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Design and Development of a House-Hold Bambara Nut Decorticating Machine

C. C. Eze
Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

ABSTRACT: *An integrated Bambaranut decorticating and winnowing machine which bears a 1 Ihp, 1000 r.p.m. electric motor was designed and developed. It is a 1000mm x 400mm x300 mm machine of gross mass 33.42kg which makes it portable. Falling pods from the hopper are struck by a rotating dehusker drum of 72.2 N force, the chaffs are blown out through a window and the seeds fall down and out via a chute. All the components of this machine were sourced locally making the overall cost cheap and affordable to the people in contrast with the decorticators imported from overseas.*

Keywords: *Groundnut, decorticator, blower, locally-sourced materials, affordable.*

I. INTRODUCTION

In Africa and in Nigeria in particular, Bambaranut has become a major source of protein food. It is eaten in various forms and prepared in a variety of ways. People roast or boil the nuts and eat with kernels or groundnut as snacks. Majorly however, people especially in the eastern regionsof Nigeria prepare the flour,add to it red palm oil, fish, pepper and or *uziza*, salt and sometimes vegetables, then wrap in waterproofs or put in metallic cups and cook for about 30- 40 minutes at between 80-100^{o}C to set it ready for consumption as puddings. This food has become so popular that the food so prepared may be available in virtually all markets, parks, and eating centres around the federation.

The puddings are carried about in wheel barrows from house to house for sale and may usually be consumed with minerals, pap or tea. It has become the fast food of the people. Travellers carry it on their journeys and students find it the fastest means of extinguishing hunger. The food may betaken inside moving vehicles or while walking along the streets without the danger of contaminations since the packs would always be wrapped in waterproofs or banana leaves and the consumer may not have finger contacts withit as he eats.

The nuts when harvested from the field are covered with hauls which must be removed before grinding to obtain the flour. This haul removal process is decortication and many farmers and users of this crop still do it the traditional way. Some do the dehusking using hands and stones. Some others use mortars and pistons to pound it lightly and even at that end upcrushing much of the seeds put in the mortar. A good number of others still use paddles and sticks to beat the nuts spread on the ground.All these are time and energy wasting. The very few that uses imported decorticator machines do that at an enormous expense. The financial involvement cannot encourage the farmers and consumers of this food seed. The cost and commitment associated with the importation of these machines from overseas are usually highand cumbersome because of the unpleasant exchange rate and dishonesty prevalent in our present society. Even these imported machines are usually of industrial sizes and scales and so the common Bambara farmers and users find it uneconomical patronising such industrial out-fits which most of the times are profit- oriented. The end point of all these activities is that the decorticating processes of this staple food of the people is not encouraged. This goes a long way in afflicting the nation's economy causing the people to suffer. It is the aim of this work to design and develop a cheap and simpledecorticator machine from locally available materials which will be affordable to farmers, families and other users of the nut. This will lead to increased farming and consumption of this staple food, relegating hunger to the background.

II. MATERIALS AND METHODS

The materials used for this work were sourced locally. They include 2 mm mild steel sheet metals, 4 mm thick angle iron lengths, 6200 size bearings, Plummer blocks, 1hp electric motor and a 41 W capacity blower which can move falling Bambara chaffs with a speed of 50m/s. Others include the sheaves and v-belts.

The shaft is of mild steel which bears a 2 mm thick sheet metal cylinder with 2 mm diameter spikes that have been created by perforating the sheet with cuppa nails from the inside before folding. The spacing of one spike from the next is10 mm on the average. The shaft sits on two bearings.

Bambara to be decorticated is fed through the hopper. It falls into the decorticating chamber through the hopper neck 5 mm by 5 mm to splash on the spiked rotating cylinder. The cylinder hits the nuts against the walls of the decorticating chamber which are themselves cut with spikes. Down the chamber is the blower which supplies the falling lots with a stream of air current that is able to separate the lighter chaff from the relatively heavier nuts. The chaffs by the action of the air pressure are thrown out of the chamber through an opposite window while the seeds fall right down and are collected through the exit chute. The isometric view of the machineare shown in figures 1 and 2.

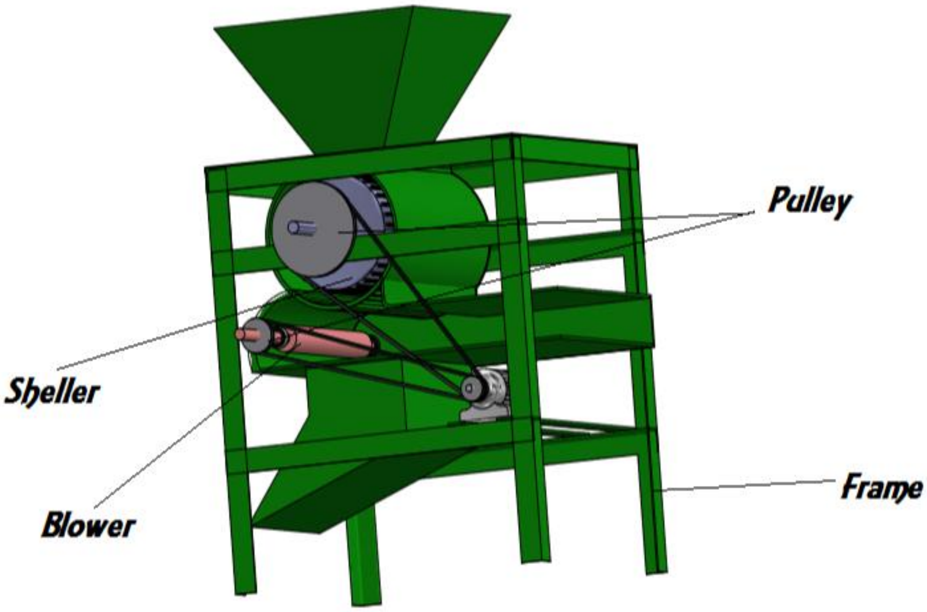

Figure 1- The decorticator machine (front view)

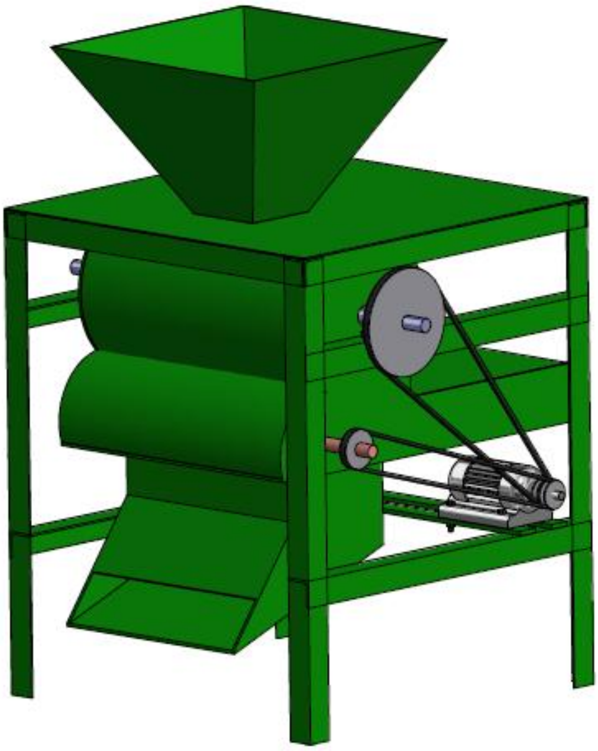

Figure 2-The decorticator machine (side view)

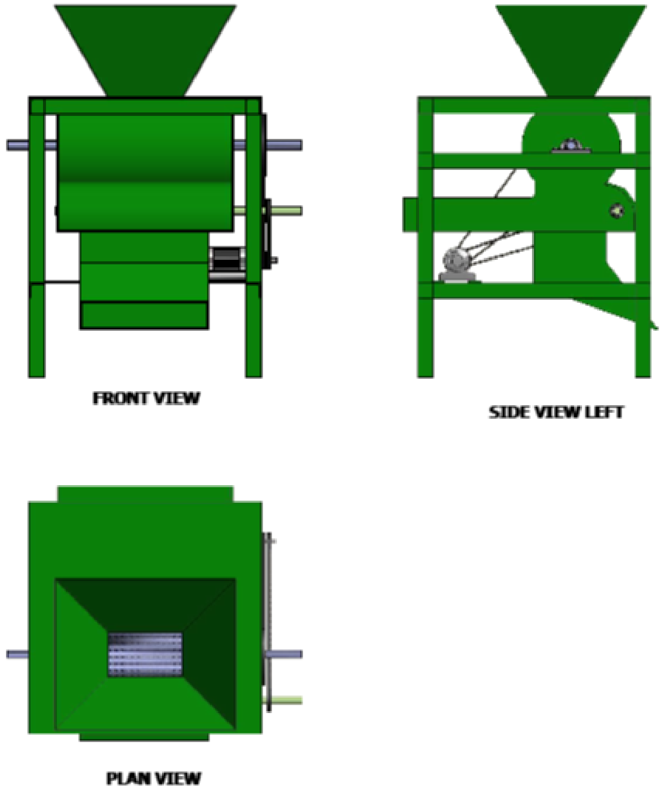

Figure 3-The orthographic iews of the decorticator.

The Beamboy computer software was used to obtain the maximum vertical and horizontal stresses acting on the

2.1 Design analysis and calculations

The Bambara used for this work was obtained from Orie-Orba, Nsukka market. Some quantity was weighed and spread under the sun for seven days. Thereafter, it was weighed again andagain it was found that there was indeed no noticeable difference in the weights indicating that the nut was no longer containing any significant moisture. It was dry enough for decorticating process.

2.1.1Weight of theundecorticatedbambara nuts

Some ground nuts were stochastically collected from a basket of the dry nuts using small plate and weighed. Average mass of one dry Bambara nut was obtained using this expression, $\mathbf{B_m} = \left(\frac{K_3 - K_1}{K_2}\right)$ (1)

where, number found in the plate = K_2 =54 nuts
Mass of both plate and contents = K_3 = 42.60g
Mass of empty plate = K_1 = 13.43g.

2.1.2 Average force required to decorticate one Bambara nut using a falling mass

The average force required to decorticate one Bambara nut was estimated using a known hanging mass to fall on itat a height wheredehuskingwas achieved without crushing the seed.
Mass of falling body used = 300g
Average force required to decorticate one nut (without crushing the seeds) may be obtained:

Employing Newton;s law for linear motion $\mathbf{s = ut + \frac{1}{2} gt^2}$ (2)

or $g = \frac{2s}{t^2}$ (the body fell from rest i.e. initial velocity u = 0)

where t and s = time taken to hit the ground and height of fall respectively.

Since the force generated by the falling body F = mg $\Rightarrow$ $\mathbf{F} = \frac{2ms}{t^2}$ (3)

where m = mass of 300g; t = time taken for mass to reach the ground = 0.6 seconds to fall freely from a height s = 0.75metres to hit the nut.
Average diameter of an undecorticated Bambara nut (using a Vernier calliper) = 6.5 mm

⇒ surface area of oneundecorticated nutS_A(assume same with area ofcircle = **πr^2),** (4)
where r = 3.25 m
Space area of hopper neck which is square, $\mathbf{S_H = L^2}$, (5)
L being 50 mm each

:. Maximum number of nuts that can pass through hopper neck per unit time$\mathbf{N_m} = (\frac{L^2}{S_A})$ (6)

Total force required to decorticate the maximum number of nuts that may possibly go through the hopper to the decorticator per unit time F_T= F x Nm

2.1.3 The decorticator

Length of decorticator cylinder = 300 mm
Diameter of decorticatorcylinder = 300mm; r_7
Mass of decorticator cylinder with shaft = M_d

The diameters of the motor and decorticator pulleys are related to their revolutionary speeds as $\frac{n_1}{n_2} = \frac{d_2}{d_1}$ [1](8)

Where
n_1 = motor pulley speed = 1000rpm
n_2 = decorticator cylinder pulley speed = 200rpm
d_1 = motor pulley diameter =40mm = 0.04 m; r_1 = 0.02 m
d_2 = decorticator cylinder pulley diameter.

From equation (8), $d_2 = \frac{n_1 d_1}{n_2}$

2.1.4 Force possessed by decorticator drum T_d

The centrifugal force possessed by the spikes born on the rotary cylinder $\mathbf{F_c} = (\frac{mv^2}{r})$ (9)

where m = mass of decorticator cylinder + mass of the maximum number of nuts that may fall on the decorticating drum per unit time =M_n (10)
v = linear velocity of drum or decorticator cylinder n_2 since n_2 = 200rpm

and v = ωr, then $\mathbf{v} = \frac{2\pi n_2 r}{60}$ (11)

r = distance from axis of shaft rotation to the top edge of spiral spikes of drum which is 1.5 mm high. This is radius of drum + height of spike = (150 +1.5)mm =151.5mm = 0.1515m
= 150 + 1.5 mm = 151.5 mm = 0.1515m
:. Force possessed by the decorticator spikes F_d from eqn. (9)= centrifugal force Fc

To minimize energy waste, the force possessed by the revolving decorticator spikes should just be slightly higher than the force required to decorticate the maximum number of pods that may get into the decorticator drum per unit time.

:. Since $F_d > F_t$, ⇒ then decortication is achievable.

2.1.5 Torque possessed by decorticator drum T_d

$\mathbf{T_d = m \alpha r}$(12)
Where m = M_n as in equation (10)
α = tangential component of the angular acceleration of the decorticator drum

$= \frac{mv^2}{r}$, normal/centripetal components being zero;

where r = radius of decorticator drum up to the apex of the 1.5mm spike= 0.1515 m

2.1.6 Motor power requirement

This involves
(i) Power required to drive the decorticator.

The power required to drive the decorticator $P_d = T_d . \square$(13)

where ω is the angular velocity of decorticator drum = $2 \square \frac{n_2}{60}$ (14)

(ii) Power required to drive the blower

The power consumption of a blower which is the function of the power required to run itwas calculated using equation 15 by [2]which is derived from adiabatic compression equation. This was modified by[3] as

$$P_w(kW) = \frac{Q_{air} P_1}{17.4 e_M e_B}\left[\left(\frac{P_2}{P_1}\right)^{0.283} - 1\right] \quad (15)$$

Here, the following particulars apply for the blower chosen

e_M : Motor efficiency (0.75)

e_B : Blower efficiency (0.86

P_1 : Inlet pressure, absolute (0.35kPa)

P_2 : Outlet pressure, absolute (0.4kPa

P_w : Power (kW)

Q_{air} : Air flow in ambient condition (8m^3/min)

Therefore, the total power required by the motor to run the machine should be a little above that required by both the decorticator and blower sections ie (Pd + Pw) = 508.24W. For an overload factor of 1.2, the total power = P_T2(Pd + Pw).

2.1.7 Motor torque

The motor torque involved in the drive according to [4],may be obtained using this expression

$T_m = P_T$ x $\frac{9.554}{n_1}$ .This is the maximum torsional stressMt (16)

2.1.8 Tensions in the V-belt drive

The belt length,X of the machine was determined using the v-belt calculation on line by (5), where the decorticator and motor pulley diameters are 100 mm and 20 mm respectively. The centre distance C = 400 mm. The tensions on both sides of v-belt are expressed by the expression of equation 17, [1].

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu \square \operatorname{cosec} \square \quad (17)$$

Where T_1 = tension on the tight side of the belt

T_2 = tension on the slack side of the belt

μ = coefficient of friction between the belt and groove side = 0.5123 [7]

α = the wrap angle**x + sin^{-1}** $\left(\frac{r_2 - r_1}{x}\right)$ (18)

x = centre distance between the two shafts = 400mm = 0.400m.

θ = angle of contact on the motor sheave = **180^o - 2** $\square$ **x** $\left(\frac{\pi}{180}\right)$ (19)

β = half of the groove angle of the sheaves, where the full angle of groove is measured as 32^o. Thus β= $\left(\frac{32^o}{2}\right)$ = 16^o

From equation (17), $\left(\frac{T_1}{T_2}\right) = \log^{-1}\left(\frac{\mu\, \theta \operatorname{cosec} \beta}{2.3}\right) \Rightarrow \left(\frac{T_1}{T_2}\right) = \log^{-1}(2.23)$ (20)

Again, the power transmitted by this v-belt is related to tensions in this expression [1]

P = (T1-T2)V$_b$(21)

Where p = motor power and V_b = belt velocity which is given as

$V_b = (\frac{\pi d_1 n_1}{60})$ **(1)**(22)

Thus combining equations (20) and (21), T1 and T2 may be obtained.

2.1.8 The decorticator shaft diameter

The shaft is made of steel having a yield stress of 240 Mpa. ASME code was used to design the diameter of the shaft for suddenly applied load with combined fatigue and shock factors in bending and torsion. Subsequently, the bending and twisting factors are kb = 2.0 and kt = 1.5 respectively. The diameter of the shaft may therefore be determined using maximum shear stress theory

$$d^3 = (\frac{16}{\pi \tau_{max}}) \sqrt{(M_b.k_t)^2 + (M_t.k_t)^2} [7] (23)$$

where

d = shaft diameter

τ_{max} = permissible shear stress = 0.3 of the material yield stress or $0.3S_{yt}$ [7]

= 0.3 x 240 = 72Mpa (x)

The resultant maximum bending moment $M_b$on shaft was obtained from this expression $Mb = \sqrt{(Mv)^2 + (Mh)^2}$(24)

14.74 Nm

Where Mvand Mh are thetotal vertical and horizontal momentson shaft obtained from the Beamboy software.

Mt = maximum working stress in torsion = 22.3 Nm (equation 18).

Kb = combined shock and fatigue factor for bending moment = 2.0

Kt = combined shock and fatigue factor for torsion =1.5

$$d = (\frac{\pi}{16}).\tau_{max} .d^3 = \sqrt{(M_b \times k_b) + (M_t \times k_t)} (25)$$

III. RESULTS AND DISCUSSIONS

3.1Results

The results of this research were presented in Tables 1-6

Table 1- The preliminary parameters/calculations leading to the machine design.

s/n	Preliminary parameters	symbol	value	Unit
1	Average mass of one dry Bambara nut	B_m	0.54	g
2	Force required to decorticate one dry bambara nut	F	1.25	N
3	Surface area of one undecorticated dry bambara nut	S_A	33.2	mm^2
4	Area of hopper neck	A_H	2500	mm2
5	Decorticator drum pulley diameter	d_2	200	mm^2
6	Maximum number of nuts through hopper per unit time	N_m	76	Nuts
5	Mass of maximum pods in decorticator per unit time	Mn	41.04	g
6	Total force required to decorticate all pods per unit time	F_t	80.63	N
7	Mass of decorticator drum (without pods)	M_d	1400	g
8	Mass of decorticator drum with all nuts per unit time	M_n	1441.04	g
9	Mass of aluminum pulley attached to the decorticator shaft	M_s	183.5	g
9	Mass of belt	M_l	40	g
10	Centrifugal force of decorticating spikes	F_d	98.8	N
11	Linear velocity of spike regions	V	3.17	m/s
12	Angular velocity of spike regions	ω	20.95	rad/s
13	Torque possessed by decorticator spikes	T_d	14.95	Nm

Table 2- Belt and motor calculated parameters

s/n	Preliminary parameters	symbol	value	Unit
1	Belt length	B_l	1051	mm
2	Tension on tight side	T_1	292.2	N
3	Tension on slack side	T_2	1.7	N
4	Centre distance between motor and decorticator shafts	X	400	mm
5	Angle of contact on motor sheave	θ	2.76	rads
6	Angle of wrap	α	11.9	degree
7	Linear velocity of belt	v_d	2.1	m/s
7	Power transmitted to decorticator shaft	P_d	467.2	W
8	Power transmitted to blower shaft	P_w	41	W
9	Motor power with an overload factor of 1.2	P_m	610	W

Table 3-Total load on decorticator shaft`

s/n	Loads on decorticator shaft	Value	Unit
	Weight of decorticator cylinder	13.7	N
	Weight of maximum number of pods that can fall into the decorticator cylinder per unit time	0.40	N
	Weight of aluminium pulley attached to the decorticator shaft	1.8	N
	Weight of belt	0.4	N
	Weight of decorticator and pods acting at 0.20m from the left of beam.	14.1	N

Table 4-Vertical and horizontal load components on the shaft.

s/n	load components of the belt	Value	Unit
1	Vertical load components of the belt ($T_1 \sin 10^o + T_2 \sin 10^o$)	50.8	**N**
2	Weight of pulley and belt	2.2	N
3	Vertical load effect at pulley side acting @ 0.4m from left of shaft.	53.0	N
4	Reaction supports at 0.05m for R_{AV} and at 0.35m for R_{BV}, both from the left	1.78, 68.9	N
5	Total moment arising from vertical load on shaftMv	2.65	Nm
6	The horizontal load components of the belt, ($T_1 \cos 10^o + T_2 \cos 10^o$)	289.1	N
7	Total moment arising from horizontal load on shaft Mh	14.5	Nm
8	The resultant maximum bending moment M_b	14.74	Nm
9	Maximum working stress in shear Mt	22.3	Nm
10	Standard shaft diameter of 16 mm was selected	16	mm
11	The horizontal reaction components, R_{AH} and R_{BH}	48.2, 231	N

Table 5- The maximum vertical stresses on shaft obtained using the Beamboy

Maximum Values

	Maximum Value	Location
Bending Moment	-2.65 N-m	0.35 m
Bending Stress	27000 MPa	0.35 m
Deflection	-3510 mm	0.42 m
Slope	-1700 degrees	0.4 m

Table 6- The maximum vertical stresses on shaft obtained using the Beamboy

Maximum Values

	Maximum Value	Location
Bending Moment	-14.5 N-m	0.35 m
Bending Stress	147000 MPa	0.35 m
Deflection	-37600 mm	0.42 m
Slope	-14100 degrees	0.4 m

IV. 4. DISCUSSIONS

Table 1 presents the preliminary parameters/calculations involved in the machine design. The approximate total force required to decorticate the 41.04g mass of maximum quantity of Bambara nuts in the decorticator drum per unit time is 80.63 N. The force possessed bythe decorticator spikes on the cylinder is 98.80 N, showing that decortication is possible.

In Table 2, the calculated belt and motor variables were presented. It may be observed that the belt length is 1051 mm, the power requirements of the decorticator and blower are 467.2 and 41 W respectively. The total motor power requirement of the machine with an overload factor of 1.2 is 610 W.

Table 3 shows the various loads on decorticator shaft.Theweight of aluminium pulley attached to the decorticator shaft is 1.8 N,and that of the belt is 0.4 N

Table 4 presentsthe vertical and horizontal load components on the shaft. It reveals that the values of the reactions at the bearing supports are 1.78 and 68.9 N at bearing supports R_{AV} and R_{BV} respectively as a result of the vertical loads on the shaft. It also reveals that the total moment arising from the vertical Mv and horizontal Hv load effects ((moments) is 14.75 Nm. It shows the Maximum working stress in shear Mtas 22.3 Nm.The selected standard shaft diameter of 16 mm.

Table 5 presents the maximum vertical stresses on shaft obtained using the Beamboy computer software. The maximum bending moment is 2.65 Nm located at 0.35m of the shaft from the left.

Table 6 presents the maximum horizontal stresses on shaft obtained,also using the Beamboy computer software.The maximum horizontal bending moment is 14.5 N, located at 0.35 m on the shaft. Reactions at points A and B arising from the horizontal force components are -48.2 N and 337 N respectively.

V. CONCLUSION

This work shows that the design and production of a Bambara nut decorticator machine is possible using locally available materials. This obviously saves the energy and cost of relying on the expensive imported decorticators for this staple food grains of the people. This locally produced machine if mass produced will encourage full scale Bambara nut farming in the African continent.

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