

DEVELOPMENT OF A TIGERNUT SEEDS CLEANING AND SORTING MACHINE

A. A. Balami¹, M. Birma² and S. M. Dauda¹

¹Department of Agricultural & Bioresources Engineering,
Federal University of Technology, Minna, Nigeria.

Email: aabalami@futminna.edu.ng

²Department of Agricultural Engineering, Federal Polytechnic, Nassarawa, Nigeria.

ABSTRACT

This study is about the development of a machine for cleaning and sorting of tiger nut seeds. Some selected physical properties of the tiger nut seeds such as size and shape, volume and density, surface area, weight, sphericity, coefficient of friction, angle of repose, as well as terminal velocity were also determined and used in the design of the machine. The average values obtained from the physical properties at 17 % moisture content are: surface area (206.12 mm²), geometric mean diameter (7.29 mm), sphericity (74.39 %), coefficient of friction (0.26) and angle of repose (25.40°) and terminal velocity of 17.60 mm/s of the tiger nut seed at moisture content of 17 % (wb). Based on the properties of the seed, a cleaning and sorting machine was developed that cleans and sorts the crop into size groups 12, 8, and 6 mm diameter. The machine was evaluated using the brown type tiger nut. The results of the ANOVA indicate that the sorting differs significantly with the three sieve diameters. The analysis also shows that the machine performed better at 12 mm diameter sieve compared to the other two sieve diameters. The developed machine has a throughput capacity and cleaning efficiency of 1.1 kg/min and 94.7 % respectively as against the manual cleaning of 0.22 kg/min and 18.94 % respectively.

KEYWORDS: Cleaning and sorting, coefficient of friction, drudgery, sphericity, tiger nut seed.

1. INTRODUCTION

Tiger nut seed (*Cyperus esculantus*) produced by a grass like plant which is ranked among the oldest cultivated plants in Ancient Egypt. It is commonly known as Chufa in Spain, Attadwe in Burkina Faso and Zulu nuts in South Africa while in Nigeria, it is known as “Aya” in Hausa, “Ofio” in Yoruba, and “Akiausa” in Igbo. It is considered a monocot and usually found in three varieties; black, brown and yellow (Fernando, 2011). It does not require heavy rainfall or high humidity it only requires a rainfall of about 50 - 100 mm and with a temperature of about 22°C and relative humidity of about 50 %. It is usually planted during April and May and usually harvested in November or December.

Tiger nut is one of the cash crops which has not been given due recognition and patronage possibly because of lack of knowledge about its nutritional benefits. According to Mordi *et al.* (2010); Addy and Eleshola,(1984), it is a known plant food that is common in West Africa especially Northern Nigeria, where they are cultivated for snacks only and recently is used for kunu (a beverage drink). It is one of the best nutritional crops that can be used to augment the diet of humans (Afenu, 2008). Tiger nut has a fairly good essential amino acids composition similar to olive oil and castor seeds and is a potential oil crop for the production of bio-diesel. It is also used in medicine and perfume production. The yellow variety of tiger nut contains low fats and has less anti-nutritional factors especially polyphenols (Temple *et al.*, 1990; Devries and Feuker, 1999; Okafor *et al.*, 2003).

Despite the huge economic importance of tiger nut crop, its potentials are yet to be fully harnessed. This is because of lack of processing facilities where the crops are mostly produced. The sequence of post-harvest operations of tiger nuts by the manual method consists of washing, drying, sorting and bagging. Post-harvest processing is still manually done particularly the sorting which is the most tedious.

Though mechanical sorting of agricultural crop according to size, shape and colour has been reported (Pasikatan and Dowell, 2002; Hannah, 2011; Risse *et al.*, 1991; Blankenship and Woodall, 1997;

Suszkwi, 2001), these machines are expensive and sophisticated to the peasant tiger nut farmers. Hence, the need for the design, construction and evaluation of a vibrating table sorting machine for tiger nuts becomes paramount in reducing the drudgery of manual sorting by the peasant farmers.

The objective of this work was to develop a tigernut seeds cleaning and sorting machine.

2. MATERIALS AND METHODS

2.1 Design Consideration and Material Selection

The materials used for the construction of the machine were chosen on the basis of their availability, suitability, economy and viability in service among other considerations (ASAE, 2003; Gupta and Das, 1997; Sahay and Singh, 1994; Mohsenin, 1986; Khurmi and Gupta, 2007). Each component was designed following standard engineering principles (Birma, 2012).

2.2 Equipment description

The developed tiger nut sorting and cleaning machine (Fig. 1) basically consists of two major units (cleaning and sorting) which is operated by a 1hp electric motor. A blower was incorporated to facilitate easy and proper cleaning and separation of the nuts from foreign materials. As the tiger nut seeds are fed into the cleaning unit through the feeding hopper, air is blown by the fan which blows off lighter and damaged seeds, while the vibrating deck does the sorting according to sizes.

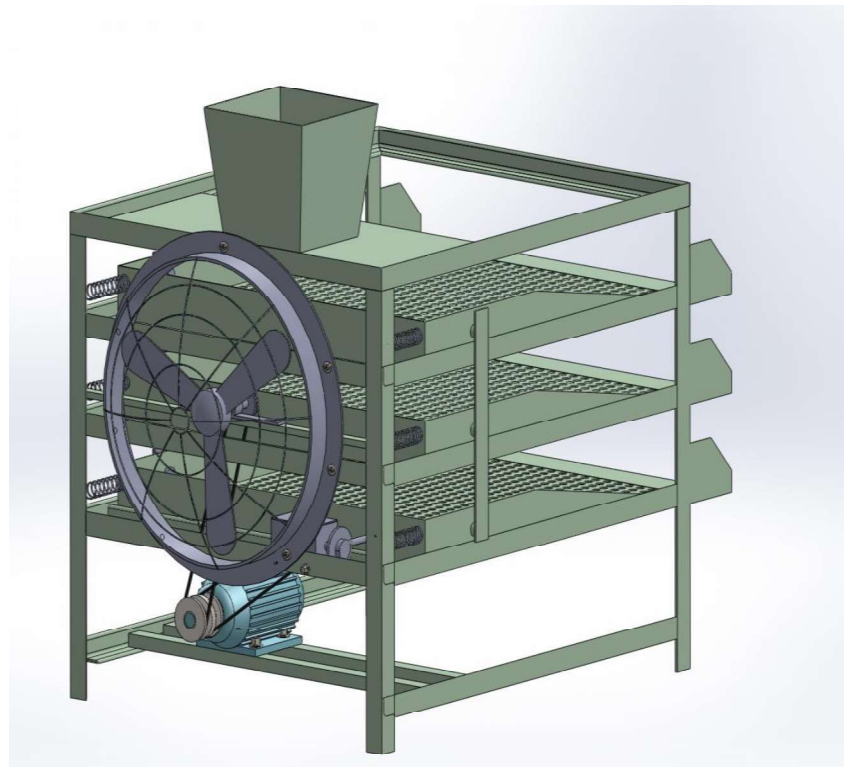


Fig. 1: The Tiger Nut Cleaning and Sorting Machine

2.3 Cam Design

The determining factors for a cam of minimum size are the maximum pressure angle, the least radius of curvature and the cam shaft diameter. The pressure angle was determined using equation 1 adopted from Rothbart (1962).

$$\tan \gamma = \frac{57.3V_{cf}h}{R_n\beta} \quad (1)$$

Where:

$\tan \gamma$ = tangent of pressure angle, in degrees; V_{cf} = velocity coefficient at any point, (mm/sec); h = total displacement of follower, (mm); R_n = Radius at the reference point on the pitch curve, (mm); β = angular displacement of cam for displacement h , (radians).

2.4 The Least Radius of Curvature

The least radius of curvature was determined from the expression given in equation (2).

$$\text{The least radius of curvature: } R_C = R_A \frac{\sin \Delta\theta}{\sin \alpha} \quad (2)$$

Where: R_A = Maximum radius of the pitch curve, (mm)

2.5 Cam Shaft Design

The diameter of the camshaft is governed by the maximum shear theory (Khurmi and Gupta, 2007) which was determined using equation 3.

The diameter of the camshaft.

$$d_c^3 = \frac{16T_e}{\pi T_{\max}} \quad (3)$$

Where: T_e = Equivalent twisting moment, (Nm); T_{\max} = Maximum Shear stress, (N/mm²)
Similarly, the cam velocity was determined using equation 4.

$$V_c = V_{cf}h\left(\frac{6N}{\beta}\right) \quad (4)$$

Where:

V_c = Cam velocity, mm/sec; V_{cf} = velocity coefficient at any point, (mm/sec); h = total displacement of follower, (mm); N = speed of camshaft (rpm); β = angular displacement of cam for displacement h , (radians)

2.6 Pulley Diameter

The ratio of the pulley for the electric motor to that of the cleaning shaft was calculated in equation 5 (Spott 1988).

$$N_1d_1 = N_2d_2 \quad (5)$$

Where: N_1 = Speed of the driving pulley, rpm; N_2 = Speed of the cleaning shaft, rpm; d_1 = Diameter of the driving pulley, mm; d_2 = Diameter of the driving pulley, mm

2.7 Tensions on Belts

The tensions on the belt were determined using Equations 6 and 7 as given by Khurmi and Gupta (2007).

$$\frac{T_1}{T_2} = e^{\mu\theta_1} \quad (6)$$

$$P = (T_1 - T_2)V \quad (7)$$

Where: T_1 = tension of belt on tight side in (N); T_2 = tension of belt on slack side (N); μ = mean coefficient of friction of tiger nut; θ_1 = angle of contact between motor pulley and belt in radian; v = velocity of belt m/s; P = power from electric motor.

2.8 Power Required to Operate the Machine

The power required to operate the machine was calculated using equation 8.

$$P_o = T_c \omega \quad (Nm) \quad (8)$$

Where:

P_o = Power in Kw, T_c = torque on camshaft (Nm), ω = angular speed of cam (rad/s).

2.9 Hopper Design

The volume of the hopper was determined using equation 9 (Tim, 2009).

$$V_{hp} = \frac{1}{3} (A_1 + A_2 + \sqrt{A_1 \cdot A_2}) h_p \quad (9)$$

Where:

V_{hp} = volume of hopper, m³, A_1 , A_2 = Areas of top and bottom base of the hopper m²,

h_p = depth of hopper, mm

2.10 Cleaning Unit Design

The housing diameter and blower width were determined using equations 10 and 11 (Sahay and Singh 1994).

$$D_{bh} = 1.5D_b \quad (10)$$

$$C_{bh} = 1.25W_{bh} + 0.1D_b \quad (11)$$

Where:

D_{bh} = diameter of blower housing in (m); D_b = diameter of the blade in (m);

C_{bh} = width of the blower housing in (m); W_{bh} = blade width in (m);

2.11 Blower Shaft Design

The diameter of the blower shaft (d_s) was determined using equation 12 (Khurmi and Gupta, 2007).

$$d_s = \left(\frac{16M_t}{2\pi S_s} \right)^{0.333} \quad (12)$$

Where: d_s = expected diameter of shaft (mm), M_t = total weight acting on the shaft (N),

S_s = permissible shear stress of shaft (mild steel) = 115×10^6 N/m²

The peripheral velocity of the belt (V_{pb}) was obtained using equation 13.

$$V_{pb} = \frac{\pi d_1 N_1}{60} \quad (13)$$

Where: V_{pb} = peripheral velocity of motor pulley in m/s, N_1 = speed of the blower pulley, d_1 = diameter of the pulley of motor (given by manufacturer = 0.15 m).

2.12 Belt Length

The belt length was determined using equation 14 (Khurmi and Gupta 2007).

$$L_{bt} = \frac{\pi}{2}(d_1 + d_2) + 2C + \left(\frac{d_1 - d_2}{4C}\right)^2 \quad (14)$$

Where: $C = 2d_1$ = center distance in (m);

d_1, d_2 = diameters of electric motor and blower pulley, mm.

2.13 Angle of Contact of Belt on Electric Motor Pulley

The angle of contact between the belt and electric motor pulley was determined using equation 15.

$$\theta_1 = 180 - \sin^{-1} \frac{d_1 - d_2}{2C} \quad (15)$$

$$\theta_2 = 180 + \sin^{-1} \frac{d_1 - d_2}{2C} \quad (16)$$

Where:

θ_1 = angle of contact between belt and motor pulley (degree), θ_2 = angle of contact between belt and machine pulley (degree), C = center distance between pulley (0.634 m), d_1 = diameter of driven pulley (0.15 m), d_2 = diameter of driving pulley (0.3m).

2.14 Blower Housing Design

The tangential velocity of centrifugal fan (V_{tc}) was determined using equation 17 (Sitkei 1986).

$$V_{tc} = \omega r \quad (17)$$

Where: $\omega = \frac{2\pi N}{60}$ = angular speed, (rad/s); r = radius of cylinder surface (m)

2.15 Sieve Selection

The basic factor taken into consideration in the design of the sieves is the diameter of the tiger nut seeds, using the three principal dimensions of tiger nut seed (12, 8 and 6 mm).

2.16 Performance Evaluation

The brown type tiger nut seeds, weighing 75 kg were obtained from a local market in Minna, Nigeria. The moisture content of the nuts was determined using the oven dry method (ASAE, 2003). The tiger nut seeds at 17 % moisture contents (wb) were divided into (5, 10, 15, 20 and 25 kg) and fed into the machine for cleaning and sorting. The quantity of the seeds collected at the ends of each of the sieve out lets (12; 8; 6 mm diameters) were recorded and the cleaning efficiency (%) and throughput capacity (kg/h) of the sieves were determined using the equations 18 and 19 (Donahue *et al.*, 1999).

$$\text{Cleaning efficiency (\%)} = \frac{S_1 \times 100}{S_1 + S_2} \quad (18)$$

Where: S_1 = total mass of clean and unclean nut (kg), T_m = time of cleaning (h), S_2 = mass of damaged seed, leaves etc. (kg),

$$\text{The throughput capacity (kg/h)} = \frac{S_1}{T_M} \quad (19)$$

The machine was tested based on the performance of the three sieves having 12, 8 and 6 mm diameters respectively.

3. RESULTS AND DISCUSSION

3.1 Physical and Aerodynamic Properties of the Tiger Nut Seed

The physical and aerodynamic properties of tiger nut seed are presented in Table 1.

Table 1: Physical and Aerodynamic Properties of tiger nut seed

S/No.	Properties	Value	
1	Mass of one piece of tiger nut seed (M)	4.3×10^{-4} , g	
2	Diameter of tiger nut	Major	9.01 mm
		Intermediate	6.80 mm
		Minor	5.26 mm
3	Density (ρ) of tiger nut seed	1.4×10^{-9} g/m ³	
4	Volume (V_m) of tiger nuts seed	0.6×10^{-6} mm	
5	Moisture content of tiger nut seed	17 % (wb)	
6	Coefficient of friction (μ)	0.26	
7	Angle of repose of tiger nut seed	25.4°	
8	Spherecity of tiger nut seed	74.39	
9	Surface area of tiger nut seed	206.12 mm	
10	Specific gravity of tiger nut seed	9.3 g	
11	Terminal velocity of tiger nut seed	17.60 mm/s ²	

The technical characteristics of the machine are presented in Table 2.

Table 2: Technical characteristics of the machine

S/No.	Technical characteristics	Values
1	Power required to operate machine	3,2 kW (electric motor of 5 hp \approx 3.73 kW)
2	Diameter of blower shaft	24 mm
3	Peripheral velocity of belt	1.89 m/s
4	Belt length	1.92 m
5	Sieve sizes	12, 8 and 6 mm
6	Angle of inclination of sieves	15°, 20° and 25°
7	Cam velocity	0.10243 m/s
8	Pressure angles	$\gamma_1 = 86.87$ $\gamma_{60} = 86.87$ $\gamma_{119} = 86.87$

9	Diameter of camshaft	20 mm
10	Centre distance	0.6 m
11	Cleaning efficiency, %	94.7 %
12	Machine throughput	1.1 kg/min.
13	Manual throughput	0.22 kg/min.

The results of the performance test are presented in Table 3.

Table 3: Results of the Performance Test

No. of test run	Input quantity (kg)	Output Quantity (kg)			Time (min.)
		Sieve 1	Sieve 2	Sieve 3	
1	5	2.4	1.6	0.8	2
2	10	6	2	1.6	4
3	15	8	4	2	6
4	20	10	6	4	8
5	25	14	8	2	10
6	30	20	4	6	14
7	35	24	6	4	18
8	40	20	10	8	26
9	45	18	20	6	40
10	50	24	20	4	46

The analysis of variance (ANOVA) at 5 % probability level is given in Table 4.

Table 4: Two-Way ANOVA of Sieve Sizes (1, 2, 3) against Input Quantity

Source of Variation	Degree of Freedom	Some of Square	Mean of Square	F Values	
				F _{Cal.}	F _{Table}
Input Quantity(kg)	2	612.04	306.021	12.34**	0.00
Time	9	597.7	66.411	2.68**	0.036
Error	18	446.41	24.801		
Total	29	1656.15			

**= highly significant at 5% level

3.2 Discussion of results

The three principle mean dimensions of tiger nut seed measured were 9.01, 6.80 and 5.26 mm for the major, intermediate and minor diameters respectively while the geometric mean diameter was 7.29 mm at the 17 % moisture content (w.b) which fall within the range given by Abano and Amoah (2011) for other grains and seed. The mean value of the sphericity of tiger nuts was found to be 74.39. This result shows that tiger nut seed are spherical and means it can roll freely (Baryeh, 2001). Also the average value of the surface area of tiger nut seed at that 17 % (wb) moisture was found to be 206.12 mm². This value is also close to that obtained by Baryeh (2001). The mean volume, density and the weight of 1000 tiger nut seeds were found to be 0.000006 m³, 1.4 x 10⁻⁹ kg/m³ and 429.63 g respectively (Table 2). It can also be observed that the mean values of the angle of repose of tiger nut seed for wood (20.5°), glass (17.5°) and

metal (14.4°) while the mean coefficient of friction for the three different materials used which were 0.37, 0.32 and 0.26 respectively. This conformed to the findings of Dutta *et al.* (1988); Joshi *et al.* (1993); Singh and Goswami, (1996); Baryeh (2001, 2002) that used similar technologies for other grains and seed. The terminal velocity of the tiger nut seed nut at 17 % moisture content (w.b) is 25.40° (Table 2). This result also agrees with that of Abano and Amoah (2011). These parameters are important in designing agricultural machinery. From Table 3 it can be seen that sieve one (12 mm diameter) performed better compared to the other two sieve diameters (8 and 6 mm diameters). The analysis of variance (ANOVA) (Table 4) shows that calculated $F_{Cal.}$ of 12.34 for 2 and 2.68 for 9 degrees of freedom is greater than $F_{Tab.}$ of 0.036 at same degree of freedom and at 5 % level of significance which means that the alternative hypothesis that there is a significant difference in the performance of the three sieves is accepted.

The cleaning efficiency obtained was 94.7% (Table 3). The capacity of the machine was 1.1kg/min as compared to manual capacity of 0.22kg/min.

4. CONCLUSION

The physical and aerodynamic properties of the brown type tiger nut seed which is spherical in shape including size, volume and density, surface area, specific gravity, weight, coefficient of friction, angle of repose and terminal velocity were determined at 17 % moisture content. The machine was evaluated using 75 kg of the brown type tiger nut at 17 % moisture content (wb). The throughput capacity of the machine and the manual operating rate of sorting tiger nut seeds were 1.1 kg/minutes and 0.22 kg/minutes respectively. The machine was found to have about 94.7 % sorting efficiency. The developed machine could reduce the drudgery associated in manual sorting and saves about 76 % operating time.

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