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# EVALUATION OF A LOCUST BEANS SEED DEHULLING MACHINE FOR SMALL SCALE FARMERS

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## ABSTRACT

*A locust bean dehulling machine was fabricated and evaluated using locally available materials. The machine performs dual operations of removing the seed coats and cleaning. Components of the machine include the frame, hopper, dehulling chamber, water container, discharge outlets, set of gears and bearings in operation. In operation, locust beans seeds introduced via the hopper moved to the auger which separates the soft pulp and conveys the material into the dehulling chamber. The seeds were washed in the dehulling chamber while the coat (residual waste) passes through the sieve into the water trough where it was discharged through the waste outlet. Throughput capacity, output capacity, recovery percentage and cleaning efficiency were 264.0kg/hr, 98.48%, and 98.75%, respectively. This machine may find applications in the processing of locust beans.*

**Key words:** Agriculture, locust bean, dehulling, evaluation, small scale farmers

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## 1. INTRODUCTION

African locust bean (*Parkia biglobosa*) is very important for food security particularly during food shortage and drought periods in the arid and semi-arid regions of Africa [1]. *Parkia biglobosa* is a perennial deciduous tree with a height ranging between 10 and 15 m. It may be as high as 20 m under exceptional conditions. It has a rounded or umbrella shaped spreading crown, with drooping leaves and is without spines (Fig. 1). The thick bark is grey in colour with a scaly texture, and has an orange coloured slash. It is a native to Africa and an important multipurpose tree of West Africa Savannah land, and one of the most common species of the parkland agro forestry system.

African locust bean is a food species whose relevance is recognized widely in many societies on the African continent because it is a healthful food and a source of livelihood for a great number of people. Rural dwellers in developing countries like Nigeria who could not afford animal products which are rich sources of protein because they are either too expensive or simply unavailable find the African locust beans seed essential as protein substitute. The pods are harvested and processed into the fermented product known as 'Iru' in Southern Nigeria, 'Dawadawa' in Niger, Northern Nigeria and Ghana, 'Ogiri' in Eastern Nigeria, 'Soubala' in Burkina Faso, Mali, Cote d'Ivoire and Guinea respectively [2,3].



**Figure 1** Locust bean pods

Processing of agricultural crops includes post-harvest activities that maintains, raises the quality or changes the form or characteristics of the crops into marketable products [4]. Dehulling is a process employed to get rid of the outer pericarp and testa (hull) of most cereal grains, grain legumes, nuts and oilseeds using mechanical means [1]. Dehulling is a very important process although hectic when carried out manually using human power. Dehulling enhances the seed quality conditions. The popular method of processing African locust bean in Nigeria is manual or traditional. 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 12 hours and cooking for 30 min in a pressure cooker is sufficient to soften the seed, but removal of the seed coat is more difficult [5].

The drudgery involved in dehulling locust bean seed by traditional methods has been identified as one of the major problems hindering the realization of the full potentials of locust bean as important food material. Traditional methods of processing African locust bean produce a low yield and increase the cost of processed seeds. The market price of the processed products can be reduced for local consumption as a staple food and enough quantity can be processed if the manual dehulling approach is replaced with mechanized dehulling.

Many researchers have made attempts to mechanize processes involved in the production of African locust bean. Many mechanical dehullers have been developed to reduce the amount of time and labour required in the manual de-hulling of many agricultural crops. Olaoye [6] developed small scale equipment for depulping locust bean seeds. Akande et al [7] described some wet dehulling machines developed by the National Centre for Agricultural Mechanization, (NCAM) Nigeria. Audu et al. [8] developed a concentric cylinder locust bean dehuller. Nnamdi et al [9] evaluated the performance of a breadfruit dehuller. Kaankuka et al [10] reported the evaluation of a dehuller for Acha (*digitaria exilis*). Adeleke and Ogunjobi [11] and Ogunnigbo and Adetan [12] and worked on mechanical processing machines for coffee and maize respectively.

Mechanization of dehulling process will help locust bean farmers and small scale producers in reducing the amount of labour employed and the drudgery involved in the process among other benefits. Therefore, the main objective of this study was to use locally

available materials to design, fabricate and evaluate a simple to operate locust bean dehulling machine for small scale locust bean farmers. Specific objectives were to investigate the machine in terms of cleaning efficiency, percentage recovery and throughput capacity. There is a general awareness in Nigeria and other developing countries that the rapid development of agriculture depends, to a large extent, on the successful introduction of modern and small scale agricultural machinery [13]. Therefore, there is the need to develop a small mechanical device for small scale locust bean processing This study will contribute greatly to existing knowledge on locust beans processing with a view of increasing its production and reduce wastage and increase quality of the locust beans and serve as a baseline for further research work.

## 2. MATERIALS AND METHODS

### 2.1. Materials selection

The factors considered in the development of the wet locust beans seeds dehulling machine includes: cost of the materials, construction technique, availability of materials, durability of materials, cost of maintenance and effect of the material used on the food material. Galvanized steel was used for the dehulling and washing chambers, while angular mild steel was used for the frame of the machine for rigidity and stability.

### 2.2. Machine description

Materials for construction of locust bean de-hulling machine were selected based on some factors which includes; availability of materials, durability, strength, safety, maintenance and operating cost. The design philosophy was to reduce drudgery in the process of de-hulling of locust beans seed. The fabricated locust bean machine consist primarily the following units as shown in **Error! Reference source not found.**

**Hopper/Loading tray:** It is the part where the locust beans are being fed into the separation chamber. It could also be referred to as the introductory section of the locust beans into the de-hulling chamber. It is made of mild steel and identified by a trapezoidal shape to enhance the movement of seed during the de-hulling process. It has a length of 600 mm, width of 300 mm and depth of 400 mm.

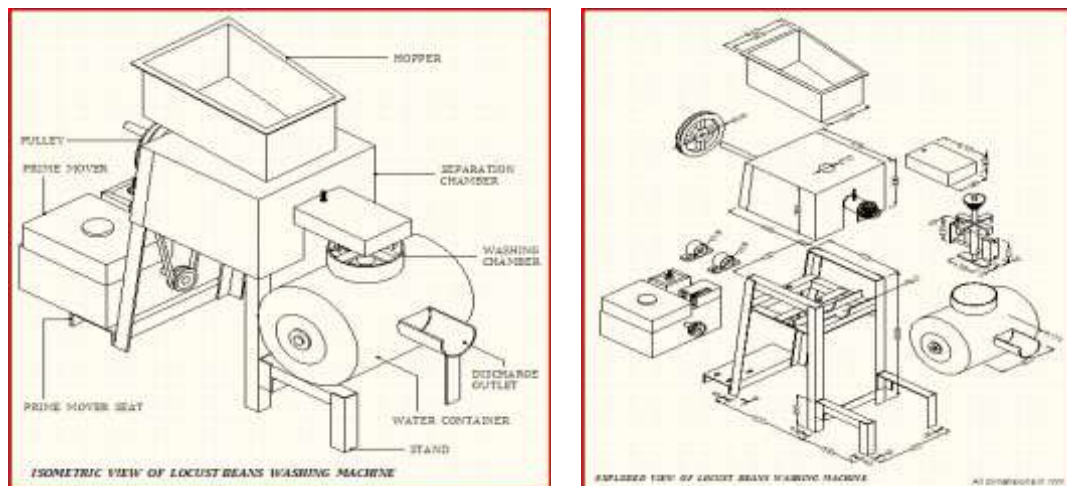
**Separation chamber:** This is the part of the wet de-hulling machine where the pulp is initially separated from the seed. It undergoes a rotary motion resulting in the removal of the coat and transported with the seeds into the de-hulling chamber.

**Dehulling chamber:** This is the main component of the washer and it was made from 1.5 mm thick galvanized sheet. It comprises of two cylinders; the small and big cylinders which are horizontally attached to each other and are segmented into two equal halves, with one of the segments perforated. The small cylinder has the overall dimension of 148.8 mm diameter and length of 170 mm

**Water container:** It is cylindrical shaped and made from 1.5mm galvanize sheet with overall dimension of 255 mm diameter and length 600 mm. It serves the purpose of holding water for final cleaning of the seeds and it is situated beneath the de-hulling chamber.

**Frame:** The frame is made from 45 mm x 45 mm x 45 mm angle iron and serves the purpose of holding the whole system in a rigid position.

**Discharge outlets:** The machine has two outlets; the first outlet is beneath the small cylinder and serves as the waste material (slurry) outlet while the second one is at the extreme end of the big cylinder and use for discharge of the washed seeds.



a) Isometric view

b) exploded view

**Figure 2:** Isometric and exploded views of the locust beans de-hulling machine

### 2.3. Principle of operation

Machine for dehulling and separating of the boiled locust beans from its coats had two compartments; dehulling cylinder and separating cylinders. The dehulling cylinder houses the dehulling shaft. A petrol engine provides drive through belt connections via pulley to the shaft. The dehulling unit comprises the hopper, the cage which houses the rotating auger. The cage is lined with abrasive stainless-steel sheet. The function of this part of the device is to do the actual dehulling of the locust bean. As the dehulling shaft rotates with the help of bearings, it provides drive to the stirrer inside the separating inner cylinder through the bevel gear connections and pulleys. Boiled locust beans are being fed into the dehulling cylinder through the hopper; the locust bean was de-hulled and at the same time conveyed through a screw conveyor into the separating cylinders through the opening under adjacent end of the dehuller cylinder. The stirrer which was being enclosed by the inner cylinder stirs or agitates the de-hulled beans solution to dislodge the coats from the seeds. Centrifugation is a process used to separate a mixture of substances with different densities. The centrifugal force is created by the rotating spindle. The spindle carries harden wooden brush which helps create turbulence in the water. The result of this is that the heavier cotyledons stays on the screen with the rest displace to the water under the sieve thereby achieving separation.

The separating unit consists of the separation bowl, loaded with specially designed spindle with brush that was bolted to create rotational motion necessary to effectively separate the testa from the de-hulled seeds in the fastest possible time. The coat of the seed will sink through the screen of the sieve and can be collected at the exit point at the bottom of the separation bowl. The separating chamber operates under the principle of floatation with the cleaned seed floating on top of the sieve. The de-hulled coats naturally sink in water while the seeds float on the sieve. During operation, the turbulence in the separating chamber aids in detaching coats that are loosely attached to the seed. The rotating shaft was driven by the main shaft through bevel gear arrangement inclined at  $90^\circ$ . After the operation, the tap at the base of the chamber shall then be opened for discharge of the dirty water and the testa of the beans and the clean locust beans seed collected at the upper exit above the screen.

The fabricated locust beans wet dehuller was evaluated at the Farm Power and Machinery Workshop of Agricultural and Biosystems Engineering Department, Landmark University, in order 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<sup>-1</sup> 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.

## 2.4. Design analysis

Design analysis was carried out to determine the necessary design parameters, strength and size of materials required for various machine parts in order to avoid failure during operation of this machine.

### *Shaft design*

Shaft design involved determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operations and loading conditions [14]. Design of shafts of ductile material based on strength is controlled by maximum shear theory. For a solid shaft having little or no axial loading, the ASME [15] code equation is given as:

$$d^3 = \left(\frac{16}{\pi}\right) \times [(K_b M_b)^2 + (K_t M_t)^2]^{\frac{1}{2}} \quad (1)$$

Where; d = diameter of the shaft, m; M<sub>t</sub> = torsional moment, Nm; M<sub>b</sub> = bending moment, Nm; K<sub>b</sub> = combined shock and fatigue factor applied to bending moment, K<sub>t</sub> = combined shock and fatigue factor applied to torsional moment; S<sub>s</sub> = allowable combined shear stress for bending and torsion for steel shaft, N m<sup>-2</sup> and π = constant = 3.14.

The diameter was calculated as 18.5 mm and shaft of 25 mm was used in order to have a higher factor of safety. The designed shaft satisfied deflection, torsional and critical speed criteria.

### *Bevel gear*

Bevel gears transmit power between two intersecting shafts at any angle or between non-intersecting shafts. Bevel gears are widely used because of their suitability towards transferring power between nonparallel shafts at almost any angle or speed. In order to get an accurate understanding of the loads transmitted by the gear, the torque values were converted to horsepower using equation (2);

$$HP = \frac{T \cdot RPM}{5252} \quad (2)$$

Where; T is the applied torque and RPM is the operating speed of the gear shaft [16].

### *Size of hopper*

The hopper was designed to have trapezoidal shape of length 600mm, width of 300mm and depth of 400mm. The hopper of the machine was designed by using Equation (3);

$$A = 2\pi r [r+h] \quad (3)$$

Where, A = Area of cylinder, m<sup>2</sup>; h = height, m; r = radius, m; π = constant = 3.14. Given that height and radius were 135 mm and 99 mm respectively, hence, A = 0.146 m<sup>2</sup>

### ***Volumetric capacity***

Volumetric capacity was determined from the dimensional layout of a cylindrical set up using the struck level method following the procedure for the determination of bin diameter in manure spreader, as described by [6]. Capacity was taken as the struck level corresponding to the portion included within the cylinder.

Gravimetric capacity was related to the volumetric capacity of the cylinder by using Equation (4) and the storage capacity of the cylinder was calculated from Equation (5);

$$G_v = V_v \rho_b \quad (4)$$

$$V = \frac{\pi d^2 L}{4} \quad (5)$$

Where;  $G_v$  = gravimetric capacity;  $V_v$  = volumetric capacity;  $\rho_b$  = nominal density of the product;  $d$  = diameter of the cylinder, m;  $L$  = length of the cylinder, m.

### ***Sieve size and physical properties of the locust bean seeds***

Size of sieve holes and clearance between rotating brush and the base of separating chamber were established with respect to the size of the seed. Seed size was determined by measuring the axial dimension of 100 randomly selected seeds using a venier caliper reading to 0.05 mm. The number of holes per  $m^2$  on the cylindrical sieve shell was evaluated based on the unit size of the seed. Experiments had shown that the average values of the major, intermediate and minor diameters of the seeds are 9.8, 7.9 and 4.6 mm respectively [6]. An approximate hole of 4 mm was drilled on the cylindrical sieve.

### ***Determination of pulley dimensions***

The dimension of the pulley was determined using the following expression

$$N_1 D_1 = N_2 D_2 \quad (6)$$

Where;  $N_1$  = Speed of drive pulley (petrol engine),  $D_1$  = Diameter of drive pulley,  $N_2$  = Speed of washer pulley,  $D_2$  = Diameter of washer pulley



**Figure 3:** Fabricated locust beans seed dehulling machine

### 3 PERFORMANCE EVALUATION

#### 3.1. Preparation of samples

Locust bean seeds were obtained from the teaching and research farm of Landmark University. The locust bean seeds were weighed using a digital weighing balance (CAMRY ACS-30-ZE41), and each was sorted out for material other than the bean after which it was divided into five (5), each of 1.5 kg before steaming. The locust bean seeds were boiled in a stainless cooking pot with lid before dehulling at different boiling time (4, 6, 8, 10 and 12 hours). Moisture content (dry basis) was determined using the digital moisture analyser. Weight of the boiled beans was determined using the weighing balance. The boiled beans were then dehulled and washed using the fabricated wet locust bean seed dehuller and washer. After the dehulling and washing process, the samples were collected. The mass of unde-hulled beans, whole beans, broken beans in the final product and the mass of the coat were determined respectively. Dehuller efficiency, coefficient of wholeness of beans defining the quality of beans recovered, the throughput capacity, coefficient defining the quantity of beans dehulled, cleaning efficiency were calculated were determined using Equations (7) - (10) at different boiling time.

**Cleaning Efficiency, ( $E_C$ )%** - this determines how efficiently the machine is cleaning, it is expressed as

$$DE = 100(C_h C_w) \quad (7)$$

Where;

$$C_h = 1 - \left(\frac{M_u}{M_t}\right) \quad (8)$$

$$C_w = \frac{M_w}{M_w + M_b} \quad (9)$$

Where;

$C_h$  = coefficient of defining the quantity of beans dehulled,  $C_w$  = coefficient of wholeness of beans defining the quantity of beans recovered,  $M_u$  = mass of unde-hulled beans in the final product, kg,  $M_t$  = mass of sample before dehulling, kg,  $M_w$  = mass of whole beans in the final product, kg,  $M_b$  = mass of broken beans in the final product, kg

#### ***Throughput of the dehuller ( $T_p$ )***

Throughput of the dehuller was determined using Equation (10):

$$T_p = \frac{3.6M_t}{T_t} \quad (\text{kg/h}) \quad (10)$$

Where;  $T_t$  = total time used in dehulling (s)

## 4. RESULTS AND DISCUSSION

### 4.1. Effect of steaming time on moisture content

Figure 4 presents the relationship between moisture contents and steaming time. The Figure shows that moisture content increases with steaming time. Minimum moisture content of 13.4% was obtained after 4 hours of steaming while 106.6% moisture content was obtained at 12 hours. Moisture absorption by the beans was initially observed to be very slow from 0 - 4<sup>th</sup> hour of steaming, but increased rapidly thereafter. Moisture take up through the seed coat was slow hence, the initial slow rate of moisture absorption. Rapid increase of moisture absorption

observed from the 4<sup>th</sup> hour was due to softness of the seed coat which allows easy penetration of water. This result was similar to that reported by Audu et al [8].

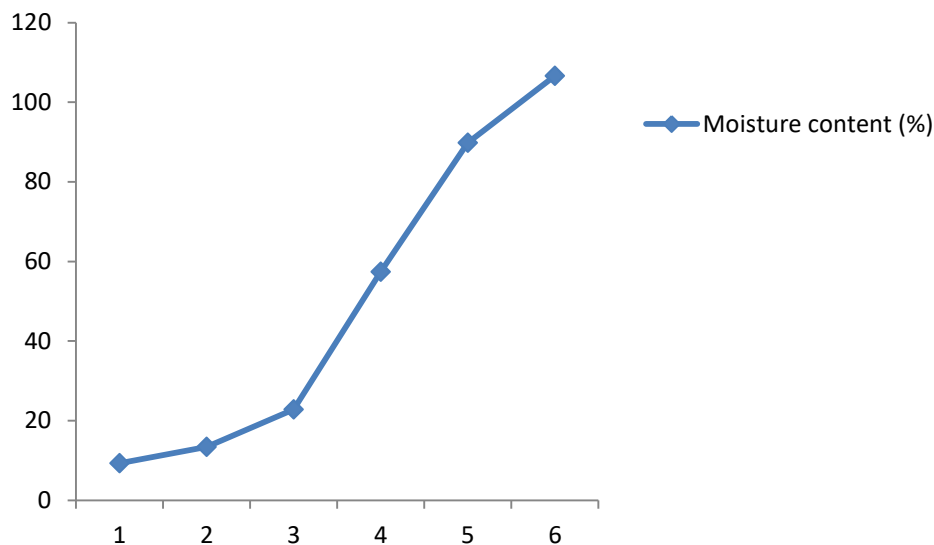


Figure 4: Effects of steaming time on moisture content

#### 4.2. Moisture content and dehulling efficiency

Figure 5 shows the correlation between moisture content and dehulling efficiency of the machine. Dehulling efficiency increased with respect to the moisture content of the locust bean. At 13.4% moisture content, 10.25% efficiency was obtained. Highest dehulling efficiency (93.58%) was obtained at 106.6% moisture content. Moisture content of the locust bean influences the efficiency of the fabricated dehulling machine. At low moisture contents, many of the beans were undeulled because the locust bean seed coats were hard and difficult to remove. The seed coats become softened and less brittle as the moisture content increased hence dehulling efficiency increased with minimum breakage. At a higher boiling time, the coats were softened, therefore making dehulling easier with less breakage, since its elasticity increases with boiling time, this is in agreement with Faleye et al [17] and Gbabo et al [18].

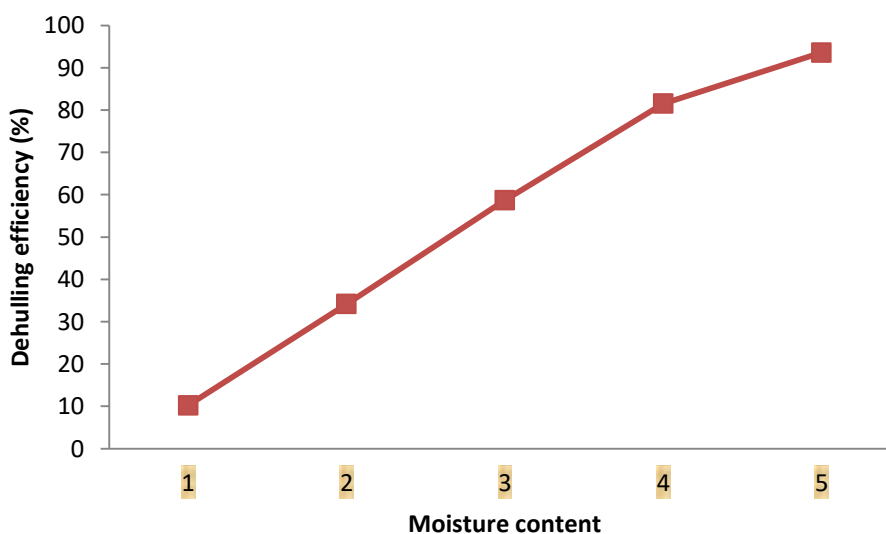


Figure 5 Moisture content and dehulling efficiency



### 4.3. Throughput (Tp)

Throughput of the dehulling machine was determined using Eq. (10). It was found to be inversely proportional to the moisture contents of the locust bean seeds as presented in Figure 6. 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%). At reduced moisture content, the locust beans were less sticky and able to flow free through the discharge outlet. However, at high moisture content, the locust bean seed coats were sticky resulting in a high force of friction between the steamed locust beans and the walls of the discharge outlet, hence, discharge of beans became difficult during dehulling. This result agrees with Adeknye et al [19].

## 5. CONCLUSION

A small-scale machine for dehulling and washing locust beans seeds was designed, fabricated and tested. The evaluation process carried out showed that the machine was portable enough for local production, operation, repairs and maintenance while all the materials were available locally and at affordable costs. The machine has average throughput capacity, output capacity, recovery percentage, cleaning efficiency of 238.875 kg/hr, 229.8 kg/hr, 88.44% and 95.80% respectively, with a production cost of ₦52, 500 (USD 145.23 ). The machine can be used for small scale locust bean de-hulling in the rural and urban communities and can be scaled up for industrial application.

The bean dehuller performs more efficiently as the boiling time increases. The machine attained a dehulling efficiency of 59.72 % and separation or cleaning efficiency of 83.39 % at 12 hours boiling time. Therefore, the best operating conditions for this fabricated locust seed dehulling machine are boiling time of 12 hours and moisture content of 53.7%, at which maximum dehulling efficiency of 59.72 % and cleaning efficiency of 83.4 % are obtained.

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## APPENDICES



**Plate 1** Locust beans seeds undergoing boiling



**Plate 2** Locust beans seed drained after boiling



**Plate 3** Locust beans fed into the washer through the hopper



**Plate 4** Locust beans seeds after the cleaning process.