Design and Fabrication of a Micro-Scale Wet Process Soya-Bean De-Coating Machine

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Abstract
The processing of soya bean seed into several by-products such as soya-meal, flour, edible oil, confectionary, akara, moi-moi, dawadawa etc requires diverse processing sequence. While the soya conversion to edible oil and flour require toasted condition, the production of soya milk, confectionary, akara, moi moi, dawadawa etc require direct wet processing. The rural dwellers in Nigeria are more in tune to the soya wet processing sequence. The operations here are mostly manual, requiring much labour and time resulting in low productivity in processing. In order to mechanize this processing sequence to some extent, a wet soya bean de-coating machine was conceptualized, designed, fabricated and tested. In this machine, the wet soybean seeds are de-coated in between two padded rollers (dynamic and static rollers) that sandwiches an abrasive fabric material. The static roller has vertical and horizontal adjustment which helps to create a vertical angular displacement between its axis and the axis of the dynamic roller immediately above it. The machine was tested at several angular displacements of the rollers ranging from $5^\circ$ to $35^\circ$ with optimum angle being $20^\circ$. 5kg of wetted soya bean seeds of moisture content 65% in each case was used for the test runs. The results of the test runs were tabulated and analysis showed 90% de-coating efficiency. It is expected that this machine would help improve productivity soya bean wet processing. Its cost of N80, 000 ($516.16) also encourages development of Micro scale industries in Nigeria.

Keywords: soya bean, wet de-coating, angular displacement, rollers, fabric material.

INTRODUCTION
The Soybean or Soya bean (Glycine max, L) is a species of legume native to East Asia, widely grown for its edible bean which has numerous uses. Among the legumes it is classified as an oil-seed, is pre- eminent for its high protein content as well as its high oil content (Perkins, 1995). Soy varies in growth and habit with the height of plant varying from 20cm up to 2meters. The pods, stems and leaves are covered with fine brown or gray hairs. The fruit is a hairy pod that grows in clusters of 3-5; each pod is 3-8cm long and usually contains 2-4 seeds, 5-11mm in diameter. Soy beans occurs in various sizes and in many hull or seed coat colours including black, brown, blue, yellow, green and mottled. The hull of the mature bean is hard, water resistant and protects the cotyledon and hypocotyls (or “germ”) from damage (Blackman et al., 1992). Cultivation is successful in climates with hot summers with optimum growing conditions in mean temperatures of 20 to 30 °C (68 to 86 °F). Temperatures below 20 °C and over 40 °C retard growth significantly.

They grow in a wide range of soils with optimum growth in moist alluvial soils with a good organic content (EBO, 2008). Approximately 85% of the world’s soybean crop is processed into soybean meal and vegetable oil. In China, Japan and Korea, the bean products made from the bean are a popular part of the diet (soyatech.com, 2010). Soybean first arrived in Africa in Egypt in 1857 and was introduced as early as 1908 in Nigeria but its cultivation as a crop began in 1937 with the introduction of the Malayan variety (SIC, 2009). Industrial and domestic processing of the crop locally has given rise to numerous products utilized for both human and animal consumption. Some of these products include; Soya bean meal (a protein supplement in poultry, hog and cattle feed); Soya bean oil (refined to produce paints, varnishes, soap and sealant and in pharmaceuticals); in vegetarian cooking and others such as soy-milk, soy-akara, soy-moi-moi, dawada and soy-ogi all local delicacies. Processing of soya beans to oil employs both the mechanical system of presses and expellers and the chemical system of solvent extraction. The solvent extraction is known to be more effective vis-a-viz the oil recovery rate (RMRDC, 2004).

Physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning,
sorting and drying. The solutions to problems of these processes involve knowledge of the physical and engineering properties (Irtwange, 2000). Various works have been carried out by researchers on physical and engineering properties of agricultural materials. Some of these include, Baryeh, E. A. (2000) for Bambara groundnut; Olajide and Igbeke, (2003) for groundnut kernel; Amin et al., (2004) for lentil seed; Coskun et al., (2005) for sweet corn; Akaiomo and Raji (2006) for Prosopis Africana seed; Aviara et al., (2007) for guna seeds.

For soybean, the physical properties such as length, width, arithmetic and geometric mean diameters, porosity, sphericity, true and bulk densities and angle of internal friction were investigated by Deshpande et al., (1993) and further by H. Kibar and T. Öztürk (2008) while Tavakoli et al., (2009) reported the moisture dependence of some engineering properties of soybean grains. In 2004, the Raw Materials Research and Development Council (RMRDC) in Nigeria carried out a survey on agricultural raw materials with emphasis on soybean. Its cultivation, processing and various uses were reported with a list of available local process equipment given in its appendix. However from the foregoing it was observed that very little abound in literature on equipment that can de-coat and separate the soybean seeds when wet. This work intends to design, fabricate and evaluate a machine for de-coating wet soybean; providing information that would improve the productivity of soybean processing in Nigeria.

**Detailed Description of the Designed Wet Soya Bean De-Coating Machine**

The schematic drawing of the wet soya bean de-coating machine is shown in figs 7 and 8. The machine consist of the following components: Structural frame, Metal casing, Inlet hopper, De-coating abrasive fabric, Dynamic roller, Adjustable (static) roller, Exit hopper (delivery chute), Plastic pad, Wooden casing, Dynamic roller shaft, Static roller shaft, Tensioning spindles, Adjusting screw spindle, Ball bearings, Electric motor, Electric motor sitting, Adapter, Washers, Pins, Screws, Rivets, Bolts and nuts

The dynamic roller is suspended on two ball bearings. The dynamic roller is padded with abrasive fabric. The circumference of this roller is provided with four ridges equidistantly located at 90° to one another. The shaft of the dynamic roller is directly connected to the electric motor shaft via an adapter. The static (adjustable roller) is mounted immediately below the dynamic roller. This roller has both horizontal and vertical adjusting mechanism. The static roller is equally padded with abrasive fabric. The diameter of the dynamic roller is twice that of the static roller. They are connected in such a manner that the pads press on one another. An abrasive fabric material connected to the inlet hopper runs in between the padded rollers to four tensioning spindles. At the point of contact between the rollers and the abrasive fabric, a plastic plate is sited. The plastic plate is connected to the exit hopper (chute). Because of the adjusting mechanism of the static roller, there is a concave formation of the abrasive fabric very close to the point of contact of the roller and the fabric. All these arrangement are housed by the wooden casing. The outside surfaces of the wooden casing are cladded with thin stainless steel sheets to give good esthetics. The stainless sheets are riveted to the wooden casing. This systematic arrangement of components including the casing is carried on a suitable angle channel framework.

**Principle of Operation**

The machine works on rolling principle. The electric motor provides the primary motion that drives the dynamic roller. This roller rotates in anticlockwise direction towards the concave formation of the abrasive fabric connected to the inlet hopper. This fabric material provides the incline that directs the wetted soya bean seeds to the contact point between the padded rollers. The wetted soya bean seeds introduced through the inlet hopper role down the incline to the concave formation where they are acted upon by the dynamic roller. The ridges on the dynamic roller forces the wetted seeds in-between the contact point of both rollers; the abrasive fabric and the plastic plate. The rollers are padded in order to prevent crushing of the soya seeds. The plastic plate acts as a pivot or seat for the seeds during de-coating operation and equally directs both peeled coats and the cotyledon (mix) to the hopper (chute).

Motion is imparted on the wetted soya bean seeds that collect at the concave formation of the fabric by the dynamic roller thereby causing them to rub against themselves, the roller pad and the abrasive fabric material. Peeling of the coats is initiated at this point and completed while rolling along plastic plate equally mounted very close to this point. For effective de-coating to be achieved, the critical gap requirement between the adjustable (static) and dynamic roller must be set. This is normally arrived at through trial runs. Also it is advised that the raw soya bean seeds be soaked in water for upward of 36hrs in order to raise its moisture content to between 65 - 70%. Both the peeled coats and the cotyledon (mix) move through the surface of the plastic plate to the chute and empty into a receiver containing reasonable quantity of water. Because the coats are light, they float on the surface while the cotyledons sink to the bottom of the receiver. The coats are then separated by decantation intermittently. The casing of this machine is adapted in such a way that it can easily be removed for settings and adjustments to be
made and also for easy maintenance and cleaning after the day’s work.

LIMITATIONS OF STUDY
The machine was designed to operate at a maximum rate of 21kg/hr and has an overall length of 0.65m, a width of 0.6m and a height of 1.3m. The dimensions of the wooden casing are length of 0.5m, width of 0.42m and height of 0.41m. The static and dynamic rollers had dimensions of 0.1m and 0.05m in diameter respectively with both having equal lengths of 0.405m. This machine is suited for micro scale processing industry in rural setting.

ADVANTAGES
1. The machine is portable and does not occupy much space
2. The output in de-coating per hour of the machine is by far higher than manual output of several persons put together.
3. The machine is simple to operate and requires only one operator
4. Materials of construction for the machine are all locally sourced.
5. Power requirement for the operation of the machine is very low. The machine can be run on single or three phase motor (1-2hp)
6. This machine can be used to de-coat other wet seeds e.g. beans, bambara nut etc.
7. The production cost of the machine is within the reach of the rural dwellers and micro processing industry in Nigeria.

OBJECTIVE
The objective of the design is to mechanize the wet process of de-coating soya bean. It is also intended to stimulate the growth of micro-processing industries by increasing productivity in wet de-coating.

Beneficiaries
The beneficiaries of this design are as follows
i. Rural dwellers
ii. Food processing industry
iii. Micro, small and medium processing industries
iv. Pharmaceutical industry
v. Chemical manufacturing industry e.g. for manufacture of paints, resin, varnish etc.

Mechanics of Operation of the Wet Soya Bean De-Coating Machine
The mechanics of operation of this machine is based on three principles namely
- The gravitational dropping of the wet soya bean seeds to the dynamic roller
- The rotational mechanics of the ridged dynamic roller and
- The rolling friction principle as a result of movement of the seeds through the contact points of the rollers and plastic plate.

The dropping of the wet soya bean seeds from the hopper to the dynamic roller is propelled by gravitational force \( f_g \) which is given as
\[
F = mg
\]
Where; \( m \) = mass of wet soya bean \( g \) = acceleration due to gravity (Ryder and Bennet, 1982)

Rotational Motion and Centrifugal Force \( F_c \):
The rotational motion from the shaft of the prime mover (electric motor shaft) is transmitted to the dynamic roller. For any object of mass \( M \) moving in a circular motion, its acceleration is directed towards the centre of the body and its linear velocity is tangential to the radius of the object. The displacement which starts from point A, then to B and continues is in terms of \( \theta \). The angular velocity is designated \( \omega \). The acceleration \( a \) of the rotary body is given as
\[
a = \omega^2 r.
\]
(John Hannah & R. C Stephens 1984)

Rotational Torque \( T \)
The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation (John Hannah and Stephens R.C, 1984)
\[
T = F_c \times r
\]
(John Hannah and Stephens R.C, 1984)

If a body rotates at the end of an arm, this force is provided by the tension on the arm, the reaction to this force acts at the centre of rotation and is centrifugal force. It represents the inertia of the body resisting the change in the direction of motion. A common concept of centrifugal force in engineering problems is to regard it as radially outward force which must be applied to a body to convert the dynamical condition to the equivalent static condition.

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\[
T = F_c \times r
\]
(John Hannah and Stephens R.C, 1984)

Work done by a Torque
If a constant torque \( T \) moves through an angle \( \theta \)
Rolling Friction Analysis
Analysis of forces on the soya bean when rolled up the incline of the plastic pad (plate):
In the process of de-coating, the wetted soya bean seeds are rolled up the incline of the plastic plate. The forces acting on the seed are illustrated in a sketch below.

\[ F_p - F_{fr} - F_{gx} = 0 \]  
\[ F_p = mg \sin \theta - \mu mg \cos \theta = 0 \]  
\[ F_p = mg \sin \theta + \mu mg \cos \theta \]

The analysis shows that when the wet soya bean is rolled up in the incline \( \theta \), it is pulled down by the partial weight force and the force of friction as shown above.
Where \( F_p \) = propelling force up the incline
\( F_{fr} \) = Frictional Force
\( F_{gx} \) = weight of the soya seed resolved in the direction of motion.

Quantifying Rolling Resistance
To quantify rolling resistance, the idea of resistance in industrial wheels is applied. The coefficient of rolling friction is a number that has been empirically determined for different materials and can vary by the speed of the wheel, the load on the wheel and the material the wheel is contacting.
The formulation;
\[ R = \mu \times \frac{\omega}{R} \]

is used to calculate the force that will overcome rolling friction
\( F \) = the force required to overcome the rolling friction
\( \mu' \) = the coefficient of rolling friction (unit must match the same unit as radius)
\( \omega \) = load on the wheel
\( R \) = radius of the wheel

Applying this equation to rolling the wetted soya bean seeds up the incline \( \theta \), then
\( \mu' \) = coefficient of friction between soya bean and fabric material
\( \omega \) = load = weight of the roller on wet soya bean
\( R \) = radius of roller
Note that \( F = F_p \)

Dynamic Roller Shaft Design
The schematic representation of the dynamic roller shaft with force acting on it is shown below.

This translates to a middle point load as shown on the sketch below.

The shaft diameter is calculated using ASME code for shafting. The ASME standard equation for shafting is a stated below
\[ D = \left( \frac{5.1}{T_f} \left( \frac{C_m \times M_{max}}{T} \right)^2 + \frac{(C_f \times T)^2}{T} \right) \]

For ASME code standard
\[ \tau_d = 0.3 \sigma_u \]  
\[ \sigma_u = 0.18 \sigma_{ul} \]

Where \( D \) = shaft diameter
\( \sigma_u \) = Ultimate stress of shaft material
\( \tau_d \) = allowable stress
\( \sigma_{ul} \) = yield stress of shaft material
\( C_m \) = bending moment factor
\( C_f \) = Torque Factor
\( M_{max} \) = maximum bending moment
\( T \) = rotational torque

Material used for shafting is stainless steel AISI 304.
Bearing Selection

The equations stipulated by Shigley and Mtscape (1961) were used to quantify bearing load and life in million revolutions

\[ P_b = X \frac{C_f}{F_r} + Y \frac{C_f}{F_a} \]

\[ L_{10} = \left( \frac{C_f}{P_b} \right)^{\frac{3}{X}} \]

Where \( P_b \) = bearing load
\( F_r \) = radial load
\( F_a \) = axial load
\( X \) = radial load factor
\( Y \) = axial load factor
\( C \) = Basic Load rating
\( V \) = inner rotation factor
\( L_{10} \) = bearing life in million revolutions

SKF bearing catalogue was used for selecting the basic load rating (c) and bearing numbers.

Determination of Optimal Angular Setting of the Dynamic and Static Rollers

Seven angular settings of the dynamic and static rollers were used for test running of the machine. The angles range from 5° to 35°. 5kg of wet soya bean seeds of moisture content 65% were used in each test run. This was repeated twice and average values of the test runs were tabulated below.

Table 1: Angular settings of the dynamic and static rollers and effects on wet soya bean de-coating.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Angle θ</th>
<th>% de-coated whole</th>
<th>% un-de-coated</th>
<th>% de-coated but broken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>40</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>55</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>68</td>
<td>18</td>
<td>14</td>
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<tr>
<td>4</td>
<td>20</td>
<td>70</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
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<td>20</td>
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<td>6</td>
<td>30</td>
<td>59</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>53</td>
<td>30</td>
<td>17</td>
</tr>
</tbody>
</table>

(Source: Agulanna and Oriaku, 2010)

Fig 4: Plot of Angular Settings versus Percentage De-coated.

(Source: Agulanna and Oriaku, 2010)

The plot above shows that percentage de-coating (whole) increased with increasing angular setting from 5° to 20° to a maximum value of 70%. After this point, percentage de-coating began to decrease gradually until the final angular setting of 35° to a value of 53%. The relationship between percentage de-coated (whole) and angular setting was best described by a quadratic equation shown below

\[ Y = 21.71 + 4.39x - 0.1019x^2 \]

\( R^2 = 0.801 \)

Fig 5: Plot of Angular Settings versus Percentage Undecoated.

(Source: Agulanna and Oriaku, 2010)

The plot above gives a similar trend to that of fig 4 but in a reverse sense. It shows angular setting of 20° as having the least unde-coated percentage of wet soya bean of 10%. It also shows decrease in percentage unde-coated from initial (5°) to 20° and then increase from this point till the 35° angular setting. The quadratic equation shown below best described the relationship between angular setting and percentage unde-coated for the range of values selected for wet soya bean samples.

\[ Y = 53.4286 - 3.7286x + 0.0886x^2 \]

\( R^2 = 0.855 \)

Fig 6: Plot of Angular Settings versus Percentage De-coated but broken.

(Source: Agulanna and Oriaku, 2010)
Fig 6 above shows that the percentage of wet soya bean de-coated but broken was the same for angular settings 20° and 25°. It also shows that the smallest angular setting (5°) produced the highest amount (25%) of broken seeds. Though 15° had the least de-coated but broken seeds, its percentage de-coating was lesser than that of 20°.

**Estimated Cost of Machine**

<table>
<thead>
<tr>
<th>Description</th>
<th>Naira Value</th>
<th>Dollar($) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing/ components (wood, cladding, rivets etc)</td>
<td>20,000</td>
<td>129.03</td>
</tr>
<tr>
<td>Structural Stand</td>
<td>8,000</td>
<td>51.61</td>
</tr>
<tr>
<td>De-coating components (shafts, spindles, fabric material etc)</td>
<td>25,000</td>
<td>161.29</td>
</tr>
<tr>
<td>Electric motor (single phase, 1hp)</td>
<td>15,000</td>
<td>96.77</td>
</tr>
<tr>
<td>Labour/ overhead</td>
<td>12,000</td>
<td>77.42</td>
</tr>
<tr>
<td>Total</td>
<td>80,000</td>
<td>516.12</td>
</tr>
</tbody>
</table>

**CONCLUSION**

- The angular setting of the two rollers that produced the optimum de-coating from the experiments run with wet soya bean de-coating machine is 20°.
- This achieved 70% de-coated whole and 20% de-coated but broken, thereby resulting in 90% de-coating (90% efficiency) put together.
- This machine processes 21kg of soya bean in 1 hour; this is estimated to be equal to 3 skilled workers working manually for the same quantity of material.

The data obtained from the experimentation can assist in scaling up through modeling.
REFERENCES


