Design and Development of a *Garcinia kola* Size Reduction Machine

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Abstract— A *Garcinia kola* size reduction machine was designed, developed and tested. The study was aimed at reducing the size of the seeds for easier packaging, storage and further processing operations. The machine consists of the frame, feeding and discharge chutes, screw auger, plates and transmission unit. Data obtained from preliminary investigations on engineering properties of the seed were used in designing the machine components. Particle size analysis, using ASABE S319.4 (2008), was carried out to evaluate the machine performance. Repeated experiment with a charge of 100g each gave an average of 93.45% efficiency.

Index Terms — *Garcinia kola*, machine design, physical properties, sieve analysis, size reduction.

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1 INTRODUCTION

Garcinia kola is found throughout western and central Africa. Its exact origin could not be traced, however, the origin is attributable to the tropics where it occurred naturally and has been utilized for centuries. The seed is mostly used for its propagation, and three year old stump-planting under shade is recommended for vegetative propagation [1]. The tree, which is about 15-17m tall, is shade tolerant with a cylindrical trunk that is slightly buttressed to the ground [2].
The seed coat is brown with branched lines, while the colour of the seed itself is milky. The seeds are covered with yellowish-red pulp. The seed contains carbohydrate (10%), crude fat (> 10%), crude protein (5%) and the most abundant mineral being Sodium (215.10 ppm) [3]. The seed and bark contain tannin, colouring matter and a brown and yellowish-white resin, but no alkaloids [3], [4], and could be used as tanning, dyestuff and astringent. Recently, it was believed that a *Garcinia kola* extract can prevent the Ebola virus from replicating itself [3]. Also, the plant has shown anti-inflammatory, antimicrobial, and antiviral properties, and possess anti-diabetic and anti-hepatotoxic activities [5]. *Garcinia kola* pulp agro waste is used for ethanol production, and the solar drying of the agro waste shows significant positive effect on the optimization of its ethanol yield [6]. Traditionally, the seeds are used in ceremonies like births, marriages, and conferring of chieftaincy titles among the Igbo and Yoruba tribes of Nigeria. The split stems and twigs of *Garcinia kola* are used as chewing sticks in many parts of Africa, and have been commercialized in the major cities for years, offering natural dental care. *Garcinia kola* is a non-timber forest product that is mostly utilized in Africa [4].

Milling, on the other hand, is one of the ways of reducing the size of solid materials by mechanical action into granules. The breaking up of materials into smaller fragments is an extraordinarily important operation in processing and utilization of agricultural and biological materials. Foods, pharmaceuticals, agro-chemicals and other biological materials are frequently processed and marketed in the form of fine products [7]. This statement is true of *Garcinia kola* seeds. In unit operation, the average size of solid pieces of food is reduced by the application of grinding, compression or impact forces [8]. The forces used to reduce size of food materials also include shearing force. The magnitude of the force applied and the time of application affect the extent of grinding achieved [9]. Products with little moisture remain dry on milling, but others that contain considerable amount of moisture become pulp or paste on extensive size reduction. Wet milling has advantage over dry milling because of high temperature involved in dry milling. For efficient milling, the energy applied to the material should exceed the minimum energy needed to rupture the material by as small a margin as possible. Excess energy is lost as heat and this loss should be kept as low as possible during milling operations. During size reduction, a product is deformed and this results in strain. On further deformation, strain increases until the 'breaking strength' is exceeded [10].

Some scientists have carried out studies aimed at overcoming some problems associated with size reduction. Size reduction and expansion on yield and quality of cumin seed oil were evaluated [11], and the shortcomings of conventional size reduction were obviated by flaking. A pre-cooler was incorporated in the design and developing of a cryogenic grinding system for spices to reduce temperature associated with grinding operations [12]. The role of feed rate and temperature in attrition grinding of cumin was studied [13], and the researchers considered some dependent variables like rise in temperature, size of ground cumin, specific energy consumption and Bond's work index. However, this work is geared towards developing a motorized milling machine for *Garcinia kola* seeds to help local farmers reduce drudgery they encounter in manual milling.

2 MATERIALS AND METHODS

2.1 Design Considerations

The following were considered in the design of the machine:

the ability to reduce the size to a specified granular size, reduction of power and energy loss, economy to make the machine affordable to local farmers, choice of material for the development of the machine, and loss of material during operation. Besides, to achieve high efficiency, the following were also considered based on results of the preliminary investigations on the engineering and physical properties of the seeds [14]. They are:

(i) Mechanical properties of the material to be ground - toughness, strength and stiffness.

(ii) The manner in which stress is applied - intensity of power and energy, and rate of their application.

2.2 Conception of the Machine

The machine was conceptualized to consists of a frame made of angle iron of adequate thickness (50mm x 50mm x 50mm) for stability, feeding chute that will hold reasonable quantity of seeds before refilling, screw auger mounted on a section of the shaft for conveying material to be ground to the grinding chamber, two grinding plates (one rotating and the other stationary), pulley, double v-belt and ball bearings for power transmission, discharge chute for collecting ground product, and housing for screw auger and grinding chamber.

2.3 Selection of Materials and Parameters

Data obtained from the preliminary investigations carried out on some physical and engineering properties of the seed were used to select the following design parameters:

a. The auger casing of 120mm diameter based on the axial dimensions of the seeds.
b. Operating speed of 1200rpm.
c. Minimum angle of inclination of hopper based on the coefficient of friction of the seed.
d. Adjustable grinding plate clearance of 10-12mm based on seed dimensions
e. Grinding plate of 100mm bore diameter

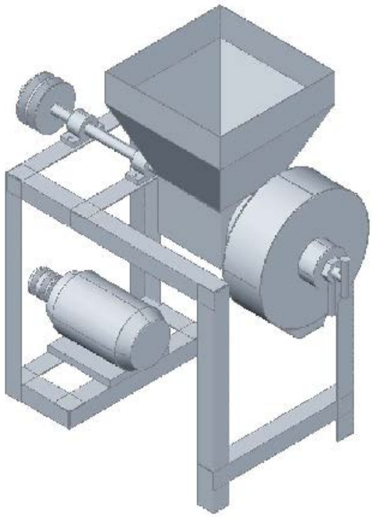

Fig. 1: The Size Reduction Machine

2.4 Design Calculations

2.4.1. The Auger Shaft

Assuming that the load due to the helical vane wound round the auger is uniformly distributed along the section of the shaft, leaving allowance between ends for the pulley and grinding plates, a shaft length of 700mm was obtained. Placing pulley and grinding plate weighing 20N and 90N respectively at both ends as point load on the shaft, the shaft was designed for bending, deflection and shear failure. The shaft diameter that will prevent failure was obtained from the following relationship [15];

$$d^3 = \frac{16}{\pi\tau}\sqrt{(M^2+T^2)} \qquad (1)$$

Where d = shaft diameter (mm), τ = safe shear stress = 40 MN/m^2, M = maximum bending moment (Nm), torque (Nm).

The torque required to run auger without load can be calculated from the following relationship given as [15];

$$T = \frac{P \times 9550}{n} \qquad (2)$$

Where T= Torque (Nm), P = power transmitted by the shaft (kW), n = speed of shaft (rpm).

Using a 4.5kW prime mover of speed 1415 rpm, a torque of 35.81Nm was obtained. With a maximum bending moment of 12.32Nm, the shaft diameter was gotten as 25mm.

2.4.2. Bearing Selection

The equation below [16] was used to calculate the radial load acting on the shaft thus:

$$F = \frac{KW \times 19.1 \times 106 \times k}{PD \times RPM} \qquad (3)$$

Where F = radial force on shaft (N), KW = power transmitted (kW), PD = pitch diameter of sheave (mm), RPM = speed of shaft (rpm), k = drive tension factor (k = 1.5 for v-belt drives, and k = 1.0 for chain drives and gears). A radial force of 778.53N was gotten and the appropriate sizes and strength of bearings that will withstand such load were selected from standard codes.

2.4.3. V-belt Selection

The v-belt pulley and dimensions were designed for, using appropriate equations and computing necessary calculations below. The shaft pulley diameter was calculated from the following relation:

$$D_2 = \frac{N_1 \times N_2}{N_1} \qquad (4)$$

Where D_2= shaft pulley diameter (mm), N_1= motor speed (rpm), N_2 = shaft speed (rpm).

The belt speed v in (m/s) was calculated from the equation:

$$v = \frac{\pi \times D_1 \times N_1}{60} \qquad (5)$$

The length of an open v-belt was gotten from the following equation:

$$L_o = \frac{\pi}{2}(D_1 + D_2) + 2C + \left(\frac{D_1 - D_2}{4C}\right)^2 \qquad (6)$$

Where L_o = length of v-belt (mm) and C = centre distance (mm) which lies between minimum centre distance and maximum centre distance. Their expressions were given as [15];

$$C_{min} = 0.55(D_1 + D_2) + t \qquad (7)$$

$$C_{max} = 2(D_1 + D_2) \qquad (8)$$

Where C_{min} = minimum centre distance (mm), C_{max}= maximum centre distance (mm), t = nominal thickness of the belt (mm).

Centrifugal tension of the v-belt can be determined using the equation [17];

$$T_c = mv^2 \qquad (9)$$

Where T_c= centrifugal tension of the v-belt (N), v = belt speed (m/s), m = mass of belt (kg) and it can be gotten from the following relation:

$$m = \rho \times t \times b \qquad (10)$$

Where ρ = belt density (kg/m^3), t × b = area of the belt (m^2).

2.4.4. The Frame

The operating convenience of the operator, assumed to be a man of average height, was taken into consideration in the frame design. As such, the frame was 0.6m high, 0.48m long and 0.32m wide. The frame was made from angle iron of dimensions 50mm × 50mm × 3mm.

2.4.5. The Feeding Chute

This was designed to hold reasonable quantity of product before refilling. The maximum axial dimension and bulk density of the product were considered also in determining the volume of product in the feeding chute.

2.5 Testing and Evaluation

The particle size distributions were analysed using ASABE Standard [18] for determining fineness of feed material by sieving. A charge of 100g was used. This charge was placed on the top sieve of the nest of test sieves mounted on an electric powered vibrator (shaker). The vibrator was switched on and the sieves were shook until the mass of material on any one sieve reaches end-point. The end point was set to be 15 minutes. The mass of material on each of the sieves was determined using an electronic balance that weighs to an accuracy of 0.001g. The mass determined was recorded and analysed using the following equations provided by ASABE Standard S319.4 [18] thus:

$$d_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n}\left(W_i log\bar{d}_1\right)}{\sum_{i=1}^{n} W_i}\right] \qquad (11)$$

$$S_{log} = \left[\frac{\sum_{i=1}^{n} W_i\left(log\bar{d}_\iota - logd_{gw}\right)^2}{\sum_{i=1}^{n} W_i}\right]^{\frac{1}{2}} = \frac{S_{ln}}{2.3} \qquad (12)$$

$$S_{gw} \approx \frac{1}{2} d_{gw}\left[log^{-1}S_{log} - \left(log^{-1}S_{log}\right)^{-1}\right] \qquad (13)$$

d_i	is nominal sieve aperture size of the i^th sieve,mm
d_{i+1}	is nominal sieve aperture size in next larger than ith sieve, mm
d_{gw}	is geometric mean diameter of particles by mass,mm
S_{log}	is geometric standard deviation of log-normal distri bution by mass in ten-based logarithm, dimensionless
S_{ln}	is geometric standard deviation of log-normal distri bution by mass in natural logarithm, dimensionless
S_{gw}	is geometric standard deviation of particle diameter by mass, mm
W_i	is mass on ith sieve, g
n	is number of sieves +1 (pan)

The equation for estimating the total surface area of particles in a charge is:

$$A_{st} = \frac{\beta_s W_t}{\beta_v \rho} exp\left(4.5\sigma ln^2 - ln\mu_{gw}\right) \qquad (14)$$

A_{st} is the estimated total surface area of a charge, cm^2; β_s is the shape factor for calculating surface area of particles (β_s = 6 for cubical, β_s = π for spherical particles), ρ is the particle density of the material, (g/cm^3); σ_{ln} is the log-normal geometric standard deviation of population by mass in natural logarithm (S_{ln} is used as an estimate for σ_{ln}); μ_{gw} is geometric mean particle diameter of parent population by mass, cm; (d_{gw} is used as an estimate for μ_{gw}). Note: μ_{gw} is expressed in cm and d_{gw} in mm; W_t is mass of a charge, g.

The number of particles in a charge N_t is calculated as:

$$N_t = \frac{W_t}{\beta_V \rho} exp\left(4.5\sigma_{ln}^2 - 3ln\mu_{gw}\right) \qquad (15)$$

The performance of the grinding machine was evaluated using the percentage of particle size of the charge that met the desired particle size diameter.

3 RESULTS AND DISCUSSIONS

The result of sieving data and calculation of log-normal particle size distribution parameters by mass is tabulated on Table 1 below. The following were obtained by calculation using equations (11) through (16) as follows:

i. The geometric mean diameter of particles by mass d_{gw}, mm
d_{gw} = 0.855mm

ii. Geometric standard deviation of log-normal distribution by mass in ten-based logarithm, dimensionless (S_{log})
S_{log} = 0.244

iii. Geometric standard deviation of particle diameter by mass S_{gw}, mm
S_{gw} = 0.506mm

iv. Estimated total surface area of a charge A_{st}, cm^2
A_{st} = 230129.72cm^2

v. Number of particles in the charge N_t
N_t = 6558024.68

The efficiency of the machine is expressed as its ability to reduce the material to a desired granular diameter (size).

The desired particle size is ≤ 0.500mm

From the Table 1 below, the mass of charge that met this desired size is equal to 94.311g. This value is the summation of charge masses contained in sieves BSS Sieve No. 31, 35, 52, 90, 100 and pan.

We can also observe from Table 1 that the total mass of charge is equal to 97.715g

Hence, the total number of particle N_p that met the desired granular size becomes;

$$N_p = \frac{94.311 \times 6558024.68}{97.715} = 6329568.6$$

It follows that out of 6558024.68 particles in the charge, 6329568.6 met the desired size.

$$Efficiency\ of\ the\ machine = \frac{6329568.60}{6558024.68} = 0.9652 = 96.52\%$$

Table 1: Sieving data and calculation of log-normal particle size distribution parameters by mass.

BSS Sieve No.	IS sieve size (d$_i$), mm	W$_i$ (g)	$P_i^{*1)}$(%)	$\sum P_i$ (%<)	d_i	$log\bar{d}_i$	$W_i log\bar{d}_i$	$(log\bar{d}_i - log_{dgw})$	$W_i(log\bar{d}_i - log_{dgw})^2$
6	2.800	4.912	5.027	94.974					
31	0.488	65.982	65.982	28.992	1.169	0.068	4.384	0.136	1.193
35	0.438	0.854	0.874	28.118	0.462	-0.335	-0.286	-0.267	0.061
52	0.300	25.640	26.240	1.878	0.362	-0.441	-9.282	-0.373	3.567
90	0.170	0.008	0.008	1.870	0.226	-0.646	-0.005	-0.578	0.003
100	0.150	1.827	1.870	0.000	0.160	-0.797	-1.456	-0.729	0.971
Pan	Pan								
Summation		97.715	100.001				-6.645		5.795

$^{1)}$ Pi is equal to mass of the particles on the i^{th} sieve divided by the total charge mass ($W_i$summation) x 100

$P_i = \frac{W_i}{\sum W_i} \times 100$

$^{2)}\bar{d}_i = [d_i \times d_{i+1}]^{1/2}$

$d_{i+1}$is nominal sieve aperture size in nest larger than i^{th}sieve (just above in a set of nest), mm

Other parameters were as defined previously

4 CONCLUSIONS

A mechanical *Garcinia kola* grinder was designed, fabricated and evaluated. The results of the study showed that the mechanization of size reduction operation for *Garcinia kola* seed is achievable. Hence, the packaging, marketing and further processing operations of the seeds will be enhanced through this work.

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