Design of a Motorized Dehulling and Centrifugal Cleaning Machine for Locust Beans

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Abstract - A Motorized Dehulling and Centrifugal Cleaning Machine for Locust Beans was designed in this study. The inlet into the dehulling chamber is a hopper made with mild steel. The dehulling chamber consists of an auger shaft and abrasive barrel which leads directly to a vertically positioned hollow cylinder that serves as the cleaning unit. This cylinder houses paddles that rotate to initiate centrifugation in the cylinder so as to both wash the seeds and separate them from their coats by floatation made possible by density differences. Boiling time and moisture content of locust beans influenced the efficiency of the machine. Mechanizing the post-harvest processing of locust bean will reduce drudgery associated with its processing, improve the quality, shelf life, acceptability of condiment and other end products from locust beans, and enhance the rural economy.

Keywords: Locust Beans, Dehulling, Cleaning, Centrifugation.

I. INTRODUCTION

The African locust beans tree is a perennial tree native to Tropical Africa. It is usually found in Savannah woodlands, bush fallows and wooded farmlands. It is also found in Tropical forests with high and well distributed rainfall and in arid zones. While the seeds are sometimes planted by farmers, its seeds are also usually propagated by wind and animals and then harvested for its pod that contains both sweet pulp and valuable seeds. The tree exhibits a dense, widely spreading umbrella-shaped crown and a barrel-like trunk that reaches up to 130cm in diameter.

The fruit is a slightly curved indehiscent pod that becomes brown and crooked at maturity. The mature pods of the bean are gotten in large bunches. These Pods hang in clusters by a club-shaped fruit base, and are dry and brown in colour when ripe. Each pod may vary between 12 and 30 cm in length and 12 and 25 mm in breadth. The pod is tough and fibrous, enclosing a soft, powdery, yellowish pulp in which small seeds are embedded. Each pod contains up to 20 seeds, which vary in shape. Some are oval while others are nearly spherical (Seed Information Database, 2006). The seeds are brown-blackish in colour, each having a 0.5 - 1 cm funicle. The testa is hard, smooth and glossy and can remain viable for 8 years.

The yellow pulp which contains the seeds is naturally sweet and is processed into a valuable carbohydrate food known as Dawadawa among the Hausa and Akamu among the Yoruba and Igbo people of Nigeria. However the most valuable parts of the locust bean, and possibly the entire tree, are the seeds themselves which are used popularly as food condiment in Africa. The seed is first cooked and dehulled to remove the seed coat and then fermented to produce the desired condiment. Local research has proved that locust beans help to promote good sight and guard against hypertension and other diseases such as diabetes, diarrhea and stroke.

Due to the inherent danger in the use of inorganic and processed food items and seasonings, nutritionists are advising on adopting organic alternatives in foods and seasonings. There are various health benefits that can be derived from locust bean. It contains nutrients such as protein which builds and repairs body tissues, and carbohydrate which is a source of energy for the body.

Locust beans also help to reinvigorate the brain, kidney, heart, muscles and the nervous system. On statistical basis, the locust beans seed contains 39-40% protein, 30-40% Oil, 11.7-15.4% carbohydrate, 15-20% fats, and 4% minerals. (Campbell-Platt, 1980).

Other than the nutritional benefits, the tree has several important uses namely; nitrogen fixation which enhances soil stability, nutrient cycling and provision of shade. The leaves, hull, and pods can be processed into livestock feed and local herbs or concoction. The industrial use includes manufacture of soap and production of grit board.

The Processing of agricultural crops includes post-harvest activities that maintains, raises the quality or changes the form or characteristics of crops into marketable products. Most agricultural crops such as locust beans can be utilized raw in many ways but their best attributes are gotten when processed.

The popular method of processing African locust bean in Nigeria is manual or traditional. The processes involved in processing the locust beans are quite detailed and procedural. These processes are highlighted below.
a) Sorting

This is the process whereby the undeveloped locust beans are separated, washed and arranged for further processing. The seeds of the locust bean are embedded in a yellowish and pulpy material which must be separated from the yellowish pulpy material before it can be further processed into fermented locust bean (food condiment). This separation is done locally by either drying the pulp in which the seeds are embedded then pounding to separate the seeds from the yellowish pulp, or done by washing it in water to remove the yellowish pulp from the seeds.

b) Boiling

This is the process whereby the beans are boiled or steamed. Large pots placed on burning firewood are used locally while the use of pressure pots is being introduced industrially. Locust bean seed has a very hard, water-impermeable testa and therefore prolonged cooking is necessary during processing to soften the seed coat prior to de-hulling. Pre-soaking for up to 12 hours and cooking for 1 to 2 hours in a pressure cooker is often required to soften the seeds depending on the quantity to be processed at once.

c) Dehulling

This is the removal of the pericarp of the beans. Dehulling occurs when firmly attached seeds coats which has been softened during cooking is removed for fermentation process. This unit operation is traditionally carried out either by action of abrasion of the cooked locust bean seeds and sea sand using hand or feet, or using of mortar and pestle to dehull.

d) Separation

This is a step introduced in the processing stage as a consolidation of the dehulling process. After the seeds have been dehulled, they are cleaned majorly with water so that the dirt, leftover and loose attaching hulls of the beans can be cleaned off. It is usually done to ensure that maximum dehulling is achieved.

e) Re-boiling

This is the process whereby the dehulled beans are boiled again prior to fermentation. Re-boiling aids further softening and warmth of the beans for ease of fermentation.

f) Fermentation

Fermentation is carried out traditionally by pouring the beans while still hot into a calabash lined with banana leaves and covered airtight with another calabash then placed in a warm place for 72 hours to ferment. The organisms responsible for the fermentation of locust beans are Bacillus, Kurthia, Staphylococcus, Listeria and Micrococcus. Bacillus spp however constitutes the bulk of organisms required for the fermentation of the seeds. (Achi 2005).

II. LITERATURE REVIEW

Several research works has been made on the development of a suitable and effective system for the processing of Locust bean; Ajayi (1991) developed a sheller for locust bean. The sheller incorporated a polisher with an abrasive surface coupled with a blower for the separation of the clean seed, the pulp and other particles. The sheller had a capacity of 9.52 kg/hr of polished and clean seeds. The machine featured a shelling efficiency of 100% at a speed of 900 rpm. It was provided with a screen separation unit and an axial fan. It also incorporated a polisher with an abrasive surface below the threshing chamber screen. However, the sheller could only work as a thrasher for non-wet seeds: For condiment purposes, seeds need to be boiled and relatively soft prior to hull removal so that subsequent processing methods can be achieved with ease.

Adewunmi and Olalusi (1995) developed a manually operated concave type locust bean dehuller. The components of the machine included hopper welded to the outer drum, drums, spur gear, crank and tray. The machine was tilted from upper base towards lower base at an angle of 300 to horizontal. The outer drum had a diameter and length of 190 mm and 450 mm respectively that houses the roller and supports the concave. The concave had a length of 240 mm that was divided into three gates (80 mm spacing). The machine was driven manually with aid of a crank. Result obtained showed that dehulling efficiency increased with speed for all concave clearance and dehulling length because the sheer force increased with increasing speed. A maximum efficiency of hulling of 70.9 % was achieved for a dehulling length of 240 mm, concave clearance of 8 mm and peripheral speed of 300 rpm. The design was labour intensive as it required human power to turn the crank that turned the dehulling shaft. Efficiency of dehulling was also very low due to the drudgery attached to the usage of the machine.

Okunola et al (2019) developed a wet locust bean seeds dehulling and washing machine that incorporated a dehulling shaft that had rods arranged concentrically to break seed coat and radial fan - like blades used as stirrer. Upon completion of fabrication, tests were carried out to determine the optimum operating conditions at which maximum efficiency could be obtained.

A preliminary test was conducted at operating speed of 125 rev/min using locust beans in pulpy media and a 2 Hp petrol engine as power source. Five samples (2.2 kg each) were
weighed to test the machine. The weight of washed seeds, weight of unwashed seed, weight of the materials at each outlet, time taken to feed the materials and time taken to discharge were collated for analysis and determination of the performance parameters. The result of the test showed that; moisture content of locust beans increased with steaming time; Dehulling efficiency of the machine increased with respect to increasing moisture content of the locust beans; The throughput of the machine was found to be inversely proportional to the moisture contents of the locust bean seeds. Highest throughput (0.58 kg/min) was obtained at the lowest moisture content (9.3%). Conversely, lowest throughput (0.05 kg/min) was obtained at the highest moisture content (106.6%). However, the machine was limited majorly by its physical attributes; the moving parts of the machine were not well enclosed and this could lead to serious injury of operators. There was also no adequate provision for collecting cleaned seeds from the separating column of the machine.

In all these designs, there existed some significant inefficiency in seed-hull separation coupled with unsatisfactory throughput capacities. Little or no significance was also attached to the hulls surrounding the seeds which could still be collected and further processed into nutritious food items for livestock. It is therefore imperative to develop a suitable alternative that will take into account the listed shortcomings and provide a more efficient Locust beans dehulling and separation system.

III. PROBLEM DEFINITION

The processing and production of locust beans in large proportions have always been challenging. An underlying cause is the actual method of processing the locust beans seeds into finished products suitable as condiments, food seasoning and other end product. The currently most prevailing method of processing at the moment is the traditional method. This method is largely inefficient owing to its apparent limitations. These limitations are brought about by poor and obsolete processing practices coupled with the use of rudimentary and inefficient production tools that result in significant seeds degradation, wastage and consequential lengthy production period.

Modern processing techniques are therefore required to improve on the traditional methods of processing and fermentation of the seeds. Mechanizing post-harvest processing of locust bean will reduce drudgery associated with its processing, improve the quality and acceptability of condiment, improve the shelf life of the condiment and enhance the rural economy.

IV. METHODOLOGY

The primary material which formed the basis of this design is the locust beans seeds. The seeds were sourced from the nearest raw locust bean market.

Galvanized steel was used for the cubing and drying compartment; produced by coating steel in zinc, the properties of galvanized steel are a unique combination that make it ideal for use in interior and exterior applications; it is corrosion resistant, formable, and durable. Angular mild steel was used for the frame of the whole machine as it offers rigidity, stability and durability.

Water was also an essential material. It served as the transporting medium for the locust beans as they were being moved from point to point in the machine.

a) Design Considerations

The factors that were considered in the fabrication of the system includes: the cost of materials, fabrication technique, materials availability, durability of materials, cost of maintenance and effect of materials used on food integrity.

b) Dehulling Unit

The dehuller consists of a hopper and a horizontally positioned barrel that houses the dehulling shaft. The dehulling shaft is a mild steel rotating auger with mild steel coils wound about the perimeter with a gap of 6.5 mm clearance between the coils and the gritty wall of the dehulling chamber. Cooked locust beans are fed into the machine through the hopper. The dehulling shaft through its rotation induces a useful frictional force by impacting a rubbing action on the beans against the walls of the dehulling chamber. Prior to dehulling, the locust beans are lightly cooked preferably in a pressure pot for about 1 to 2 hours based on specified quantity. Overcooked beans tend to be very soft and the impact force can be overwhelming as to exceed the compressive force on the seeds, and eventually lead to crushing of the seeds to be dehulled. Through an exit lid, the dehulled beans are transported further into the cleaning cylinder where further cleaning of the beans takes place.

c) Cleaning Unit

The cleaning unit is a vertically positioned hollow cylinder where beans that have passed through the dehulling unit are further cleaned to remove residue hulls from the beans. The cylinder houses a rotating shaft with attached paddles that stirs the beans as it is been fed into the cylinder. The cylinder is filled with water and a centrifugal pump attached overhead is activated to create turbulence in the medium. The resulting whirlpool generates a centrifugal force which in turn effects a
centrifugal separation of bean and hull. The lighter hulls move upward and are collected at the overflow while the heavier beans are displaced downward and are collected at the underflow.

Figure 1: Orthographic and Isometric views of the Dehulling unit

Figure 2: Overview of the Cleaning chamber
d) Design Analysis of Component Parts

**Hopper** - Four steel sheets inclined at 74° to the horizontal
- Diameter: 300mm
- Height: 250mm

**Screw Conveyor Housing**
- Length: 600mm
- Diameter: 250mm

**Separating Cylinder**
- Length: 800mm
- Diameter: 600mm

**Shaft**
- Dehulling Shaft Length: 725mm
- Cleaning Cylinder Shaft Length: 725mm
- Radial gap: 6.5mm

Design of shafts of ductile material based on strength is determined by the maximum shear stress theory. For a solid shaft having little or no axial loading, the ASME [15] code equation is given by equation (1):

$$d^3 = \frac{16}{\pi^2t} \sqrt{\left(K_t M_t\right)^2 - \left(K_b M_b\right)^2}$$

(1)

Where $St$ is Allowable combined shear stress for bending and torsion = 42x10³N/m²
- $K_t$ is Torsional fatigue factor
- $M_t$ is Torsional moment
- $K_b$ is Bending fatigue factor
- $M_b$ is Bending moment

For a rotating shaft with gradually applied load
- Bending fatigue factor ($K_b$) = 1.5
- Torsional fatigue factor ($K_t$) = 1.0 (Hall et al. 1983)

*Torsional moment, $M_t=9550$ kW/rev min Nm (Hall et al., 1983)*

**Loads on the shaft are due to**

i. Locust seed:
- Mass of locust beans = 0.5kg
- Weight of locust beans = (0.5kg x 9.81m/s) = 4.905N

ii. Auger:
- Mass of the auger = 0.50kg
- Weight of the auger = 4.905N

**Driver Engine Parameters**
- Power rating: 2hp = 1.492kw
- Speed: 1435 rpm

**Determination of Pulley Dimensions**

$$N_1 D_1 = N_2 D_2$$

(2)

- Diameter of driver pulley ($D_1$): 150mm = 0.15m
- Speed of driver pulley ($N_1$): 1435 rpm
- Diameter of driven pulley ($D_2$): 300mm = 0.30m

1435 x 0.15 = $N_2$ x 0.30

$$N_2 = \frac{1435 \times 0.15}{0.3} = 718$$

Speed of driven pulley ($D_2$) = 718rpm
Belt size Determination

Length of belt can be calculated using equation (3).

\[ L = \pi (r_2 + r_1) + 2x + \frac{(r_2 + r_1)^2}{x} \]  (3)

Where;
- \( L \) = length of belt (m)
- \( x \) = distance between the driving and the driven pulley.
- \( r_1 \) = radius of driving pulley
- \( r_2 \) = radius of driven pulley (Khurmi and Gupta, 2005)

Design for power requirement

The power requirement is divided into two

i. Power required to drive the shaft (Ps)

ii. Power required to dehull (Pd)

- Power required to drive the shaft (Ps) is determined from the power rating of the shaft driving engine which is 2hp equivalent to 1.492kw
- Power required to dehull was obtained using equation (4) (Hall et al., 1983)

\[ Pd = Tw \]  (4)

Where \( T \) is Torque and it is given by

\[ \frac{L^3 x t}{16} \]  (5)

\( W \) is angular speed given by

\[ \frac{2\pi N}{60} \]

\( t \) is shear stress and
\( N \) is speed in revolution/minute

The total power is given as the sum of the power required to drive the shaft and the power required to dehull as given in equation (6)

\[ P = Ps + Pd \]  (6)

Selection of Key (from table of proportion of standards and parallel rectangular keys)

- Width: 0.008m
- Thickness: 0.007m
- Shear stress: 113kN/m²
- Length of key is given by

\[ L = \frac{r}{\omega + \sigma} \]

Where \( T \) is torque transmitted by the shaft
\( L \) is the required length of key

Width of the key is \( \omega \)
Shear Stress of key material is \( \sigma \)
Length of key is therefore equal to 0.015m

Bevel Gears Design (Oseni Kehinde Owolarafe et al 2011)

<table>
<thead>
<tr>
<th>Description</th>
<th>Bevel gear 1</th>
<th>Bevel gear 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of teeth</td>
<td>30ul</td>
<td>30ul</td>
</tr>
<tr>
<td>Pitch diameter at end</td>
<td>0.2485ul</td>
<td>0.2485ul</td>
</tr>
<tr>
<td>Pitch diameter in middle plane</td>
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<td>72.04mm</td>
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<tr>
<td>Outside diameter at end</td>
<td>93.19mm</td>
<td>95.3mm</td>
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<tr>
<td>Outside diameter at small end</td>
<td>56.0mm</td>
<td>57.3mm</td>
</tr>
<tr>
<td>Root diameter at end</td>
<td>83.8mm</td>
<td>85.96mm</td>
</tr>
<tr>
<td>Vertex distance</td>
<td>43.41mm</td>
<td>42.35mm</td>
</tr>
</tbody>
</table>

Figure 4: Overview of the Locust beans Dehulling Machine

V. RESULTS AND DISCUSSION

a) Dehulling Efficiency

The dehulling efficiency is given by the ratio of dehulled beans collected at the underflow in the cleaning cylinder to the total mass of beans before dehulling. It is then multiplied by 100 to get the percentage value. This is expressed mathematically by equation (7).

\[ DE = \frac{\text{Mass of dehulled beans}}{\text{Total mass of beans}} \times 100 \]  (7)
b) Effect of Boiling Time on Dehulling Efficiency

The use of pressure pot was adopted for the boiling of Locust Beans seeds prior to dehulling as this significantly reduces the boiling/cooking time of any material. Boiling with normal cooking pots would have required the Locust Beans be continually cooked for over 6 hours before dehulling can be achieved. (Timothy et al, 2019).

Fig. 5 above shows that the dehulling efficiency of the machine increased with increasing boiling time. However, the threshold efficiency was reached at 60 minutes boiling time in the pressure pot because as heat was sustained under the pot and the boiling time continually increased, the beans gradually became too soft and started to get sticky in the dehulling chamber of the machine thereby reducing the dehulling efficiency of the machine.

VI. CONCLUSION

A Motorized Dehulling and Centrifugational Cleaning Machine for Locust Beans was designed in this study. The dehulling unit is made of a hopper and a horizontally positioned barrel that houses the dehulling shaft which facilitates the beans hull removal while the cleaning unit is made of a vertically positioned hollow cylinder which houses a rotating shaft that influences centrifugal turbulence in the medium for further cleaning of beans through density displacement. The result showed that 60 minutes boiling time of beans in a pressure pot is the threshold time for optimum efficiency of the machine.

VII. FUTURE SCOPE

Improvements can be made on the physical aesthetics of the machine to make it safer for use. The part where the dehulling shaft and the cleaning chamber shafts connect are exposed and can cause serious injuries to any one operating the machine. The cleaning chamber is also exposed to intrusions and spills as it has no covering to limit such intrusions into the materials being processed. Due to frequent price variations, materials purchase for fabrication can warrant higher bills. Further research work can be directed towards incorporating more processing procedures for locust beans such as fermentation, cubing and drying processes. This machine can also be upgraded from simple local productions to industrial scale production so as to contribute to economic development after the economic downturn experienced due to the Covid-19 pandemic.

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AUTHORS BIOGRAPHY

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