Development of African Locust Bean (*Parkia Biglobosa*) Depulping Machine

W. A. Akinfiresoye, A. A. Akintade and S. A. Fasoyin

***Abstract* — The traditional method of using hands to depulp African Locust Bean (ALB) inside a flowing river led to the conception and development of a simple operated 3 kg capacity ALB depulping machine at the Farm Power and Machinery Workshop of Agricultural and Bio-Environmental Engineering, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria. The depulping machine has the hopper, the depulping unit which has the shaft carrying paddles to beat off the seed from the pulp, the frame, the water reservoir to aid the process and 2.2 kW power unit. ALB of moisture contents 60%, 71% and 78% were depulp at machine speed of 173 rpm. The time taken for each operation to be completed was taken. It was discovered that the machine performance in terms of efficiency and throughput increases as the moisture content of the ALB increases while the specific mechanical energy decreases as the moisture content increases. At moisture content of 78%, the efficiency of the depulping machine was 83%, the throughput was about 236 kg/h and the specific mechanical energy was 122.32 KG/KJ. The cost of the machine was Seventy Eight Thousand Naira (NGN 78,000:00). It is recommended for small and medium ALB farmers.**

***Index Terms* — African Locust Bean, Depulping, Machine, Cost.**

I. Introduction

African Locust Bean (ALB) is a member of the *leguminoseae* family commonly grown in Africa and used basically as condiment and ingredients in soup preparation [1]-[3]. In Nigeria, ALB is called "iru" or "dawadawa" which serve as traditional condiments to flavour soups and stews [1]. The extraction of ALB from its pod traditionally requires eight cumbersome processing which are, shelling (after ripening), pre-drying, pounding, sieving, washing in water, sorting by principle of floatation, drying, and visual sorting by hand [4]. The pod was sun dried and beaten by pestle and mortal to remove the seeds. At times, the dried pods are packed inside a sack and beaten against hard object, usually, the wall for the seed removal. Thereafter, the seeds with its pulp are put inside woven basket and placed inside a flowing river, as the water drenched the pulp, and with hands used in washing the pulps, the seeds are removed while the flowing water wash away the pulp. [4]. The disadvantages of this process include provision of large volume of water, loss of seeds, time consumption and intensive labour [4], [5]. Reference [6] developed a water / thermal for the separation of ALB seed from its pulp, but this method leaves the seed with dis-colouration due to excessive heat during steaming. This work was improve on by other researchers who observed that this method of ALB depulping only gives 50% efficiency and may not be efficient among peasant farmers who are cultivating the seeds in large scale [7]. Reference [8] now developed ALB thresher which operated by drying the ALB upon harvesting and now introduce dry air instead of heated steam to blow off the pulp from the seed. But this method did not give a clean separation of the seed from the pulp. We still have the pulp glued to the seeds and there is also discolouration of the seed due to the excessive exposure to heated air. In view of this problem, it becomes imperative to develop another mechanical way of removing ALB from its pulp without any damage and discolouration. This is what led us to develop an affordable, simple to operate and maintained ALB depulping machine that will do this work.

II. Materials And Methods

The depulping machine was designed to depulp 30 kg of African Locust Bean. The major components of the machine include the hopper, the depulping unit which has the shaft carrying paddles to beat off the seed from the pulp, a water reservoir which splashes water into the depulping chamber steadily to ease the operations, the frame and the power unit. The performance evaluation of the machine after fabrication was carried out at a constant motor speed of 173 rpm. Comparism Experimental Design was used in this evaluation. Three samples of ALB called the input variables were weighed in respect of their different moisture contents of 60%, 71 % and 78 % as A, B, and C respectively. The output variable which were the seeds of the ALB after depulping for each of A, B, and C were weighed and the time taken to depulp each of the samples was taken as well. The effect of the moisture content on the depulping parameters of the machine such as the efficiency, throughput and specific mechanical energy were calculated from data obtained. Analysis of variance (ANOVA) at ($P \leq 0.05$) significance level was carried out to ascertain the variance between the mean values of the parameters under investigation.

III. Design Considerations

The factors considered in the design of ALB depulping machine include safety, ergonomics, power requirement, rigidity, vibration stability, speed and ease of maintenance.

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IV. Machine Conception and Description

The ALB depulping machine has the trapezoidal hopper through which the already soaked ALB is introduced to the depulping chamber and water from the mounted reservoir release water into the chamber for easy depulping during operations. The depulping chamber has two cylindrical shaped galvanized mild metal sheet with the outer one of dimension 450 mm diameter and 600 mm length, while the internal one has a diameter of 250 mm and 400 mm length, it has 20 mm diameter perforated holes as sieve. The shaft of 30 mm diameter made from carbon steel of grade 40 C 8 was supported on both ends with roller bearings inside the inner depulping chamber. The shaft carries four beaters made from synthetic rubber to beat off the seed from the pulp and also serve as paddle to move the ALB in a rotational movement during the operations. There are two discharge units for the pulp and the seed respectively. The machine is mounted on a rigid frame and powered by 2.2 kW electric motor. Figures 1, 2 and 3 shows the orthographic, exploded and isometric view of the machine respectively.

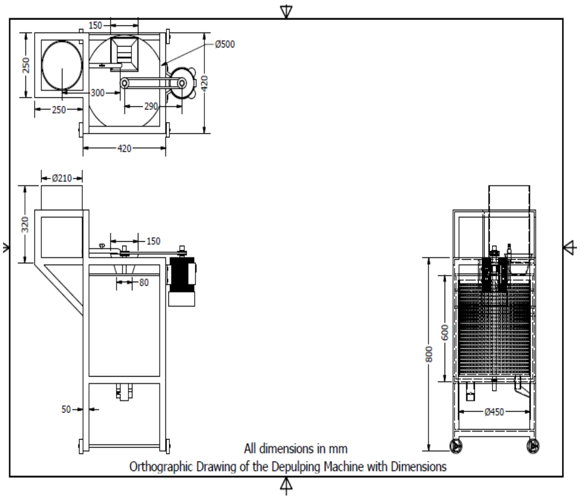

Fig. 1. Orthographic view of African Locust Bean Depulping Machine.

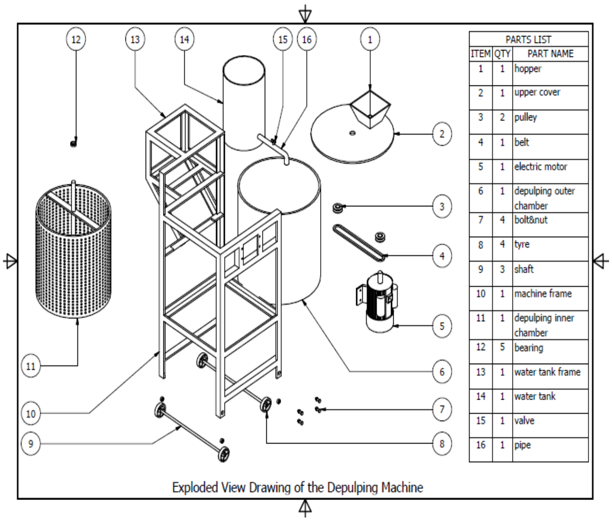

Fig. 2. Exploded view of African Locust Bean Depulping Machine.

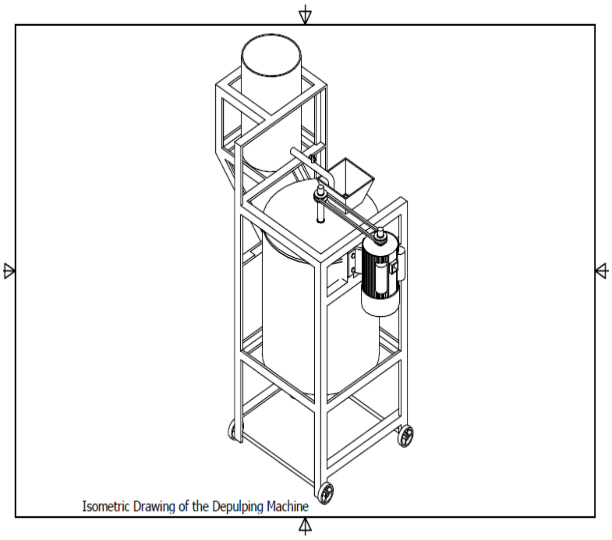

Fig. 3. Isometric view of African Locust Bean Depulping Machine.

V. Design Analysis

The major components of the machine were designed as follows:

A. The Hopper

The hopper and the seed discharge chute were constructed at an angle of inclination of 35^{o} to ensure free flow of the material into the depulping chamber in respect to the angle of repose of the un-depulp material and oil seeds [9]. Reference [10] shows the calculation of the volume of the hopper as represented in equation (1).

$$v = A\ X\ h \tag{1}$$

where v is the volume of the trapezium; A is the area, and h is the height of the trapezium

The area of the hopper, A, was calculated from the relationship in equation (2) as in (10)

$$A = \frac{1}{2}\ (a + b)h \tag{2}$$

where A is the area of the trapezium, a is the base length of the trapezium =(400+210) mm, b was the upper length of the trapezium =350mm and h is the height of the trapezium =350mm.

$$A = \frac{1}{2}\ (a + b)h$$

$$A = \frac{1}{2}(610 + 350)X350$$

$$A = \frac{1}{2}\ (960)350$$

$$A = 480X350$$

$$A = 168000mm^2$$

Therefore, the volume of the hoper was calculated to be:

$$v = 168000mm^2\ x\ 350mm$$

$$v = 58800000mm^3$$

$$v = 58.8X10^6mm^3$$

B. Capacity of Depulping Chamber

The capacity of the depulping chamber follow the procedure for the determination of bin diameter in manure spreader as in [8] in equation (3).

$$V = \frac{\pi\, d^2}{4}\,(L_h) \tag{3}$$

where V is the Volumetric Capacity, π is 3.142, d is the diameter of the depulping chamber = 500 mm and $L_h$is the Struck Level of Cylinder while the machine is in operation which is H - δ and H is the height of the depulping = 600 mm and δ is 2 % of H [10].

Therefore, the volume of the depulping machine is:

$$V = \frac{3.142\ \times\ 500^2}{4}\left(\frac{2}{100}\ \times\ 600\right) = 2356.5\ cm^3$$

C. Belt and pulley design

For smooth drive and compactness due to short distance between the two pulley centres, belt and pulley drive system was selected. The velocity ratio, (V.R.) was determined in equation 4 according to [11].

$$V.R = \frac{N_1}{N_2} = \frac{d_1}{d_2} \tag{4}$$

where, N_1 is speed of rotation of electric motor which is 1733 rpm, N_2 is speed of rotation of the shaft in rpm, d_1 is the pulley diameter of electric motor, d_2 is the diameter of the shaft pulley. The motor gear box was used to reduce the speed of the electric motor at 100:10.

$$N_1 d_1 = N_2 d_2$$

where, $\frac{d_2}{d_1}$ is the teeth ratio which is 10:1; therefore, $\frac{N_1}{N_2} = \frac{d_2}{1}$ $\frac{1733}{N_2} = \frac{d_2}{d_1} = \frac{10}{1}$ and $N_2 = 173\ rpm$

D. Design of the Shaft

The shaft was designed as in [11] using the relationship in equation (5). Since the shaft is vertically positioned, there will be minimal or no axial loading on it and the bending moment, $m_b = 0$.

$$d^3 = \frac{16}{\pi\tau}\left(\sqrt{(K_b m_b)^2 + (K_t m_t)^2}\right) \tag{5}$$

where d is the diameter of the shaft, τ is the allowable shear stress of metal with key way = 0.044727 N/m^2 , m_b is the maximum bending moment = 0, m_t is the torsional moment = 121.42 Nm. k_t is the combined shock and fatigue factor applied to torsional moment = 1.0

The Torque or twisting moment, T and the polar moment of inertia, J acting on the shaft were calculated from the relationship in equations (6) and (7) respectively [12].

$$T = \frac{P \times 60}{2\pi N} \tag{6}$$

where P is the power of the electric motor which is 2200W and N is the speed of the shaft which is 173 rpm. Therefore, the twist moment, m_t is:

$$m_t = \frac{2200\ \times 60}{2 \times 3.142\ \times 173} = 121.42\ Nm$$

$$\frac{T}{J} = \frac{\tau}{r} \tag{7}$$

where T is the twist moment, which is 121.42 Nm, J is the polar moment of inertia which is calculated as $\frac{\pi\, d^4}{32} = \frac{3.142 \times 24^4}{32}$ = 60352 and r is 14 mm.

Therefore, from equation 5:

$$\tau = \frac{Tr}{J} = \frac{121.42 \times 12}{603351.5} = 0.044727$$

Substitute in equation 3:

$$d^3 = \frac{16}{3.142 \times 0.044727}\left(\sqrt{(0)^2 + (1\ \times 121.42)^2}\right) = 24$$

$$d = 24\ mm$$

Considering factor of safety to be 6, therefore the diameter, d, of the shaft is calculated as:

$$d = 24\ mm + 6 = 30\ mm$$

E. Design of paddle

The depulping paddle were made of synthetic rubbers and thistles to provide effective means of removal of locust bean pulp from the seed without damaging the seeds. This operation is achieved through combination of cutting, abrasion, and rubbing actions. The paddle creates the cutting effect on the pulp by impact and the clearance between the cylindrical sieve shell and the attached brushes on the paddles creates the desired abrasion and rubbing actions for the depulping operation.

VI. Machine Testing

The ALB depulping machine developed was tested at a constant machine speed of 173 rpm. The ALB was soaked in 5 kg water at a temperature of 20^{o}C for 10 minutes (t), the moisture content (MC) was measured to be 60 % and weighed to 2 kg (W_1). The soaked ALB was then introduced into the depulping machine and was allowed to depulp for 2 minutes with splashing of water from the water reservoir to ease the operations. The seed and the pulp were then collected from the two separate discharge units designed for them respectively. The seeds collected are weighed as W_2. This procedure was replicated for ALB of moisture content 71 % and 78 % respectively. The depulping efficiency, throughput and specific mechanical energy of the machine were calculated as in (11) from the relationship in equations (8), (9), and (10).

$$D.E. = \frac{W_2}{W_1} \times 100 \quad (8)$$

where D.E. (%) is the depulping efficiency, W_1 (kg) is the initial weight of ALB before depulping and W_2 (kg) is the weight of the seed after depulping.

$$TP = \frac{w_2}{t} \quad (9)$$

where TP is the throughput, w_2 (kg) is the weight of the seed after depulping and t (h) is the time taken to depulp.

$$SME = \frac{P \times t}{w_2} \times 100 \quad (10)$$

Where SME (KJ/KG) is specific mechanical energy, P (rpm) is the speed of the motor and W_2 (kg) is the weight of the seed after depulping.

VII. Results And Discussion

The results of the performance evaluation of the ALB depulping machine using 2.2 kW electric motor with step down speed of 173 rpm is shown in Tables 1 and 2.

TABLE 1: Results of ALB depulping machine test

ALB Sample	Moisture Content (%)	Time (min)	Time (h)	Initial Weight (kg)	Final Weight (kg)
A	60	1.1	0.02	2	0.91
B	71	0.9	0.02	2	1.51
C	78	0.7	0.01	2	1.65

TABLE 2: Parameters calculated from ALB depulping machine test

ALB Sample	Moisture Content (%)	Efficiency (%)	Throughput (kg/h)	SME (KJ/kg)
A	60	45.50	82.73	348.5
B	71	75.50	167.78	171.8
C	78	82.50	235.71	122.3

A. Effect of Moisture Content on the Efficiency of ALB Depulping Machine

It was observed that when the moisture content of the ALB was 60 %, the efficiency of the depulping machine was about 46 %. By the time the moisture content was increased to 71 %, the efficiency of the machine increased to 76 % and when it was further increased to 78 %, the efficiency equally increased to 83 %. As shown in Fig. 4, it was discovered that the higher the moisture content, the higher the efficiency of the depulping machine and the lower the moisture content, the lesser the efficiency of the machine which agrees with the work of other researchers on subject [12].

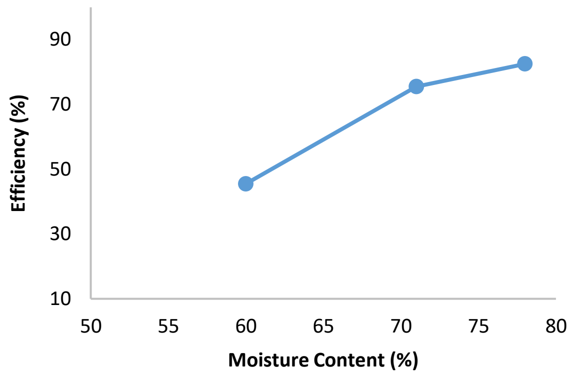

Fig. 4. Effect of moisture content on machine efficiency.

B. Effect of Moisture Contents on the Throughput of ALB Depulping Machine

The throughput of the machine was 236 kg/h when the moisture content of the ALB was 78 %. It reduced to 168 kg/h when the moisture content was reduced to 71 %. A further reduction of the moisture content to 60 %, the throughput decreased to 83 kg/h. As shown in Fig. 5, the throughput of the machine increased as the moisture content of the ALB increases. This can be said to happen because of the hydrophilic nature of the dried ALB to absorb more water which lead to the softness of the pulp and easy depulping.

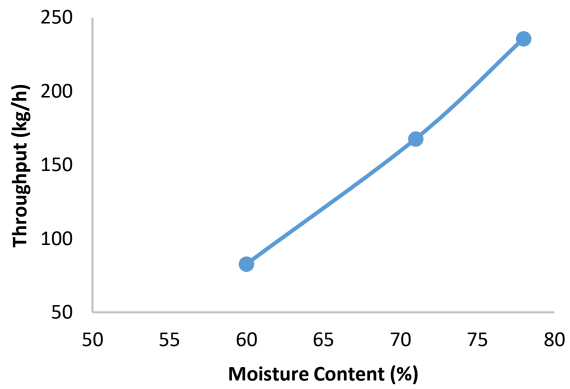

Fig. 5. Effect of moisture content on throughput of depulping machine.

C. Effect of Moisture Contents on the Specific Mechanical Energy of ALBDM

The Specific Mechanical Energy (SME) of the depulping machine was 348.53 KJ/KG when the moisture content of the ALB was 60 % and decreased to 171.85 KJ/KG when the moisture content was increased to 70 %. The trend continued when the moisture content was increased to 78 %, the SME was further reduced to 122.32 KJ/KG. As shown in the scatter diagram of Fig. 6, the SME of the depulping machine decreases with an increase in the moisture content of the ALB.

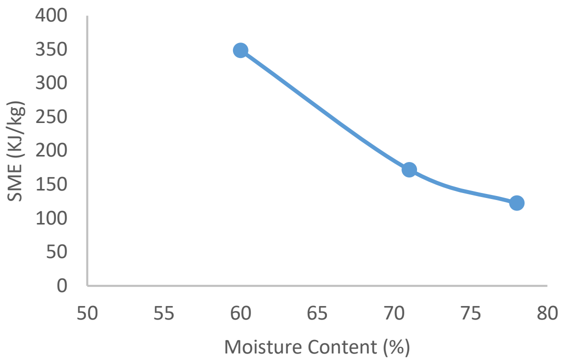

Fig. 6. Effect of moisture content of ALB on SME.

D. Analysis of Variance

The Analysis of Variance (ANOVA) carried out on the parameters calculated on the machine is presented in Table 3. Since $p - value = 0.01\, which\ is \leq 0.05$, therefore, the moisture content of ALB has significant effects on the depulping machine efficiency, throughput and specific mechanical energy.

TABLE 3: ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3124588	2	1562294	8.109704	0.01969	5.14325285
Within Groups	1155870	6	192645			
Total	4280458	8				

VIII. Conclusion

African Locust Bean depulping machine was developed and its performance evaluation was carried out at constant speed 173 rpm. It was discovered for ALB with moisture content of 78 % that the depulping efficiency of the machine was 83%, the throughput was 236 kg/h and the specific mechanical energy was 122.32 KG/KJ. The efficiencies increased with an increase in ALB moisture content. This was same observation for the throughput of the machine. However, the Specific Mechanical Energy of the machine decreases as the moisture content decreased. The development of this machine will eradicate drudgery associated with the processing of ALB in Nigeria. With affordable cost price, the machine is affordable to small and medium scale farmers in the country and in Africa generally where ALB is greatly used as condiments for meal preparations.

IX. Recommendation

The following recommendations are made:

1. The machine speed should be varied for further work.
2. There should be an alternative to electric motor because of the epileptic nature of electricity in Nigeria.

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