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Society for Multidisciplinary & Advanced Research Techniques (SMART)

Accra Bespoke Multidisciplinary Innovations Conference (ABMIC)

Development of a Pedal-Powered Locust Bean Dehulling Machine

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ABSTRACT

Dehulling is the process of efficiently removing the outer layer that surrounds the cotyledon, leaving the seed cotyledon free. Locust bean dehulling technology has improved significantly in the past few years in the century, but many women still dehull their products manually because of the high cost of equipment particularly the internal combustion engine. This study aims to design and fabricate a pedal-operated machine capable of dehulling and separating boiled locust bean seeds from its hull. A pedal-operated machine was designed and fabricated for ease of dehulling locust bean from its hull. The physical dimensions of a locust bean seed are length (10.20 mm), width (8.32 mm), thickness (4.40 mm), and density (1.14 g/cm3) which were well determined. Two samples of boiled locust bean seeds were dehulled using the pedal-powered dehulling machine. Sample A was boiled for 6 hours and dehulled in 97 seconds while Sample B was boiled for 10 hours and dehulled in 69 seconds resulting in dehulling efficiency of 77.17% for Sample A and 83% for Sample B as the dehulling efficiency. The results revealed that samples of locust bean that were boiled for a shorter time had a lower dehulling efficiency than those boiled for a longer time. The efficient performance of the machine shows that it has a high potential for replacing the manual technique of dehulling locust bean.

Keywords: Locust bean, Pedal-operated machine, Parkia biglobosa, Dehulling, Machine fabrication

Proceedings Citation Format
Odesola I.F. Abu R. Adegbulugbe O.I., Mustapha O.F. & Odunfa, K.M. (2022): Development of a Pedal-Powered Locust Bean Dehulling Machine. Proceedings of the 31st Accra Bespoke Multidisciplinary Innovations Conference. University of Ghana/Academic City University College, Ghana. 1st – 3rd June, 2022. Pp 141-150, www.isteams.net/ghanabespoke2022. dx.doi.org/10.22624/AIMS/ABMIC2022P15

1. BACKGROUND TO THE STUDY

Dehulling is the process of completely removing a cotyledon's covering, making the seed cotyledon-free. The African locust bean (Parkia biglobosa) is essential for food security in Africa's dry and semi-arid regions, especially during times of scarcity and drought. The locust bean seed is the most valuable component of the Parkia biglobosa plant due to its high nutritional content, which includes protein, glucose, lipids, vitamin A, B2, and lysine (Simonyan, 2012). The locust bean seed is dehulled and boiled throughout West Africa to form a pungent-smelling culinary spice. It is known in Nigeria as 'iru' among the Yoruba-speaking tribe, 'Dawa Dawa' among the Hausa-speaking tribe, and 'soumbala' in Burkina Faso, Mali, Coted' ivory and Guinea.

The traditional method of dehulling locust bean seed, which requires foot pressing of the seeds, has proven to be one of the most time-consuming and unclean processes involved in locust bean seed processing (Okunola et al, 2019; Adeyemo et al., 2013). This method is time-consuming, inefficient, and exposes the bean to excessive water treatment, which causes colour deterioration and uncontrolled microbial activity. The rigors and difficulties associated with the locust bean processing as a result of excessive wood for fuel usage, the use of basic equipment, and low productivity, are inhibiting the production and consumption of the African locust bean thereby promoting the introduction of international soup spices (Beaumont, 2002).

In order to addressing the challenges of dehulling locust bean seed, some researchers developed an electrical motor-powered locust bean processing machine (Okunola et al., 2019; Okonkwo et al. 2018; Agidi et al., 2013; and Audu et al. 2004), while Owolarafe et al. (2013) developed a locust bean processing device with hand-operated dehulling unit which solved challenges of high cost and non-availability of electricity and fuel (petrol) for machines. Abu et al. (2019) stated that a hand-operated machine could be operated effectively by powering it with a pedal instead. The authors confirmed this by developing a pedal-powered hacksaw which performed efficiently and improved the operator's physical and mental health through cycling exercise. Therefore, the present study adopted a pedal-powered drive mechanism for the development of a locust bean dehulling machine.

2. STATEMENT OF PROBLEM

Locust bean dehulling technology has improved significantly over decades, but the majority of women in Africa still dehull their locust bean seeds manually because of the high cost of equipment particular the engine (prime mover) and electricity (Simonyan, 2012; and Akande et al., 2010). As a result of these challenges, most of the women produce small quantity and earn little income from the trade. Therefore, there is a great need for efficient manually-operated dehulling machine that is efficient but still affordable by them.

3. OBJECTIVE

The objectives of this study are:
i. Design a pedal-powered machine that can dehull locust bean seeds.
ii. Fabrication of the machine.
iii. Perform evaluation of the machine.

4. METHODOLOGY

4.1 Major Components of the Machine

The following machine components were built according to standard specifications and materials:

(i) **Hopper:** A top diameter of 200 x 150 mm, a bottom diameter of 100 x 60 mm, and a total slant height of 200 mm through the hopper.
(ii) **Dehulling Cylinder:** The shaft and conveyor were encased in a 700 mm long tube with a 120 mm diameter (a dehulling mechanism).
(iii) **Cylinder Shaft (Dehuller):** The dehuller had a total length of 600 mm and a shaft length of 800 mm.
(iv) **Mainframe:** Angle bar measuring 50 x 50 mm was used to construct the frame. It was made up of four stands that were kept in place by welding. The stand had dimensions of 700 x 200 mm at the top, 700 × 300 mm at the bottom, and a total height of 650 mm from the ground level, based on design considerations.
(v) **Chain and Pedal:** These are the major components of the drive mechanism.
(vi) **Shaft:** The major driving element is the solid shaft made of a mild steel.

4.2 Principle of Machine Operation

Drumming rotation is enabled in this machine using sprocket rotation. A chain drive rotates the sprocket. The gear linked through the sprocket chain begins to transmit power once an operator starts pedalling. The input power determines the spinning of the drum, and the entire operation is dependent on the compound gear system. The power is transferred by a roller chain, also known as the drive chain or transmission chain, which passes over a sprocket gear and engages the teeth of the gear with the holes in the chain links. When the gear is turned, the chain is pulled, providing driving force to the system. The power is sometimes output by simply rotating the chain, which is used as the drum's input. Pour the Locust beans with some water into the hopper while another person begins cycling slowly and increasing pace. Pedal for about 8 -10 minutes for about 2 kg of locust beans at a time.

4.3 Design of Machine Components

The engineering properties employed in the design of the machine components is as follows:
Seed length of the locust bean = 10.20 mm
The locust bean seed's width = 8.32 mm
Seed thickness of locust bean = 4.40 mm
The locust bean seed's average diameter = is 7.50 mm
Seed density of the locust bean = 1·14 g/cm^3
Bulk density of locust beans seed = 538.02 kg/m^3 (Ogunjimi et al., 2002)
Max allowable mass of locust beans = 500 g

The required volume, *V* of hopper = maximum volume of locust bean seeds that can be loaded at a time

$$V = \frac{mass}{density} = \frac{0.5}{538.02} = 9.293 \times 10^{-4}\ m^3$$

The hopper was made of stainless material with dimensions is 250 x 250 x 270 mm inclined at an angle of 73.6^{o} to the base (Ogunjimi et al. 2002). The total volume is 0.061m^{3} with a maximum capacity of 0.5 kg.

4.3.1 Screw Diameter for Shaft Conveyor Determination:

This was done to calculate the conveyor's minimum screw diameter. The theoretical capacity of a fully-loaded screw conveyor is calculated in Equation (1):

$C = (D^2 - d^2) \times P \times N \times 60$ (1)

where,
$C = C_{vph}$ = 0.2075m^{3} / hr is the machine's capacity in terms of volume per hour
D = diameter of the screw for the conveyor
d = diameter of the shaft = 0.022 m
P = pitch of the conveyor = 0.014 m
N = speed of the shaft = 500 rpm
The conveyor's minimum diameter was calculated as follows:
$0.2075 = (D^2 - 0.022^2) \times 0.014 \times 500 \times 60$
D = 0.031 m

4.3.2 Determination of Shaft Torque:

The shaft torque is calculated using Equation (2):

$$T_s = \frac{P_s}{W_s} \quad (2)$$

where T_s = Torque of the shaft
P_s = power delivered from the pedal to drive the shaft
W_s = Angular speed of the shaft

$$W_s = \frac{2\pi N_2}{60}$$

N_2 = Required speed of the shaft pulley = 600 rpm

$$W_s = \frac{2 \times \pi \times 600}{60} = 62.84 \text{ rad/s}$$

The power generated by pedalling a bike at a moderate speed is around 100 Watts.

$$T_s = \frac{100}{62.84} = 1.5913 \text{ Nm}$$

4.3.3 Length of Chain Drive

The length of the chain is determined using Equation (3).

$$L = p\left(\frac{T_1 + T_2}{2} + 2m + \frac{\left(\cos ec\left(\frac{180^o}{T_1}\right) - \cos ec\left(\frac{180^o}{T_2}\right)\right)^2}{4m}\right) \quad (3)$$

where T_1 = Number of teeth on big sprocket
T_2 = Number of teeth on the small sprocket
r_1 = radius of the big sprocket

r_2 = radius of the small sprocket
Taking m = 29.28, T_2=44 and T_2=18,

$$L = 14\left(\frac{44+18}{2} + 2(29.8) + \frac{\left(\cos ec\left(\frac{180^o}{44}\right) - \cos ec\left(\frac{180^o}{18}\right)\right)^2}{4(29.8)}\right)$$

L = 1262 mm

Different drawings are produced for the pedal-powered locus bean dehulling machine as shown in Fig. 1. The drawings were used for the fabrication of the machine.

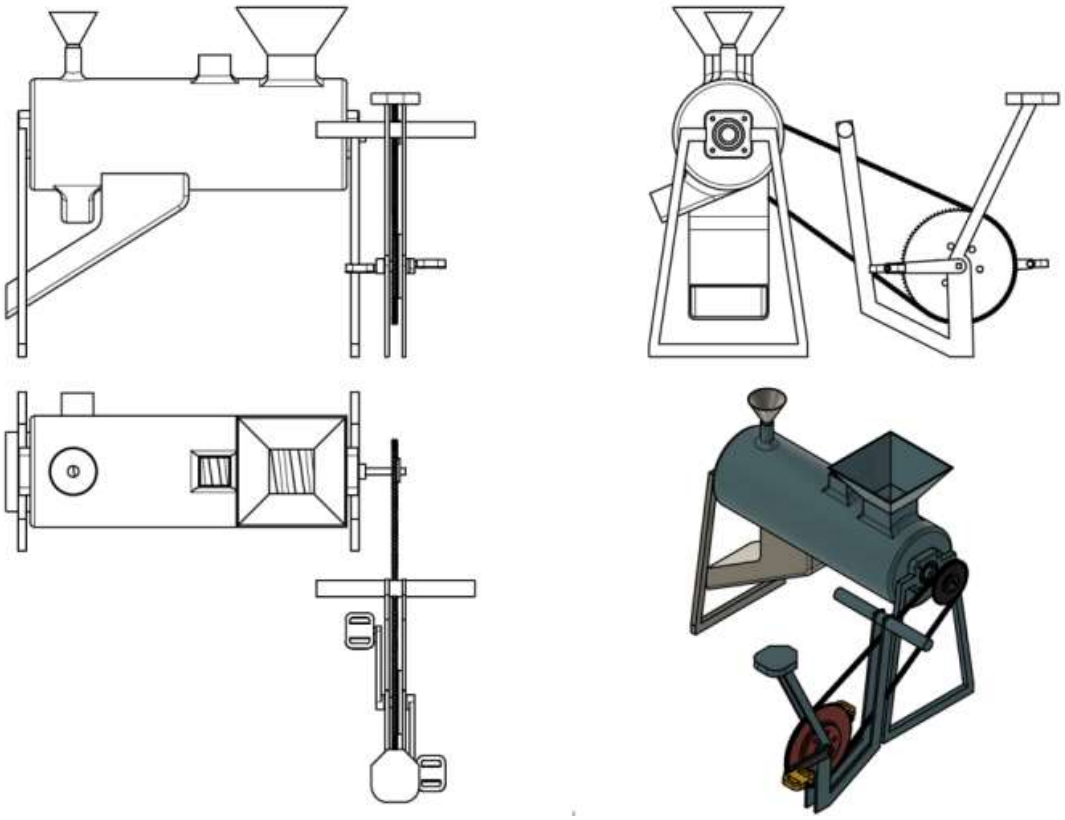

Fig. 1: Different Views of the Pedal-Powered Locust Bean Dehulling Machine

4.4 Performance evaluation of the machine

Two Samples A and B of the locus bean seeds were tested with the pedal-powered locust bean dehulling machine. The Sample A was boiled for 6 hours, while Sample B was boiled for 10 hours.

The dehulling efficiency $\mathcal{E}$ of the machine is evaluated using Equation (4).

$$\mathcal{E} = \frac{N_o}{N} \qquad (4)$$

where N_o is the number of dehulled seeds after the operation and;
N is the total number of seeds scooped out.

5.0 RESULTS AND DISCUSSION

5.1 Fabricated Machine

The fabricated components of the locust beans dehulling machine are hopper (Fig. 2), mainframe (Fig. 3), shaft (Fig. 4) and sprocket with pedal link (Fig. 5). The components were assembled to obtain the pedal-powered locust bean dehulling machine (Fig; 6).

Fig. 2: Hopper

Fig. 3: Mainframe

Fig. 4: Shaft

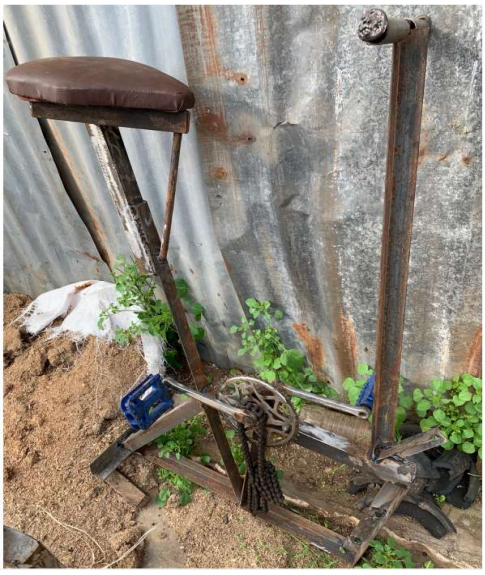

Figure 5: Sprocket with Pedal Link

Fig. 6: Fabricated Pedal-Powered Locust Bean Dehulling Machine

5.2 Performance evaluation

The batches of two samples A and B of the locus bean seeds were dehulled and the results are stated in Tables 1 and 2. The Sample B has higher percentage of dehulled seeds than Sample A. The highest percentage of dehulled seeds of Sample B is 87.9%, while highest percentage of dehulled seeds of Sample A is 81.3%.

Table 1: Batches of Sample A

Batch number	Number of dehulled seeds	Number of undehulled seeds	Total number of seeds	Percentage of dehulled seeds (%)
1	20	7	27	74.1
2	26	6	32	81.3
3	25	8	33	75.8

Table 2: Batches of Sample B

Batch number	Number of dehulled seeds	Number of undehulled seeds	Total number of seeds	Percentage of dehulled seeds (%)
1	27	6	33	81.8
2	32	8	40	80.0
3	29	4	33	87.9

The dehulling machine efficiencies for samples A and B are 77.1 and 83%, respectively, while the machine dehulling times for samples A and B are 97 and 69 seconds, respectively as shown in Table 3. All results show that the pedal-powered locus bean dehulling machine performed better with Sample B than Sample A.

Table 3: Performance Evaluation of the Samples

Parameter	Sample A	Sample B
Machine efficiency (%)	77.1%	83.0%
Dehulling time (seconds)	97	69

7. CONCLUDING REMARKS

A pedal-powered locust bean seed dehulling machine was designed and developed to alleviate the hardship experienced by women who work directly in the locust bean processing industry. The availability of information on the mechanical and physical qualities of locust bean (Parkia biglobosa) has aided in the creation of a mechanical dehulling machine. The boiling duration was shown to have an impact on the machine performance. Dehulling efficiency improves as the boiling duration is lengthened. For boiling times of 6 hours and 10 hours, the machine was able to achieve dehulling efficiencies of 77.2 percent and 83.0%, respectively. At machine efficiency of 83%, the highest percentage of dehulled seeds is 87.9%. This good machine performance shows that it has a high potential for replacing the manual technique of dehulling locus bean seeds.

8. CONTRIBUTIONS TO KNOWLEDGE

The specific contributions to knowledge are:

(i) Establishment of engineering design procedures for a pedal-powered locust bean dehulling machine.
(ii) Development of a pedal-powered locust bean dehulling machine that performed efficiently.

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