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Design of Breadfruit Shelling Machine

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Abstract

Breadfruit (Treculia Africana) or simply breadnut is very important both as food and a potential source of oil. The economic importance of this tropical seed on domestic and commercial basis has necessitated the design of a mechanized shelling method. This would reduce the tedium of the traditional manual shelling methods which though are quite efficient, are rather time-consuming. In the engineering design of this machine, the action zone consisted essentially of two rollers; one adjustable and the other rotating. A separating unit that cleans the seed while pneumatically separating it from the shell was incorporated. The design of this separating unit was such that practically 80% cleaning was achieved at an average *air flow rate of 740m^3/hr. Overall, the efficiency of the machine was about 78%.*

Introduction

The tree Treculia Africana (or simply breadfruit) belongs to the botanical family maraceae. It grows well in forest region of Southern Nigeria either as wild or cultivated plant and its seed is used for the preparation of various dishes.

Work carried out has revealed that the oil from bread-fruit seed could be economically used for vegetable oil production. On a commercial scale, breadfruit yields 10.23% of oil. This value as well as its chemical and physical contents compare very favourably with those of the common oil seeds like cotton seed and palm kernel that are used for commercial oil production. The presence of linoleic acid in the oil gives the seed a high nutritional quality as source of an essential fatty acid. The physical and chemical properties of fats and oil make them not only valuable as edible food nutrients but can be used in the manufacture of soap, candles, perfumes, cosmetic and many pharmaceutical preparations.

Composition of Breadfruit Seeds

Some previous research works have investigated percentage composition of the breadfruit seed. The results of those investigations are shown in table 1.

Uses of Breadfruit

Breadfruit is used mainly as an important food item. The seeds are cooked and eaten with sliced cassava or boiled maize. However, breadfruit loaf, cookies, biscuits and soup mix have been prepared from the fruit. The seeds of African breadfruit are used as food and source of flour in West Africa, while the fruits are eaten by elephants. The seeds can also be roasted and eaten as snacks. Breadfruit can equally be processed into flour from which several produces like breadfruit loaves, biscuits, dry-packs and soup-mixes could be made.

Traditional Method of Shelling Breadfruit

Traditionally, breadfruit is shelled manually. Prior to this manual operation, the breadfruit seeds are parboiled with water for some minutes (about 4 minutes). This partial boiling will facilitate easy separation of the shell from the cotyledon. After the seeds have been extracted from the hot water, they are lightly sprinkled with cold water to further temper the seed for easy shelling.

A cylindrical or rectangular shaped log of wood or in some cases, a cylindrical bottle is employed in rubbing the unshelled bread fruit seeds against a wider surface such as sack, mat, cement floor or traditional clay floor. The robbing operation goes to and fro on a convenient quantity of the seed a number of times or cycles before it is properly shelled. In the process, the seeds are slightly crushed with the shell detaching from the cotyledons. This traditional method requires a lot of expertise and skill to estimate how much force to be applied in order not to over crush the seeds. Parboiled breadfruit seeds can also be robbed in between fingers to achieve the shelling. In this case, shattering of cotyledons is more controlled. These methods have proved very efficient but for the huge time involvement.

Materials and Method

Physical Properties of Breadfruit Seeds

In order to design a machine capable of shelling the breadfruit seeds and separating the shells from the shelled seeds or cotyledon, certain physical properties of the seed were determined. Mechanical shelling of the seed is influenced by the size of the seeds (i.e. length, breadth and thickness). Performance of the machine is influenced by the crushing strength of the seed at different moisture contents. The procedure used to characterize the dimension of the breadfruit is similar to that of melon seeds. Based on a large number of measurements, empirical equations were proposed to express the co-relation between the three principal dimensions of the two most common types of breadfruit seed found in the Eastern part of Nigeria.

Characteristic Dimensions of Breadfruit Seeds

The mature breadfruit seeds are essentially ellipsoidal or spherical in shape depending on the variety. There are two most common varieties of breadfruit. These two varieties can be distinguished on the basis of size and shape. While one variety is larger and may be approximated to ellipsoidal, the other is similar and fairly spherical. The thickness of the shell of both varieties is about the same.

Measurement of the Size of the Breadfruit Seeds

For each variety, a bulk sample was provided. One hundred seeds were picked randomly from each bulk sample. For each of the 100 seeds, the major, intermediate and minor diameters (i.e. L_1, L_2, and L_3 respectively) were measured with a vernier caliper. The same measurements were carried out for the shelled seeds.

The seeds were then shelled by hand, careful enough not to alter the shape or the cotyledon and similarly the major, the intermediate and the minor diameters (i.e. Ls_1, Ls_2 and Ls_3 respectively) were determined for the shelled seed (Fig.1). The above procedure was carried out for the two varieties. The results of the measurements were subjected to statistical analysis. The results are summarized as shown in tables 2 and 3. It could be noticed that there is little or no difference between the intermediate and minor diameters of the two varieties. For the major diameter, there is a significant difference, which is indicative of their size difference.

Weight and Volume of Breadfruit Seed

Bulk samples of the two varieties were roughly mixed and about 50 seeds were randomly picked out for digital measurements. The volume of the breadfruit seeds was also determined for both shelled and unshelled seeds.

From table 4, densities of unshelled and shelled breadfruit seeds can be calculated as follows;

Density = mass/volume
The density of unshelled bread fruit seed;

$$e_u = (0.23 \text{ x} 10^{-}3) / (0.21 \text{ x } 10^{-6})$$
$$= 1095.24 \text{Kg/m}^3$$

The density of shelled bread fruit seed;

$$e_s = (0.20 \text{ x } 10^{-3}) / (0.15 \text{ x } 10^{-6})$$
$$= 1333.33 \text{Kg/m}^3$$

As would be expected the density of the cotyledon is greater than that of the unshelled seed because the shell in the later has a considerable volume but contributes very negligible weight.

Force Required in Cracking the Breadfruit Shell

The load to crack the breadfruit shell without causing a considerable crushing or shattering of the cotyledon is necessary in the estimation of power requirement for the shelling of the seed. Measurement of this load was carried out under different level of moisture content of the breadfruit seeds; without soaking in water, then after soaking in water for 2,3, and 24 hours respectively. After each period of soaking, the seeds were put into shelling condition by boiling with water for 3 minutes. The force to crack the breadfruit shell was determined with a grain hardness tester by noting the reading on the dial immediately crack developed on the seed shell. The seeds under test were placed in such a way that their axes were in horizontal plane (this corresponds to the natural rest position of the seeds). A plot of load against moisture content shows that less force is needed to cause a crack on the breadfruit shell at higher moisture content and vice-versa (Fig.2). Generally, the hardness of grains decreases with increase in moisture content except for unshelled groundnut.

Terminal Velocity of Shelled Bread Fruit Seed:

In free fall, an object will attain a constant velocity, V_t at which the net gravitational acceleration force, F_g equals the resisting upward drag force, $F_{r.}$

Under the steady state condition where terminal velocity has been achieved, if the particle density is greater than the fluid density, the particle motion will be downward. If particle density is smaller than the fluid density, the particle will rise. Terminal velocity has been used as important aerodynamic characteristics of material in such applications as pneumatic conveying and separation from foreign materials.

The relevant equations used in the calculation of terminal velocity are as follows;

$$C = \frac{2\omega(P_p P_f)}{V_t^{\,2} A_p P_p P_f} \qquad \text{Eqn. (1)}$$

Where:

- C = drag coefficient
- ω = weight of particle (breadfruit)
- P_p = mass density of particle
- P_f = mass density of fluid (air)
- V_t = terminal velocity
- A_p = projected area of particle = $\pi D^2/4$

$$R_e = \frac{D V_t P_f}{\mu_f} \qquad \text{Eqn. (2)}$$

Where:

- D = average diameter of particle
- μ_f = absolute viscosity of fluid
- Re = Reynolds' number

If equations (1) & (2) are combined while first substituting $A_p = \pi D^2/4$ in eqn. (1)

$$C = \frac{2\omega(P_p - P_f)}{V_t^2 A_p P_p P_f}$$

Where: $A_p = \pi D^2/4$

$$= \frac{2\omega(P_p - P_f)4}{V_t^2 \pi D^2 P_p P_f}$$

$$C = \frac{8\omega(P_p - P_f)}{V_t^2 \pi D^2 P_p P_f} \qquad \text{Eqn. (3)}$$

Since, $Re = \frac{D V_t P_f}{\mu_f}$ thus, $V_t = \frac{Re\, \mu_f}{D P_f}$

Substituting V_t in equation (3)

$C = [8\, \omega\, (P_p - P_f)] / [(Re\, \mu_f / D P_f)^2\, \pi\, D^2\, P_p\, P_f]$

$$= \frac{8\, \omega\, P_f\, (P_p - P_f)}{Re^2\, \mu_f^2\, \pi\, P_p}$$

Therefore;

$$CR_e^2 = \frac{8\omega P_f (P_p - P_f)}{\mu_f^2 \pi P_p} \qquad \text{Eqn. (4)}$$

Data:

$\omega = 2.0 \times 10^{-4}$ Kg/m
$P_f = 1.15$ Kg/m^3
$P_p = 1333.33$ Kg/m^3
$\mu_f = 17.85 \times 10^{-6}$ Kg/sec.m

Substituting values in equation (4)

$$CRe^2 = \frac{8 \times 2.0 \times 10^{-4} \times 1.15(1333.33 - 1.15)}{\pi\,(17.85 \times 10^{-6})^2 \times 1333.33}$$

$$= \frac{2.4512}{13.35 \times 10^{-7}}$$

$$= 0.18 \times 10^{-7}$$

$$= 1.8 \times 10^{-8}$$

$Re = 7 \times 10^3$

Thus, $C = 1.8 \times 10^{-8} / Re^2$

$$= 1.8 \times 10^{-8} / (7 \times 10^3)^2$$

$$= 3.67 \times 10^{-16}$$

$$V_t = \frac{Re\,\mu_f}{D\,P_f}$$

$$= \frac{7 \times 10^3 \times 17.85 \times 10^{-6}}{6.7 \times 10^{-3} \times 1.15}$$

$$= \frac{124950 \times 10^{-6}}{0.007705}$$

$$= 16\text{m/s}$$

The terminal velocity of shelled breadfruit seed is 16m/s

Theoretical Analysis and Design of the Machine

Clearance between the Shelling Surfaces

The distances between the shelling surfaces have a very important bearing on the shelling efficiency of the machine. For the rollers it is designed to be adjustable particularly to tolerate variations in size of different species or varieties of breadfruit.

The Cleaning Unit

The peculiar shape of the cleaning unit makes the cleaning operation possible. The lower portion at which the mixture of shelled breadfruit and chaff enters is designed to be of smaller capacity. This will ensure that both the breadfruit and shells are blown up to the upper portion with the velocity of blower fan greater than the terminal velocity of the mixture. The bigger capacity of the middle portion makes it possible for the sharp drop in the velocity of the dragging air. Since discharge or flow rate, Q is the product of the cross-sectional area, A, and the velocity, V (i.e. Q = AV) and since this must be maintained through the unit, it means that the velocity 'V' must drop.

Power Requirement of the Rollers:

To determine the torque requirement of the rollers we have that;

$$P = \frac{2\pi\, nT}{60}$$

Where:

P = power, KW
n = shaft speed, rpm
T = Torque, Nm

Therefore, substituting values where;

P = 0.75KW
n = 2820 rpm

From the formula:

$$P = \frac{2\pi nT}{60}$$

$$T = \frac{60P}{2\pi n}$$

$$= \frac{60 \times 0.75 \times 10^3}{2 \times 3.142 \times 2820}$$

$$= \frac{45000}{11720.88}$$

$$T = 3.839\text{Nm}$$

The Assembly Drawing of the Breadfruit Shelling Machine

The assembly of the breadfruit shelling machine is shown in figure 4.

Conclusion

The design and operations of this breadfruit shelling machine achieved the following:

- Determination of some physical properties of breadfruit.
- Determination of throughput capacity and power requirement of the machine.
- Construction and testing of a prototype machine with special design considerations given to the distance between the shelling rollers, the clearance of the shelling section, and the surfaces of the shelling sections.
- 80% of the cleaning of the seeds was achieved at an average air flow rate of 740m^3/h.
- Considering the left out job and the properly cleaned product, we conclude an efficiency of 78%.

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Table 1a: % Composition of Breadfruit Seed

Breed	**% fat**	**% protein**	**% CHO**
1	10.23	17.23	-
2	10.27	17.23	-
3	15.80	19.00	40.30

Table 1b: Mineral and Vitamin Content of Breadfruit

Mineral or Vitamin	**mg/100g food**
Calcium	30.00
Phosphorous	30.00
Iron	0.80
Carotene or vitamin A	0.004
Ascorbic acid	25.00
Thiamine	0.01
Riboflavin	0.50
Niacin	0.50

Table 2: Summary of the characteristic dimensions of breadfruit seeds

(a) Variety 'A' (large)

	Major Diameter L_1 (cm)	Intermediate Diameter L_2 (cm)	Minor Diameter L_3 (cm)	Major Diameter Ls_1 (cm)	Intermediate Diameter Ls_2 (cm)	Minor Diameter Ls_3 (cm)
Mean Value	1.24	0.69	0.58	1.06	0.59	0.52

Variety 'B' (small)

	Major Diameter L_1 (cm)	Intermediate Diameter L_2 (cm)	Minor Diameter L_3 (cm)	Major Diameter Ls_1 (cm)	Intermediate Diameter Ls_2 (cm)	Minor Diameter Ls_3 (cm)
Mean Value	0.99	0.69	0.59	0.84	0.64	0.52

Table 3: Difference between the two varieties

Dimension	Variety 'A'	Variety 'B'	Difference	Percentage difference based on variety 'A' [(A-B)/A]x100%
L_1 (cm)	1.24	0.99	0.25	20.2
L_2 (cm)	0.69	0.69	0.00	0
L_3 (cm)	0.58	0.59	0.01	1.7
Ls_1 (cm)	1.06	0.84	0.22	20.8
Ls_2 (cm)	0.59	0.64	0.05	8.5
Ls_3 (cm)	0.52	0.52	0.00	0

Table 4: Summary of values of weight and volume of breadfruit seeds

	Unshelled seeds Weight (g)	Unshelled seeds Volume (ml)	Shelled seeds Weight (g)	Shelled seeds Volume (ml)
Mean Value	0.23	0.21	0.20	0.15

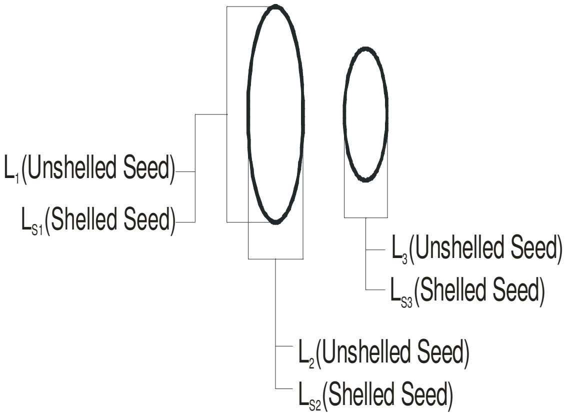

Fig.1: Principal Dimensions of Breadfruit Seed

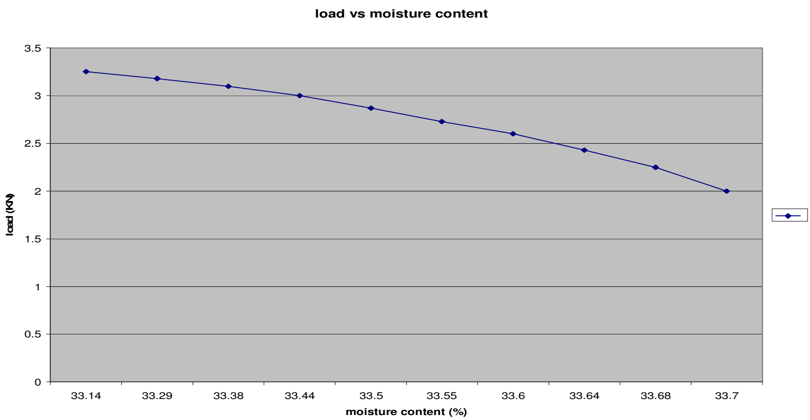

Fig.2. Relationship between Load and Moisture Content

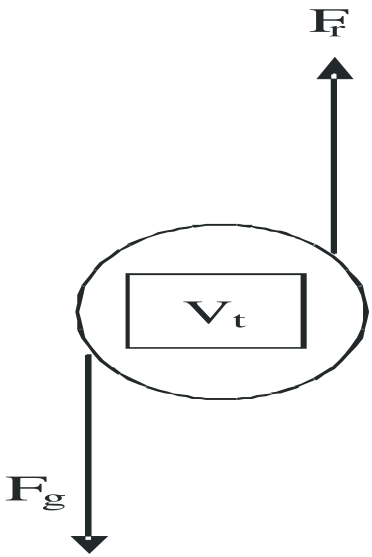

Fig.3. Terminal Velocity of Shelled Breadfruit Seed

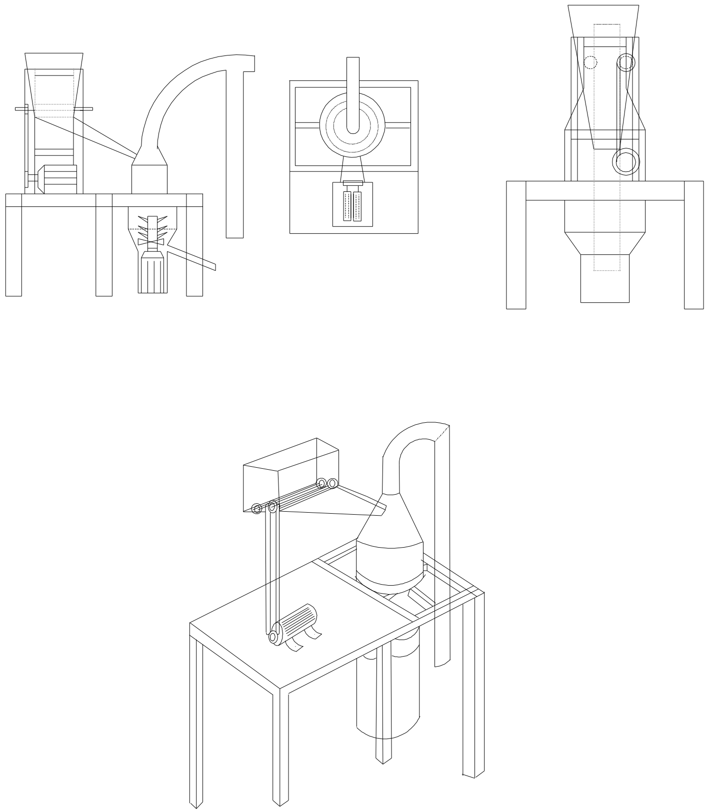

Fig.4. Assembly Drawing of the Breadfruit Shelling Machine