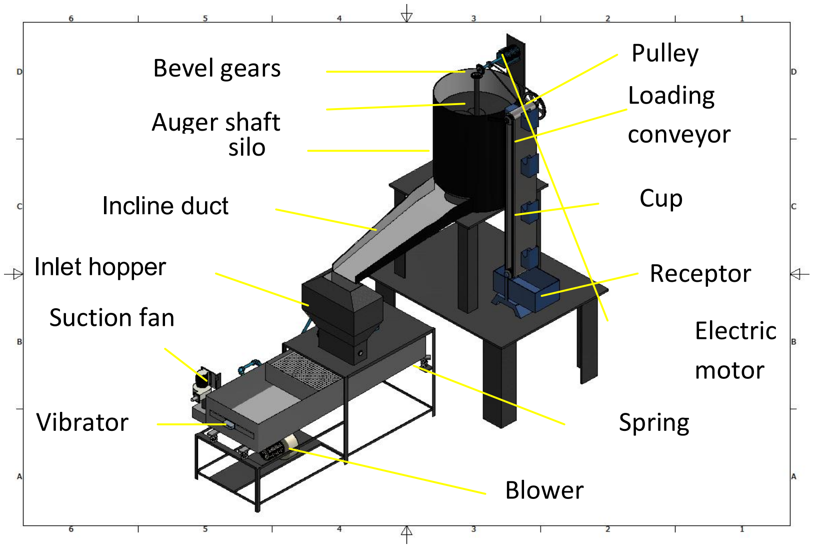


Fig. 1. Isometric view of proposed winnower

2.3 Summary of Design Analysis

The Components, their designed factors, models used as well as the designed values are as shown in Table 2.

2.4 Expected Machine's Principles of Operation

When the machine will be energised, the beans' silo loading conveyor will transport cocoa beans from the cocoa beans receptor on the ground floor into the top mounted beans silo.

Inside the silo is an auger shaft driven by connection of bevel gears meshed together. These bevel gears (driving and driven) will be rotated by torque from electric motor designed to have a speed reduction gear.

The auger rotation will metered cocoa beans out of the silo into the crushing units that breaks the cocoa beans into shells and nibs.

The shell and nibs will fall by gravity on the sieving unit that is operating by reason of vibration caused by the attached vibrator. This caused the nibs to be separated from the shells. At the right end of the sieving unit is a suction fan that caused aspiration process that separate the shell from the nibs.

There is a blower underneath the sieving unit that blows up all uncrushed cocoa beans back into the crushing chamber for recycling process.

The isometric drawing of this machine is shown is shown in Fig. 1. With it's labelling parts for it's components identification.

The orthographic views as well as the exploded drawing are in Figs. 2, 3, 4 and 5 below:

2.5 Estimated Production Cost

The estimated production cost involves: material cost, expected fabrication cost, bought out parts, expected machining cost and expected non-machining cost. These are stated in Tables 3, 4, 5, 6, and 7.

3. RESULTS

The proposed cocoa winnower has been designed for production. The necessary materials for it's production has been suggested with reasons for their selection. The engineering drawings required for the production of this mechanical system based on the designed values computed has been made available. The expected working principle has been made known as well as the estimated cost for the machine production.

The attainable designed values for major components for this mechanical system that will aid their production before assembling them are: the inlet hopper (0.016 m^3), cocoa receptor (0.00835 m^3), conveyor belt speed and power rating are (28 m/s and 0.81 kW), bean silo capacity (0.08 m^3) auger loading strength and power are: 0.028 kN, 0.022 kN, and 1.0 kW respectively.

Table 2. Summary of the models, source and design values

S/N	Component	Design factor	Mathematical models used	Equatio-n number	Source name	Year	Design value
1	Inlet hopper	Capacity	$\frac{(a+b)h^2}{2} + (l+b)h$	--- (1)	Free online Math Help	[18]	0.016 m^3
2	Cocoa receptor	Capacity	$L \times B \times H + \frac{1}{2}(a+b)h^2$	--- (2)	Free online Math Help	[18]	0.00835 m^3
3	Conveyor drive and electric motor.	(a) Belt speed (b) No of belt. (c) power	$S = \pi dn$ $N_b = \frac{p \times f_a}{kW \times f_c \times f_d}$ P = selected	--- (3) --- (4)	PSG PSG	[19] [19]	28 m/s 1 belt 0.81 kW
4	Silo	Capacity	$\frac{\pi}{4}d^2 l + \frac{1}{2}(a+b)h^2$	---(5)	Free online Math Help	[18]	0.08 m^3
5	Auger shaft	power	$P = \frac{2\pi NT}{60}$	--- (6)	Akinnuli et al.	[20]	1 kW
6	Auger shaft bevel gear	Load Strength	$F_s = \sigma_{av} \cdot b \cdot P_c \cdot y(\frac{L-b}{l})$ $F_d = K_v \times K_s \times K_m \times F_t$	---(7) ---(8)	Khurmi and Gupta Khurmi and Gupta	[21] [21]	0.028 kN 0.022 kN
7	Auger electric motor	Power	$P = \frac{2\pi NT}{60}$	--- (6)	Khurmi and Gupta	[21]	2.5 kW
8	Crusher shaft	Power	$P = \frac{2\pi NT}{60}$	---(6)	Akinnuli et al.	[20]	1.8 kW
9	Crusher blade	Weight	$\rho = \frac{m}{v}$ $m = \rho v$ $w = \rho vg$	---(9) --10) --(11)	Khurmi and Gupta	[21]	0.06 kg
10	Crusher belt	Velocity No of belt	$S = \pi dn$ $N_b = \frac{p \times f_a}{kw \times f_c \times f_a}$	--- (3) --- (4)	PSG	[19]	25 m/s 1 belt
11	Electric motor of crusher	Power	$P = \frac{2\pi NT}{60}$	--- (6)	Akinnuli et al	[20]	1.5 kW
12	Rectangular tray	Capacity	$L \times B \times H$	--(12)	Free online Math Help	[18]	0.285 m^3
13	Spring	Rate	$\frac{f}{y}$	-- (13)	Allen, Hall, Holowenko and Laughlin	1961 [22]	50 N/m
14	Blower	Power	$P = \frac{2\pi NT}{60}$	--- (6)	Akinnuli et al.	[20]	0.02 kW
15	Suction fan	Fan wheel speed	$Rpm_{fan} = rpm_{motor} \frac{D_{motor}}{D_{fan}}$	--(14)	UNEP Ghosh	[23] [24]	583.3 rpm

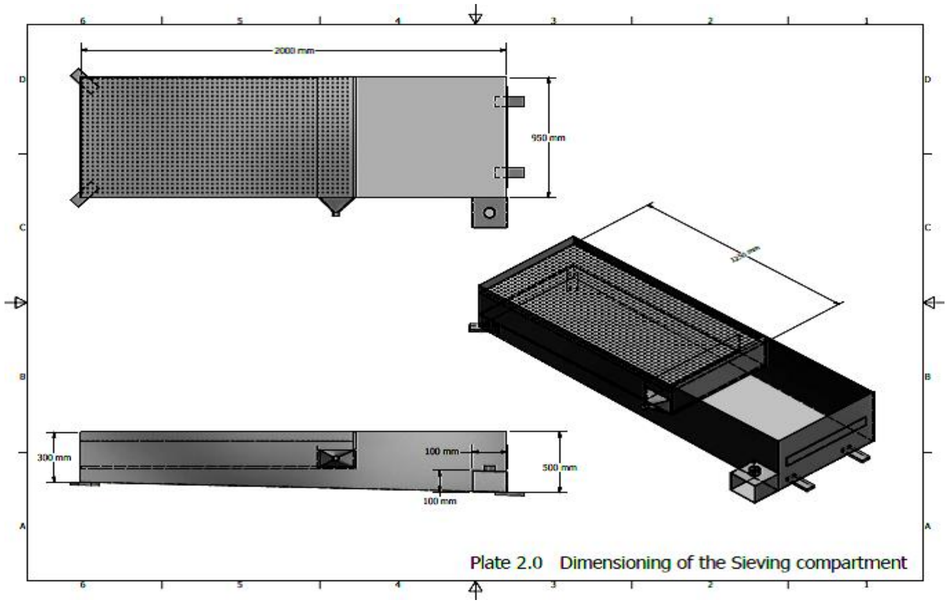


Fig. 2. Sieving unit orthogonal drawing

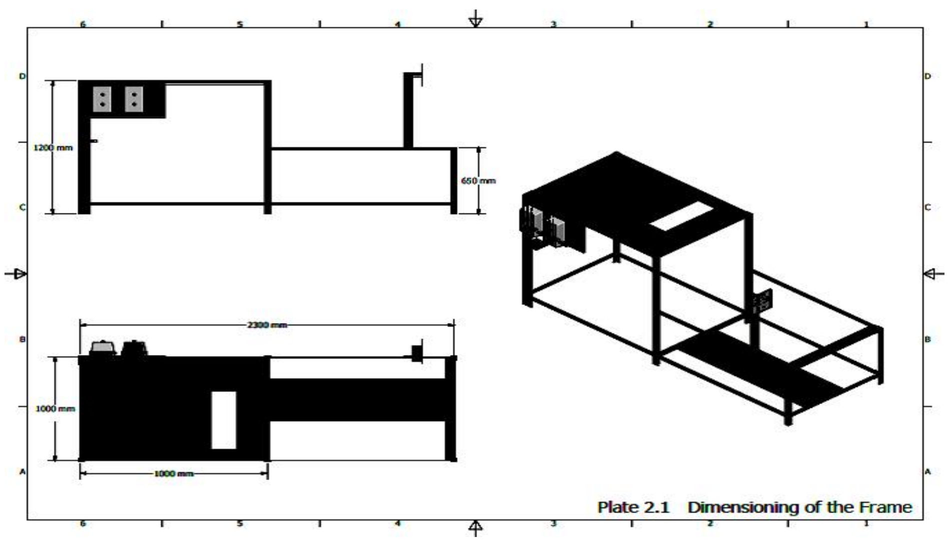


Fig. 3. Machine's frame orthogonal drawing

Table 3. Material cost proposed (A)

S/no	Material description	No required	Unit price ₦	Total amount ₦
1	Crusher blades	8	4,000	32,000
2	Crusher hub	1	40.000	40.000
3	Crusher housing	1	8,000	8,000
4	8 angular plate	10 lengths	6,500	50,000
5	5 mm thick plate	1	15,000	15,000
6	Emery cloth	1 roll	2000	2000
7	7.5 mm angle Iron	3 lengths	7,500	27,500
8	6 mm angle Iron	5 lengths	6,000	20,000
Cost of materials				**194,000**

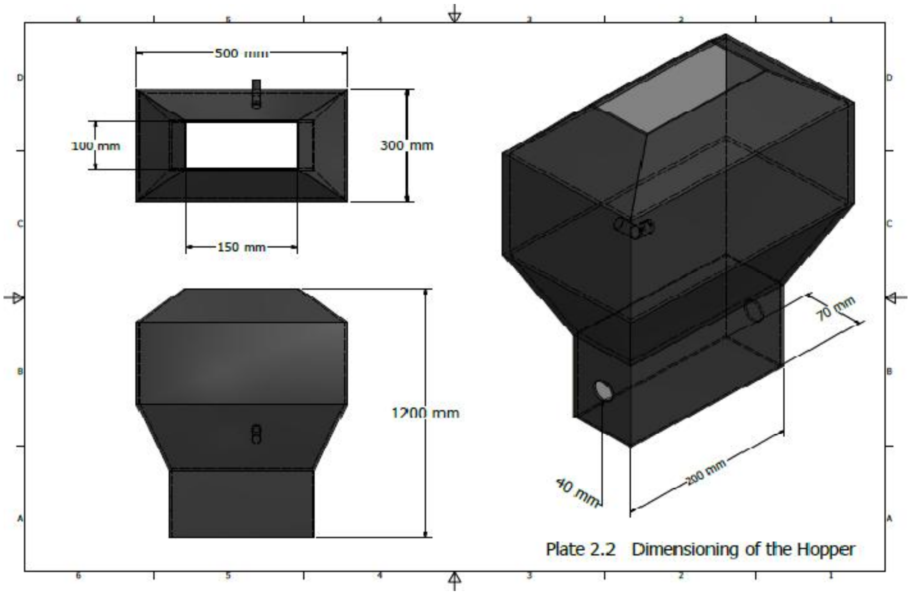
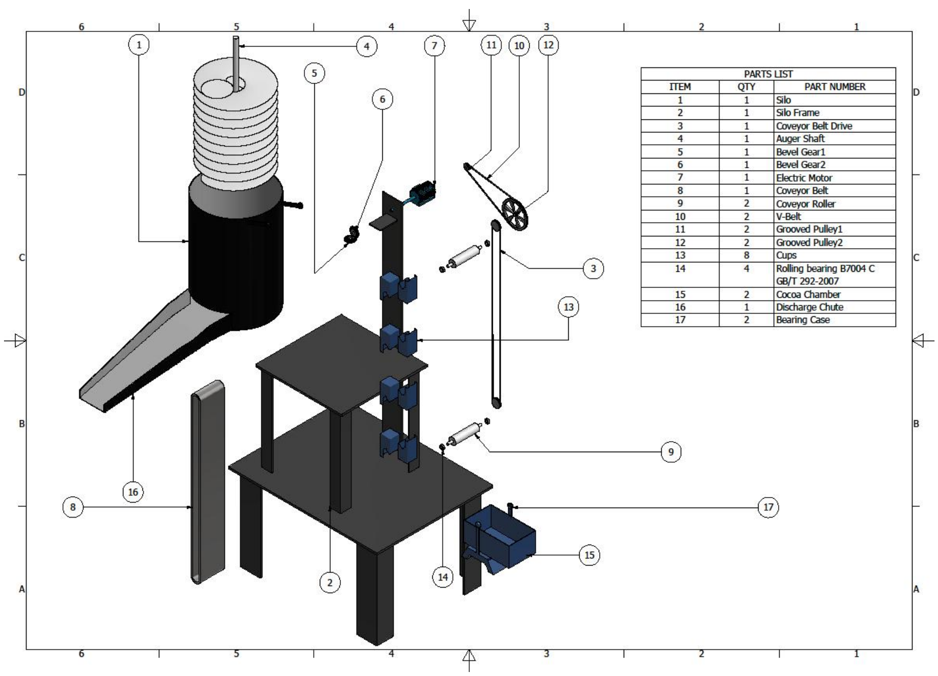


Fig. 4. Bean's hopper orthogonal drawing



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Silo
2	1	Silo Frame
3	1	Coveyor Belt Drive
4	1	Auger Shaft
5	1	Bevel Gear1
6	1	Bevel Gear2
7	1	Electric Motor
8	1	Coveyor Belt
9	2	Coveyor Roller
10	2	V-Belt
11	2	Grooved Pulley1
12	2	Grooved Pulley2
13	8	Cups
14	4	Rolling bearing B7004 C GB/T 292-2007
15	2	Cocoa Chamber
16	1	Discharge Chute
17	2	Bearing Case

Fig. 5. Exploded view of the designed machine

Table 4. Expected fabrication cost (B)

S/no	Component name	Specification	Quantity	Material
1	Crusher blades	15 mm mild steel plates	8 pieces	Mild Steel
2	Crusher hub	10 mm mild steel plates	1 piece	Mild Steel
3	Crusher housing	10 mm mild steel plates	1 piece	Mild Steel
4	Bearing housing	10 mm mild steel plates	2 pieces	Mild Steel
5	Pulley	Mild steel	1 piece	Mild steel
6	Auger shaft	15 mm mild steel iron	1 piece	Mild steel

Table 5. Proposed bought out components (C)

S/no	Component name	Specification	Quantity	Unit Cost ₦	Amount ₦
1	Bolt and nut	M 12	8	250	2,000
2	Allen bolt	M 8	16	250	4,000
3	Allen bolt	M 10	8	250	2,000
4	Pulley	(100 × 15)	2	2,500	5,000
5	Sucking fan	0.02 kW	1	47,500	47.500
6	Square key	(8 × 8 × 30)	1	500	500
7	Vibrator	1.5 kW	1	35,000	35,000
8	Spring	-	4	750	3,000
9	Electric motor	1.5 kW	1	35,000	35,000
10	Mild steel plates	2 mm	2 Sheets	7,500	15,000
11	Mesh		1	2,500	2,500
12	Vee belt	A37	2	250	500
13	Bearing housing	207	2	2,500	5,000
14	Duct line hose		5 Lengths	2,500	12,500
15	Discharge hose		1	6,500	6,500
16	Hose clips		6	200	1,200
17	Conveyor belt		1	4,000	4,000
18	Screw conveyor		1	4,000	4,000
19	Bevel gear		1	4,000	4,000
20	Electric motor	1.5 kW	2	4,000	8,000
Sub total					**197,200**

Table 6. Expected machining cost (D)

S/no	Material	Type of Job	Machine used	Time spent (hour)	Labour cost per (hour)	Machine cost (₦)	Total cost (₦)
1	Mild Steel	Bending	Bending machine	1 hour	1,500	500	2,000
2	Mild Steel	Drilling	Pillardrilling machine	2 hours	600	300	1,500
3	Mild Steel	Cutting	Grinding machine	5 hours	260	200	1,500
4	Mild Steel	Milling	Milling machine	10 hours	2,940	600	30,000
5	Mild Steel	Grinding	Grinding machine	7 hours	2,800	200	3,000
6	Mild Steel	Folding	Folding machine	1 hour	1,200	300	1,500
Sub total							**39,500**

Table 7. Expected non-machining cost (E)

S/no	Job	Time spent (hours)	Labour cost per hour (₦)	Equipment cost per hour (₦)	Total cost (₦)
1	Welding	25	600	600	30,000
2	Cutting	3	386	380	2,300
3	Machine assembly	4	1,250	-	5,000
4	Machine disassembly	1	2,000	-	2,000
Sub total					**39,300**

$$\text{Total Cost of Production} = A + C + D + E$$
$$= 197{,}000 + 193{,}200 + 39{,}500 + 39{,}300$$
$$= 470{,}000$$

4. CONCLUSION

The concept for designing a mechanical system for winnowing cocoa beans nibs production in manufacturing industries has been achieved. The components required has been identified and designed values to each component has been made available as well as the materials for their production.

The next step which is production and performance evaluations of the machine is highly recommended. This production is now underway by the authors of this concept in the Department of Mechanical Engineering of Federal University of Technology, Akure, Nigeria.

ACKNOWLEDGEMENTS

The authors acknowledged the roles of Professor O.C Ademosun, of Department of Agricultural Engineering Federal University of Technology, Akure Nigeria and Professor A. A. Aderoba of Department of Mechanical and Mechatronics Engineering, AfeBabalola University Ado Ekiti Nigeria for their technical advice as well as materials made available to this research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Wood G, Lass R. Cocoa 4th edition. Longman, London. 1985;610.
2. Bamgboye AI. Effect of some physical properties of cocoa bean on post Harvest delay on its compressive and impact rupture. Discovery and Innovations. 2003; 15(3):137-141.
3. Opeke LK. Tropical Tree Crops. John and Sons, Clichester. 1987;108–119.
4. Are MO, Gwynee J. Cocoa Pod Breaker. Messrs Christy and Norris of Limited, England; 1974.
5. Dotse SK, Boateng- Appiah G. A design concept: Towards the efficient mechanization of cocoa pod breaking and beans extraction, Gratis Foundation, Tema, Ghana; 2010.
6. Donahue W, Alfred A, Keith, E, Lagasse J. Maine wild blueberries field winnowing systems. Department of Bio Systems Science and Engineering Department of Food Science and Human Nutrition, University of Maine, Orone 04469; 1999.
7. Adewumi BA. 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. 1997;17.
8. Ademosun OC. Performance evaluation of a medium scale dehulling and winnowing machine. Agricultural Mechanization in Asia, Africa and Latin America. 1993;24(2): 57-60.
9. Faborode MO, Oladosun GA. Development of a cocoa pod processing machine. The Nigerian Engineers. 1991; 26(4):26-31.
10. Wikipedia ''Material selection'' Available:http://en.wikipedia.org.material selection Retrieved on 31/11/2012, 2011.
11. Carl W. Kauri gum and gum digging', TeAra - the Encyclopaedia of New Zealand, updated 1-Mar-09 Available:http://www.TeAra.govt.nz/en/kauri-gum-and-gum-digging/4/5 2000
12. Wiener B, Duyvis V. Cocoa beans processing for chocorate production; 2005.
13. Raid I, Gray MI. Winnowing machine. National Library of New Zealand; 1992.
14. Jabagun JA. A mechanised cocoa pod sheller. The Nigeria Aquaculture Journal. 1965;2(1):44-45.
15. Pandya AC. Mechanics of winnowing fans. Pap at I.S.A.E. meeting, Kharagpur, India; 1964.
16. Kashayap MM, Pandya AC. A qualitative theoretical approach to the Problem of winnowing. J. Agric. Engng Res. 1965;10 (4):348.
17. Takeda F, Peterson DL. Machine harvest of eastern Thornless blackberry cultivars. Hort. Science. 1988;23(1):120-123.
18. Calculus.geometry.hubpages.com› free online Math Help › Education and Science. Retrieved on 10/12/2012.
19. Post-graduate (PSG) Design Data compiled by faculty of Mechanical Engineering PSG College of Technology Cembatore, B410004, India; 1982.
20. Akinnuli BO, Ayodeyi SP. Development and performance evaluation of multi-purpose motorised water based chemical sprayer. Internation of Journal of

Engineering and Engineering Technology FUTAJEET. 2012;7(1).
21. Khurmi RS, Gupta JK. Eurasia Publishing House, 2005- Machine design-1230 pages; 2005.
22. Allen S, Hall A, Holowenko HG, Laughlin. Mcgraw Hill Professional, 1961- study aids-352 pages; 1961.
23. UNEP. Electrical Energy Equipment- Fans and Blowers. 2006;21.
24. Ghosh BN, Introduction to crop processing machinery. Uganda Publishing House, Kampala, 1970 (in press) Stenning, BC. Choosing a fan for crop drying. Farm Mech. 1963;15 (168):28.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1069&id=5&aid=8538