DEVELOPMENT AND PERFORMANCE EVALUATION OF A THREE ROLLERS ACHA (DIGITARIA EXILIS) DEHUSKING MACHINE

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Abstract
In this study, a three rollers Acha-dehusking machine was designed, constructed and tested. The machine has the following units - feeding, processing and separating unit. The materials used for the fabrication were selected locally based on the design considerations and design analysis of the machine components. The three rollers Acha-dehusking machine which cost ₦52 300 at the time of its fabrication was finally assembled and evaluated. The Acha paddy fed through the hopper was made to pass through two roll gaps between fixed and adjustable rollers rotating in opposite direction at a speed ratio of 1.5:1 where it was abraded and dehusked. The mixture of the dehusked grain and the husk were separated by current of air blown from the winnowing fan in the separating unit. The dehusked grains, husk and the undehusked grains were separated and weighed. From the outcome of the test, the efficiency and the output of the machine were found to be 69.6% and 22.14Kg/hr respectively.

Keywords: Acha grains, dehusking, three rollers, Adjustable mechanism.

1. Introduction
Acha (Digitaria Exilis) as it is popularly called in Nigeria is suggested to be the oldest and world’s fastest maturing cereal grains in west Africa, it’s use as cereal can be traced back to 14th century (Luka, 2009). Acha provides food early in the season when other crops are yet to mature for harvest (Ibrahim, 2001). After being sown, depending on the variety, Acha takes just 6 or 8 weeks to produce grains and 75 to 150 days to be matured for harvest (NTAP, 1996; Jideani, 1999). This crop fits into the low-input farming systems as it has unique ability to tolerate poor and marginal soils and can withstand the effect of drought (Aslafy, 2003). According to Vietameyer, et al. (1996), Acha grains are the tastiest and the most nutritious of all grains, although it contains 7% crude protein which is similar or slightly lower than that of other grains, Acha contains some essential amino acids like leucine (19.8%), methionine and cystine of about 7% and valine 5.8% which are vital to human health and are deficient in most major grains (Cruz, 2004; Temple et al., 1991). Acha digests easily and for it nutritional values, it is traditionally recommended for children, aged, women after delivery, people suffering from diabetes, stomach diseases and also as diet for weight lose (Cruz, 2004; Jideani, 1999). Acha forms the staple in some of the producing areas where it is processed in to various kinds of menus like porridge, couscous, bread to mention a few. Acha grains are extraordinarily tiny and oval in shape with 1000 grains weighing 0.4-0.6g (Aviara, et al. 2017, Cruz, 2004, Philip, 2011). Like rice, the grains are surrounded by an outer protective covering called husk. Acha grains with husk measured between 1.5 to 1.8 mm long and approximately 0.9 mm wide with specific gravity of 1.47 (Ballogou, et al. 2013). Husks are removed by dehusking to get whole white grains, and the husk constituted about 23% of the Acha’s weight (Cruz, et al. 2011). Despite the aforementioned benefits of the grains, its production as reported by Cruz (2004) remained low and the market price as compared to its counterparts remained high, these could all be attributed to the difficulties in cultivating and dehusking the grains owing to its tiny nature. Traditionally, the dehusking of Acha paddy is done in a mortar with the help of manually reciprocating pestle, and the separation of the chaff from the grain is done by washing with water, or winnowing (Luka, 2009). The traditional methods of Acha processing is tedious and time consuming as it takes 1 hour to dehusk 1-2 kg of raw Acha grains (Cruz, 2004). Attempts have been made to develop Acha-dehusking machine to reduce the drudgery involved in manual dehusking of the grains and to
encourage increase in productivity, quality and availability of the marketed product. In Nigeria these machines are few, scarce, costly and not simple enough to be within the technical capability of our local artisans (Bashiri et al., 2012). For example, Tokan et al. (2012) designed, fabricated and evaluated the performance of Acha-dehusking machine but the limitation of the machine is that it has high percent of broken grains and lower capacity (20Kg/hr) in addition to its complex drive system. To this end, this study was undertaken to remedy some of the deficiencies of the existing Acha-dehusking machine in term of efficiency, capacity, reduce cost and simplicity of construction in order to be within the technical capability of our artisans.

2. Materials and Methods
2.1 Machine Description
The designed Acha-dehusking machine shown in Figure 1, can be divided into three major units namely; feeding unit, dehusking unit and separating unit.

![Figure 1. Isometric and partial explosive views of the Acha dehusking machine](image)

2.1.1 The feeding unit
The feeding unit of the machine comprises the hopper and the processing unit top cover. The hopper and the cover are designed in a way that they can be detached from the processing unit and the Hopper can also be detached from the processing unit cover. Attached to the cover are two deflectors that convey and regulate the amount of Acha grains passing through the roll gap. The hopper, the processing unit cover and the deflectors were made from one of the most readily available and acceptable construction material that suit many design requirements, mild steel plate of 3mm, 5mm and 2mm thickness respectively.
2.1.2 The dehusking unit
The dehusking unit of the machine is the processing unit, it is box shaped to contain and support the three 250mm long processing rollers two of which are fixed and are held in position by bearings attached to the housing walls. The third roller was designed to be adjustable so as to regulate the roll gap between the fixed and the adjustable roller in order to suit variety of Acha and also to compensate for the softening and wearing of the rubbers. Each roller comprises of Ø25mm shaft, drums of 150mm external diameter and 3mm thickness, and 10mm thickness rubber wound around the drums to provide the compressive and frictional forces sufficient to strip the grains out of the surrounded husk. The adjustable mechanism comprises of four studs and nuts, two attached to opposite sides of the housing walls via the bearing support that hold the roller. The studs are so placed to hold the bearing housing containing the shaft and to allow sliding of the bearing along the studs. Compression springs are placed between the bearing support and the bearing housing through the studs to permit easy operation of the adjustable mechanism. The mechanism also comprises short pipes of 20mm outer diameter and 5mm thickness that extend from the bearing to the front of the processing unit, a flat bar of 25mm width and 5mm thickness was used to connect the pipes. The flat bar passes through the U-channel that is welded to the front of the processing unit at the centre to allow the rotation of a screw shaft that was used to control or regulate the gap between the adjustable roller and the fixed rollers. The material selected for the construction of the processing unit was mild steel except for the dehusking rubber which was Nitrile Butadiene Rubber (NBR) material for its good physical and mechanical properties such as thermal stability, acceptable hardness, and excellent adhesion to metals, good; compression set, resilience, bound and resistance to impact, abrasion, tear and chemical attack (Robinson rubber products, 2005).

2.1.3 The separating unit
The separating unit is attached to the machine support and comprises of the conveyor made from metal sheet of 2mm at an angle of 30° for easy flow of the grains and the belt driven winnowing fan made up of a shaft with three steel plates of 250mm by 70mm by 2mm welded along the length of the shaft at 120° apart. Attached to the support is the 1Hp electric motor that drives the dehusker.

2.1.4 The Machine Frame
The machine support is a skeletal frame made from angle iron to withstand the weight and lift the feeding and processing unit to a convenient height to avoid fatigue during operation.

2.2 Mode of operation
The machine was designed to be driven by an electric motor, as the machine is on; the roll gap is to be adjusted, the Acha grains are fed into the processing unit from the hopper through the deflectors. In the hopper, the grains move through the deflector to the roll gap between the first fixed rollers and the adjustable roller. The deflectors guide and allow certain amount of grains to pass through the roll gap at a time. The pressure and the relative velocity between the rollers provide the forces required to dehusk the grains. The dehusk grains and chaff proceed for another pass between the second fixed roller and the adjustable roller. The second pass was to dehusk the undehusk grains that must have survived the first pass and to polish the dehusk grains. After the second pass the grains fall to the conveyor during which air blown from the separating unit forces the chaff to flow out through an opening at the back of the machine. The polish grains are then collected at the front of the machine.
2.3 Design Consideration
The design analysis of the Acha-dehusking machine was done base on the following considerations: the size and weight of the husk and undehusk grains, strength and rigidity of the machine, use of locally available materials, compatibility, affordability, detachability, ease of construction, operation, maintenance and transportation to meet the need of local farmers and small scale industrialist.

2.4 Design Theory
The components of the three rollers Acha dehusker were design based on standard design principles and theories.

2.4.1 Hopper design
Hopper is a storage reservoir used for collecting and dispensing granular material through the help of gravity. The machine hopper was designed for a predetermined mass of 6Kg of Acha grains and the shape of the hopper chosen was that of truncated triangular prism to permit even distribution of the grains along the length of the rollers.

The hopper volume, $V_a$, to be occupied by 6Kg of Acha grains was calculated from the expression in equation (1);

$$V_a = \frac{m_a}{\rho_a}$$  \hspace{1cm} (1)

where: $V_a$ = Volume of Acha grains expected to fill $\frac{3}{4}$ of the hopper ($m^3$), $m_a$ = Mass of Acha grains that filled $\frac{3}{4}$ of the hopper ($Kg$), and $\rho_a$ = Density of Acha grains $Kg/m^3$.

From computation, the volume of the hopper $V_a= 0.0041958m^3$

A trapezoidal cross sectional shape hopper with side walls inclined at $30^\circ$ to the horizontal (which is slightly higher than the angle of repose of the grain) was considered to permit easy flow of the grains into the processing unit. Hence, the hopper parameters were obtained from the expression in equation (2) as given by Greer and Hancox, (1977);

$$V_a = \frac{1}{2} (A + B)H \times l$$  \hspace{1cm} (2)

Where: $A$ = Length of the base of the triangular prism (m), $B$ = Length of the truncated part of the prism (m), $H$= Height of the prism (m) and $l$ = Thickness of the prism (m).

From computations, the hopper dimensions were found to be $A = 0.244$m, $B = 0.020$m, $H = 0.150$m and $l = 0.250$m

2.4.2 Determination of Roller parameters
The processing unit comprises of three rollers that rotated in opposite direction with different angular velocity. According to the expression given by Tokan et al. (2012), the total forces acting on the roller shaft can be calculated using equation (3);

$$F = w_a + w_{rN} + w_d$$  \hspace{1cm} (3)

where: $F$ = Total force acting on the roller shaft (N), $w_a$ = Weight of Acha grains between two rollers (N), $w_{rN}$ = Weight of the rubber peg on the drum (N), and $w_d$ = Weight of the drum (N).
In (3), the weight of Acha grains between two drum is given by:
\[ w_a = M_{ar} \times g \]  
(4)
where: \( M_{ar} \) = Mass of Acha grains between two rollers (Kg), and \( g \) = Acceleration due to gravity (m/s²).

In (3), Weight of rubber acting on the roller shaft can be obtained from equation (5) as given by Tokan et al. (2012):
\[ (W_{RN}) = \rho_r \times V_r \times g \]  
(5)
where: \( \rho_r \) = Density of the rubber material (Kg/m³), and \( V_r \) = Volume of the rubber material (m³).

Also in (3), the weight of the drum can be determined from the expression given by Shigley and Mischke (2001):
\[ (W_d) = \rho_d \times V_d \times g + 2\pi \left( \frac{d_{po} - d_{pl}}{4} \right)^2 \times t \]  
(6)
where: \( \rho_d \) = Density of the drum material (Kg/m³), \( V_d \) = Volume of the drum material (m³), \( d_{po} \) = Outer diameter (m), \( d_{pl} \) = Inner diameter (m), and \( t \) = thickness of the cover plate (m).

From computations, the total forces action on the roller shaft was found to be \( F = 19.2591 \text{N} \).

### 2.4.3 Determination of power required to drive the rollers

The power required to drive the shafts considering the weight of peg, Acha grains and the drum was calculated from the following expressions as specified by Khurmi and Gupta (2005):
\[ P = T\omega \]  
(7)
where: \( P \) = Power required to drive the shafts (watts), \( T \) = torque (N/m), and \( \omega \) = angular velocity (\( \frac{rad}{s} \)).

\[ T = F \times \frac{(d_i - d_o)}{2} \]  
(8)
Where \( F \) = total forces acting on the shafts (N), \( d_i \) = Inner diameter of the roller (m), \( d_o \) = outer diameter of the roller (m).

The angular velocity was obtained from the expression;
\[ \omega = \frac{2\pi N}{60} \]  
(9)
where; \( N \) = the number of revolutions per minute (rpm).

From computations, the power required to drive the three roller was obtained as \( P = 100 \text{W} \).

### 2.4.4 Determination of the belt tension

The belt tension was obtained from the expression in equation (10);
\[ P = (T_1 - T_2)\nu \]  
(10)
where: \( T_1 \) = Tension on the tight side (N), \( T_2 \) = Tension on the slack sides of the belt (N), and \( \nu \) = linear velocity of the pulley (m/s).

The ratio of the tensions on the belt and the coefficient of friction between the belt and the pulley are related by the expression:
\[ \frac{T_1}{T_2} = e^{\mu \alpha \cos \beta} \]  
(11)
where: \( \mu \) = Coefficient of friction between the belt and pulley, \( \beta \) = groove angle (rad), and \( \alpha \) = angle of lap (rad).
Using equation (11), the tension on the slack and tight sides of the belt was calculated as 0.289N and 5.0N respectively.

The diameters of the fixed and adjustable roller pulleys for the speed ratio of 1.5:1 were calculated from equation (12).

\[ \frac{N_1}{N_2} = \frac{d_2}{d_1} \] (12)

For a fixed roller diameter of 0.1m the diameter of the adjustable roller was found to be 0.15m.

### 2.4.5 Determination of the belt length

The total nominal length \( L_t \), for the belt used was computed from the following expressions as given by Khurmi and Gupta (2005).

The nominal length \( L \) for an open belt between two pulleys can be obtained from the expression;

\[ L = 2C + \frac{\pi}{2}(D_2 + D_1) + \left[\frac{(D_2-D_1)^2}{4C}\right] \] (13)

where: \( L \) = Nominal length of the belt (m), \( C \) = centre distance between the pulleys (m), \( D_2 = Diameter \ of \ the \ driven \ pulleys \ (m) \), and \( D_1 = Diameter \ of \ the \ driving \ pulleys \ (m) \).

The angle of contact of the belt round a pulley for an open belt two pulleys system can be determined using the expression, as given by Shigley and Mischke (2001);

\[ \theta_{D_2,D_1} = (180 \pm 2 \sin^{-1} \left( \frac{D_2-D_1}{2C} \right)) \times \frac{\pi}{180} \ \text{rad} \] (14)

For cross belt two pulleys system the nominal length \( L \) (m) can be obtained from the expression;

\[ L = 2C + \frac{\pi}{2}(D_2 + D_1) + \left[\frac{(D_2+D_1)^2}{4C}\right] \] (15)

The angle of contact of belt around a pulley for a cross belt two pulleys system can be determined using the expression Shigley and Mischke (2001);

\[ \theta = (180 + 2 \sin^{-1} \left( \frac{D_2+D_1}{2C} \right)) \times \frac{\pi}{180} \ \text{rad} \] (16)

From computations through (13) to (16) the total belt length was determined as 2.552m and the correction factor of 1.10 for A-type belts length in the range 2400-2800mm was considered (Shigley and Mischke, 2001).

### 2.4.6 Determination of shaft diameter

The diameter of the roller shafts that can withstand the applied load was determined using the American society of Mechanical Engineers (ASME) codeas expressed in equation (17);

\[ d^3 = \frac{16}{\pi S_s} \times \sqrt{\left((M_bK_b)^2 + (M_tK_t)^2\right)} \] (17)

where: \( d \) = Diameter of the shaft (mm), \( S_s \) = Allowable stress for mild steel\((42 \times 10^6)(Nm^{-2})\), \( K_b \) = Combine shock and fatigue factor applied to bending Moment, \( M_b \) = Bending moment (Nm), \( K_t \) =
Combine shock and fatigue factor applied to torsion moment, \( M_t = \) Torsion moment (Nm). For rotary shafts, subjected to suddenly applied load; \( K_b = 1.5 \) to \( 2.0; \) \( K_t = 1.0 \) to \( 1.5. \)

The diameter of the shaft considering the maximum bending moment on the shaft due to the subjected load was found to be 20mm.

2.4.7 Determination of spring parameters

The springs used for the adjustable mechanism are compression helical springs and were selected based on the following standard theories;

The spring index was determined from the expression in equation (18);

\[
C = \frac{D_s}{d_s} \tag{18}
\]

where; \( C = \) Spring index, \( D_s = \) Spring helix diameter (m), and \( d_s = \) Spring wire diameter (m). From equation (18), \( C \) was calculated as 8

The shear stress, \( (\tau) \), at the inside fibre of the spring when the effect of curvature is neglected was specified by equation (19) as given by Shigley and Mischke (2001);

\[
\tau = \frac{8FDK_s}{\pi d^3} \tag{19}
\]

Where; \( \tau = \) Shear stress (N/m²), \( F = \) Force acting on the spring (N), and \( K_s = \) Shear stress augmentation factor and is defined as;

\[
K_s = \frac{2C+1}{2C} \tag{20}
\]

If the effect of curvature is considered as in the case of fatigue loading, \( K_s \) becomes

\[
K_s = \frac{4C+2}{4C+3} \text{(Bergstrasser factor)} \tag{21}
\]

From computations, the shear stress \( \tau \), was found to be \( 128 \times 10^3 \) N/m².

The deflection of the helical spring can be obtained from equation (22);

\[
\delta = \frac{8FD^3N}{d^4G} \tag{22}
\]

where; \( G = \) Modulus of rigidity of the spring material (MN/m³), \( N = \) Number of active coil.

The spring rate was obtained from the expression in equation (23);

\[
K = \frac{d^4G}{8D^3N} \tag{23}
\]

From calculations, the spring deflection and the spring deflection were found to be 3.51KNm and 10mm respectively.
2.4.8 Bearing selection for the rollers
Radial ball bearings was selected to serve as support for the roller shafts, and to permit easy transmission of power from the pulley to the roller, this type of bearing was selected owing to its compact size, ease of mount, ability to withstand momentary shocks, and good service reliability. Moreover, it requires low maintenance and no starting torque (Khurmi and Gupta, 2005).

The bearing was selected from the expression as given by Shigley and Mischke (2001);

$$ L = 60NL_H $$

Where \( L = \) Bearing life, \( N = \) Angular speed (rpm), and \( L_H = \) Working life (hrs).

According to Khurmi and Gupta (2005), the life of a ball bearing in hours used for agricultural machines use for short period or intermittently is between 4 000 to 8 000 hours. Base on this the average life of the bearing used was found to be 8 months.

2.4.9 Evaluation of machine efficiency and output
The efficiency and the output of the machine were computed from the expression in equation (25) and (26) respectively.

The efficiency of the machine was calculated from the expression;

$$ E = \frac{w_c - w_u}{w_c} \times 100 $$

where: \( E = \) Percentage efficiency of the machine, \( w_c = \) Weight of Acha collected after passing between the rollers, \( w_u = \) Weight of undehusk Acha grains.

The machine output was evaluated from the expression;

$$ \text{Output, } p = \frac{w_c}{t} \times 60 $$

where: \( t = \) Time to dehusk the Acha grain (minute).

2.5 Construction of the Machine
The components of the machine were constructed and assembled (as shown in figure 2) in the Department of Mechanical Engineering workshop, Ahmadu Bello University, Zaria, in accordance to the predetermined and designed calculated parameters.

2.6 Cost evaluation of the Machine
The total cost of constructing the machine was evaluated considering; the cost of consumable and non-consumable materials, overhead cost, machine and labour cost. At the end of the construction the overall cost of the machine was found to be ₦ 52, 300.

2.7 Performance Evaluation
The machine which was electrically powered by 1 Hp was ON, the adjustable roller was adjusted to obtain 1mm roll gap. 3Kg of Acha paddy was fed into the processing unit from the hopper through the deflectors. The deflectors delivered the Acha paddy to the first roll gap where it was dehusked by the combined action of the compressive force exerted by the rollers in the roll gap and the shear force resulting from the relative speed between rollers rotating in opposite direction at a speed ratio of 1.5:1. The dehusk Acha, the husk and some Acha paddy proceeded for the second pass through the second roll gap, after which the dehusked grains, the husk and the undehusked grains fall to the conveyor. The blower separated the husk from the mixture. The mixture was then collected. The
time taken to complete the process was taken and recorded using a stop watch. The collected mixture was separated (into dehusked grains, husk and undehusked grains) through successive winnowing, and were separately weighed using weighing balance. The test was repeated five times with 3kg of Acha paddy using the same procedure.

### 3. Results and Discussion

The results of the performance evaluation of the Acha-dehusking machine is summarized in Table 1.

<table>
<thead>
<tr>
<th>S/No</th>
<th>( W_f ) (Kg)</th>
<th>( W_c ) (Kg)</th>
<th>( W_d ) (Kg)</th>
<th>( W_u ) (Kg)</th>
<th>( t ) (min)</th>
<th>( E ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2.70</td>
<td>1.44</td>
<td>0.96</td>
<td>7.40</td>
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<td>1.50</td>
<td>0.81</td>
<td>7.10</td>
<td>69.43</td>
</tr>
<tr>
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<td>3</td>
<td>2.70</td>
<td>1.67</td>
<td>0.68</td>
<td>7.30</td>
<td>74.82</td>
</tr>
<tr>
<td>Average</td>
<td>3</td>
<td>2.68</td>
<td>1.54</td>
<td>0.82</td>
<td>7.26</td>
<td>69.55</td>
</tr>
</tbody>
</table>

*\( W_f \) = Mass of Acha paddy, \( W_r \) = Mass of Acha recovered, \( W_d \) = Mass of dehusked Acha, \( W_u \) = Mass of undehusked Acha, \( t \) = Time taken and \( E \) = Efficiency of the machine.

The results of the preliminary test showed that the machine has a dehusking efficiency of 69.55% at an output of 22.14Kg/hr, the percentage of broken grains from the dehusked grains was found to be 5%, this was achieved by sieving through 1mm mesh sieve and weighing. The high percentage of the undehusked Acha grains was due to construction and assembly error which include inaccurate parallelism of the rollers shaft axes, bulge at the lap joint of the Nitrile butadiene rubber around the drum, higher rate of feeding that lead some grains to fall to the collector without passing through the roll gaps. However, the result showed good promise for an efficient Acha-dehusking machine.

![Figure 2: The assembled Acha dehusker](image-url)
4. Conclusion
From the design analysis and performance results, the following conclusions can be made:
A simple, portable and low cost three rollers Acha-dehusking machine that can easily be operated and maintained was designed, constructed and tested for used by farmers of the grain. The performance evaluation results showed that the machine can dehusk 1Kg of Acha paddy in 2.41minutes at an efficiency of 69.55%.

References


