Full Paper

DEVELOPMENT OF A LOCUST BEAN DEPULPING DEVICE

O.K. Owolarafe
Department of Agricultural Engineering
Obafemi Awolowo University, Ile-Ife, Nigeria
owolarafe@yahoo.com

T.O. Omobuwajo
Department of Food Science and Technology
Obafemi Awolowo University, Ile-Ife, Nigeria

G. A. Olatunde
Department of Agricultural Engineering
Obafemi Awolowo University, Ile-Ife, Nigeria

O.O. Owagbemi
Department of Food Science and Technology
Obafemi Awolowo University, Ile-Ife, Nigeria

ABSTRACT

Locust bean is an important food condiment that is very rich in protein, carbohydrate fat and oils. Depulping of the seed (which is still carried out manually) is one of the major operations in processing the seed to obtain the condiment. A machine for depulping locust bean was designed, fabricated and evaluated in this study. The machine works on the principles of agitation and abrasion. The comprising of the hopper, depulping chamber equipped with paddle, screw conveyor, screw housing and a discharge chute is mounted on a standing frame and powered by a 2 hp electric motor. The locust bean depulping machine was tested using samples of locust beans soaked for 30 and 60 mins. the soaking efficiency was observed to increase as soaking time was increased from 30 to 60 mins. The highest depulping efficiency of 82.5% was recorded for the sample soaked for 60 min.

Keywords: *Locust bean,, motorised device, depulping, agitation abrasion.*

1. INTRODUCTION

Locust bean *(Parkia biglobosa)* is a perennial deciduous tree with height ranging between 10 and 15 m and sometimes may grow as high as 20 m . It has a rounded or umbrella shaped spreading crown, with drooping leaves without spines. The thick bark is grey in colour with a scaly texture. The plant is native to Africa; it is an important multipurpose tree of West Africa Savannah land, and one of the most common species of the parkland agro forestry system (Audu *et al*., 2004; Sina, 2006,). The tree can also be grown on rocky slopes, stony ridges or sand-stone hills. It is naturally grown in the sub-Saharan, semi-arid zone of Senegal in the west, to Cameroon and Sudan in the east. It is also cultivated in tropical America and western India and West African countries such as Benin, Burkina Faso, Chad and Cote d'Ivoire (Sina, 2006).

African locust bean has valuable domestic, medicinal, and nutritional uses. The most important part being the seed, which is a grain legume, the bean is usually processed to form a strong-smelling food condiment/flavouring known as *Dawadawa* in Niger, Northern Nigeria and Ghana; *Iru* in Southern Nigeria; *Soumbala* in Burkina Faso, Mali, Cote d'Ivoire and Guinea (Audu *et al*., 2004). Dehydrated "*tempeh*" is an equivalent fermented product in Indonesia (Steinkraus *et al*., 1965). The average daily per capital intake of Dawadawa among some Hausas in Northern Nigeria constitutes 1.4% of daily calorie and 5% of the protein (Simeon, 1976).

On a moisture-free basis, the fermented locust bean contains about 31-40% protein, 39-40% oil and 11.70-15.40% carbohydrate (Campbel, 1980). Diawara *et al*. (2000) reported that it has essential acids and vitamins and serves as a protein supplement in the diet of poor families. The yellow powdery pulp surrounding the seed is edible in any form as it contains a high level of sucrose. Locust bean could be added to maize to produce pap with a better protein base, just as in the case of soy-ogi. Dawadawa is used in soups, sauces and stews to enhance or impart meatiness (Klanjcar *et al*., 2002).

Stabilisation of the product is achieved by moulding and sun-drying. (Audu *et al*., 2004). The extraction of locust bean from the seed requires shelling of matured pods, depulping, dehulling, steaming, and subsequent fermentation into various forms of condiments. The local processing is tedious and time consuming. Though efforts have been made to mechanise some of the unit operations in locust bean processing, notably shelling, steaming dehulling and separation (Adewumi, 1988; Ajayi, 1991; Adewumi and Igbeka, 1993; Audu *et al*.., 2004), little consideration has been given to the pulp surrounding the seeds. At present, the depulping of locust bean is still done manually. The seeds obtained after shelling are surrounded by the yellowish powdery pulp. The seeds together with the pulp are placed in a basket or a locally fabricated screen, usually a perforated calabash known as "Ajere". The pulp is removed manually without damaging the seeds. This method is not only tedious but also time-consuming. This study therefore undertakes the design and evaluation of a locust bean depulping device with a view to incorporating the technology into the processing line for locust bean.

2. METHODOLOGY

2.1. Description of the machine

The design simulates the traditional method of rubbing between palms and fingers to create shearing action hence achieving the depulping of locust bean. The operation (which is a prerequisite to dehulling) is a little different from dehulling in the sense that while the seed coat is removed in dehulling, the pulp surrounding the seed is removed here. The design is a modified form of the breadfruit depulping devic (Enibe, 2001). The design as shown in Fig.1 consists of the following units, hopper, screw conveyor, screw housing unit depulping chamber, pulley and the standing frame.

The screw conveyor (Fig. 2) is housed in a screw cage with appropriate clearance between the tip of the conveyor blades and the conveyor housing to avoid breakage of the seed The clearance is such that it is slightly less than the minimum minor diameter of the seeds as determined from available data (Audu *et a.l.*, 2004).

The depulping chamber has seven identical paddles, attached to the main shaft. These paddles are equispaced circumferentially and at different angles to the horizontal shaft. The pulping chamber is cylindrical in shape having a rectangular opening under it and is mounted horizontally on the support frame. This opening facilitates the removal of cleaned locust bean seeds and slurry when desired. The cover of the opening has both outer and inner portions, which can be removed in turns. The inner portion is perforated to allow for the release of the slurry alone while the machine is in operation.

An output shaft is located between two bearings with a pulley keyed to one end. Based on the work of Audu *et al.*, (2004) on dehulling of the seed, a three phase electric motor of 2 hp, running at a speed of about 1435 rpm through a pulley which is keyed directly to the motor shaft. The two pulleys are linked by a V-belt. This arrangement provides some level of speed reduction which is required to increase the resident time of the material in the depulping chamber and achieve efficient removal of the pulp.

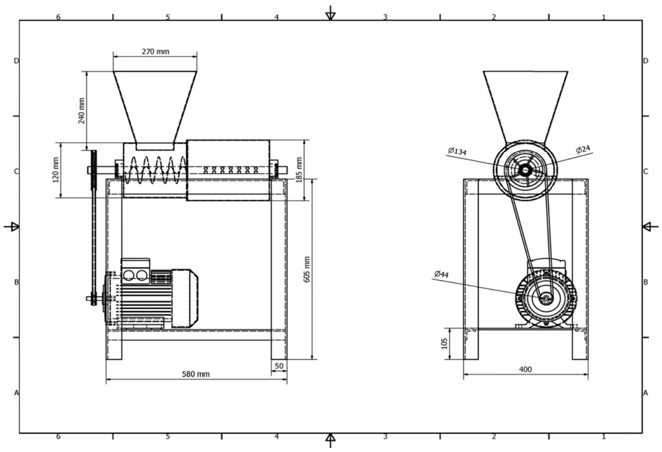

Fig. 1: Projected front and side views of the machine

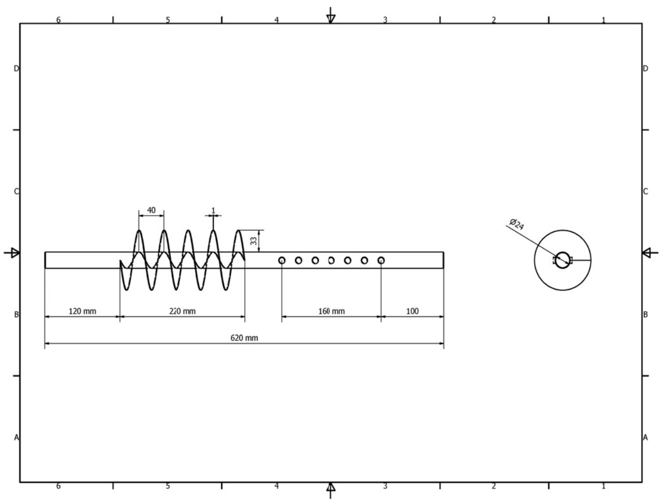

Fig. 2: The shaft of the machine (with the screw conveyor)

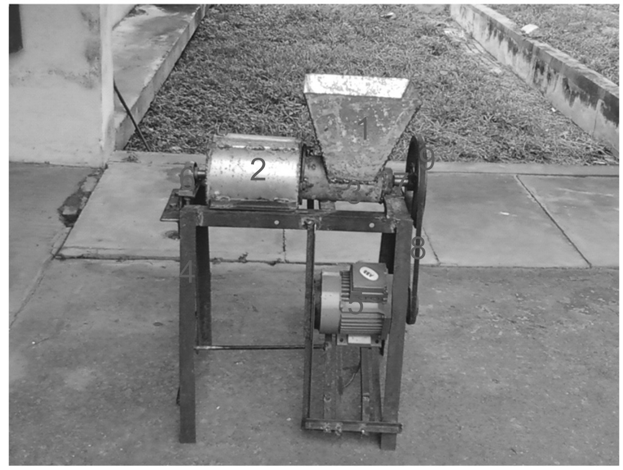

Plate 1: Picture of the machine

2.2. Operation of the machine

With locust bean fed into the hopper then is switched on from the mains and water is supplied. As the shaft is driven the screw conveyor mounted on it set into operation and transports the locust bean to the depulping chamber. In the depulping chamber, the seven paddles together with the abrasive lining of the depulping chamber provide the required agitation and abrasion respectively, thereby depulping the locust bean seeds as it is washed with water. This continues for a period of time until the slurry flowing out of the perforated cover plate at the underside of the pulping chamber is majorly clean water. This gives an indication that the depulping process is complete. As such, the principles governing the mechanical depulping process are agitation and abrasion.

2.3. Design of the shaft

This design is based on maximum shear theory. Shafts are usually subjected to torsion, bending and axial loads (Hall *et al.*, 1983). For torsional loads, the torsional stress τ_{xy} is:

$$T_{xy} = \frac{M_t r}{J} = \frac{16 M_t}{\pi d^3} \text{ (for solid shaft)} \quad (1)$$

For bending loads, the bending stress S_b (tension or compression) is

$$S_b = \frac{M_b r}{I} = \frac{32 M_b}{\pi d^3} \text{ (for solid shafts)} \quad (2)$$

For axial loads, the tensile or compressive stress $S\alpha$ is

$$S\alpha = \frac{4F_\alpha}{\pi d^2} \text{ (for solid shafts)} \quad (3)$$

$$d^3 = \frac{16}{\pi S_s} \{(K_b M_b)^2 + (K_t M_t)^2\}^{1/2} \quad (4)$$

where,

M_t = torsional moment (Nm)
M_b = bending moment (Nm)
K_b = combined shock and fatigue factor applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment

2.3.1 Bending and Torsional Moments

Bending and torsional moments are the main factors influencing shaft design. From the bending moment diagram, the point of critical stress was determined

The torsional moment acting on the shaft can be determined from:

$$M_t = (T_1 - T_2)R- \quad (5)$$

Where,

T_1 = tight side of belt on pulley (N)

T_2 = loose side of belt on pulley (N)

R = radius of pulley (m)

Using the methods described by Hannah and Stephens [13], T_1 and T_2 can be calculated as detailed below (Figs, 3 shows the loading and bending moment diagrams of the shaft).

$$\text{Cos } \left(\frac{\theta}{2}\right) = \frac{r_1 - r_2}{l} \quad (6)$$

Where r_1 = 65 mm, r_2 = 27.5 mm and l = 400 mm

$$\text{Cos } \left(\frac{\theta}{2}\right) = \frac{0.065 - 0.0275}{0.4}$$

$$\text{Cos } \left(\frac{\theta}{2}\right) = 0.0938$$

$$\Theta = 2.954 \text{ rad}$$

Hence angle of wrap of smaller pulley Θ, is 2.954 rad

$$V = 1435 \times \frac{2}{60} \times 3.142 \times 0.0275 = 4.13 \text{ m/s}$$

$$M = \rho\, b\, t$$

where M= mass (kg), ρ (density) = 970kg/m^3 = b (width) = 10 mm and t (thickness) = 11 mm

Therefore, M= 970 × 0.01 × 0.011 = 0.11 kg/m

$MV^2 = T_c$ (for maximum power)

$T_c = MV^2$ (where m is the mass of the belt in Kg)

T_c = 0.11 × 4.132 = 1.88N

$T_1 = 3T_c$

T_1 = 3 × 1.88 = 5.54 N

$$\frac{T_1 - T_c}{T_1 - T_c} = e^{\mu è} \quad (7)$$

Where μ = coefficient of friction between the belt and pulley = 0.12 and θ = 2.954 rad

$$\frac{5.54 - 1.88}{T_2 - 1.88} = e^{0.12 \times 2.954}$$

T_2 = 4.44 N

Therefore T_1 =5.54 N and T_2 = 4.44 N

$M_t = (T_1 - T_2) \times r$

where r = radius of the pulley 0.065 m

= (5.54 – 4.44) × 0.065

= 0.0714 Nm

M_b= 0.78 Nm (from bending moment diagram)

$$d^3 = \frac{16}{s_3}\sqrt{(k_b M_b)^2 - (K_t M_t)^2} \quad (8)$$

For rotating shaft Kb= 1.5 and Kt = 1.0

Mb =0. 78 Nm, Mt = 0.0714 Nm

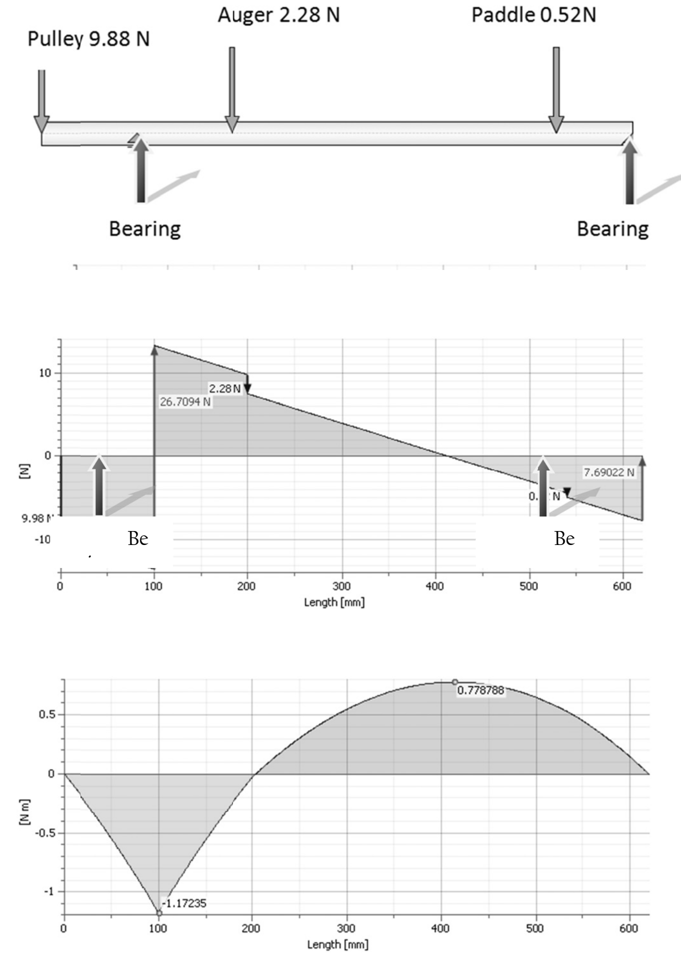

Fig. 3: Loading and bending moment diagrams of the machine shaft

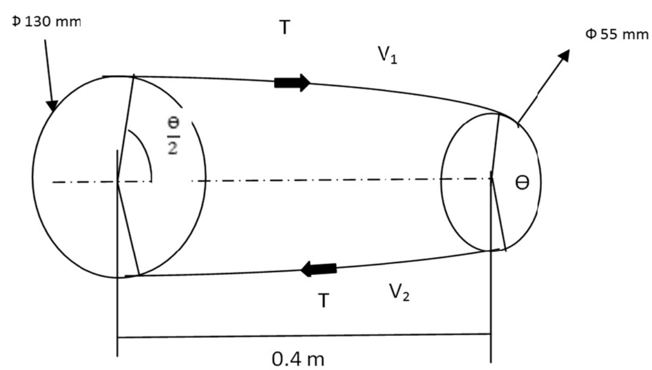

Fig. 4: Belt and pulley arrangement for power transmission on the machine

$$d^3 = \frac{16}{\pi 5.3E6}\sqrt{(1.5 \times 0.78)^2 - (1 \times 0.0714)^2}$$

Therefore, d^3 = 1.122E-6,

d = 0.0104 m hence, 10.4 m

Hence, a shaft diameter of minimum of 15 mm will be suitable

2.4 Materials for Fabrication

Machine parts were fabricated from different kinds of material based on their physical, mechanical and chemical properties. These materials were chosen to maximize the usefulness of the machine and optimize performance as well. Table 1 provides details of the machine parts description.

2.5 Performance Evaluation of the Machine

A bulk quantity of freshly harvested locust bean was obtained from Ilorin in Kwara State of Nigeria. The locust bean was shelled and divided into two portions each weighing 0.45 kg. The shelled pods were prepared to test the machine by varying the moisture content to have two different moisture levels, using the methods reported by Oluwole *et al.* (2004).

Table 1: Material Selection

Parts of the device	Material of construction
Hopper	Gauge 16 steel sheet
Screw conveyor	Galvanised steel
Shaft	Mild steel
Pulping chamber	Gauge 16 steel sheet
Paddles	Galvanized steel rods
Abrasive	Wire mesh
Support frame	Mild steel
Pulleys	Cast iron

The method involved soaking the initially weighed samples in water at room temperature for different duration. The first sample (A) was soaked for 30 mins and the second sample (B) 60 mins. Using an output pulley of diameter 260 mm, giving and output shaft speed of about 300 rev/min, the machine was turned on from the mains and sample A was fed in through the hopper. Water was also introduced through the hopper while the machine was in operation. The operation was allowed to continue until the liquid from the pulping chamber became clean. The machine was switched off and the quantity of water consumed as well as duration of the operation were quantified .

The total number of depulped seeds in three batches scooped at random was counted. Each batch weighed 0.1kg. The depulping efficiency ε was calculated using the expression:

$$\varepsilon = \frac{N_0}{N} \times 100 \text{ - - - - - - - - - - - - - } \quad (9)$$

where

N_0 = the number of depulped seeds after the operation and;

N = the total number of seeds scooped.

3. Results

Using equation (9), the efficiencies for both samples A and B were calculated:

Sample A:

$N_0 = 13 + 20 + 24 = 57$

$N = 28 + 26 + 28 = 82$

Hence, efficiency $(\varepsilon) = \frac{54}{82} \times 100 = 69.51\%$

Sample B:

$N_0 = 23 + 25 + 18 = 66$

$N = 27 + 28 + 25 = 80$

Hence, efficiency $(\varepsilon) = \frac{66}{80}$ X $100 = 82.50\%$

It was observed that the samples with shorter soaking period took a longer time to depulp, consumed more water and had a lower depulping efficiency than those soaked for a longer period. The sample soaked for 30 min (sample A) required 15 litres of water to depulp and depulped in 10 min while sample B required 10 litres and depulped in 5 min. The sample that was soaked for a longer period, took up more water, thus requiring only minimal agitation and abrasion to depulp.

Table 1: Number of Seeds in Different Batches of Sample A

	Batch 1	Batch 2	Batch 3
Number of depulped seeds	13	20	24
Number of undepulped seeds	15	12	14
Total number of seeds	28	26	28

Table 2: Number of Seeds in Different Batches of Sample B

	Batch 1	Batch 2	Batch 3
Number of depulped seeds	23	25	18
Number of undepulped seeds	4	3	7
Total number of seeds	27	28	25

Table 3: Final Output of Processed Samples A and B

	Sample A	Sample B
Efficiency (%)	60.20	82.50
Processing time (min)	10	7
Amount of water consumed (litres)	15	10

4. Conclusion

The availability of data on the mechanical and physical properties of locust bean (*Parkia biglobosa)* has been useful in the development of a mechanical device to depulp it. The design, construction and testing of a locust bean depulping machine carried out in this study was successful. It was observed that soaking time affected the efficiency of the machine. Depulping efficiency increased with increase in soaking period, while amount of water consumed and period of depulping decreased with increase in soaking period. The machine was able to achieve a depulping efficiency of 69.51% and 82.50% for soaking periods of 30 min and 60 min, respectively. This suggests that an even higher period of soaking can achieve better depulping result. With the current results, the machine can be perfected for inclusion in the locust bean processing industry.

References

Adewumi, B. A., Design, fabrication and testing of a steamer/dehuller for locust bean. Unpublished M.Sc thesis. University of Ibadan, Ibadan, Nigeria, 1988.

Adewumi, B. A. and Igbeka J. C The effect of steaming on the physical and dehulling characteristic of locust beans (*parkia bilobosa*). Trop. Agric (Trinidad) 70 (3), 380 – 382, 1993.

Ajayi, O.A., Design of a thresher for locust bean. Agricultural mechanisation in Asia, Africa and Latin America. 22 (3): 21-24, 1991.

Audu, I., Oloso, A. and Umar, B., Development of a concentric cylinder locust beans dehuller. Agricultural Engineering international. The CIGR Journal of scientific Research and development. Manuscript PM 04 003 volume VI A, 2004.

Campbell, P.G., African locust bean (Parkia species) and its West African fermented food product, dawadawa. Ecology of Food and Nutrition. 7(3): 123-132, 1980.

Diawara, B., Sawadogo, L., Amoa-Awua, W.F. and Jakobsen, M., Capability building for research and development in quality assurance and fermentation technology for African fermented

foods HACCP system for traditional African fermented foods. soumbala. WAITRO. 2000.
Enibe, S.O., Design, Construction and testing of a breadfruit depulping machine, Landwards, summer, 16-21, 2001.
Hall, A.S., Holowenko, A.R. and Laughlin, H.G., Schaum's outline of theory and problems of machine design. McGraw-Hill Publishers Incorporated, 113-121, 1983.
Hannah, J. and Stephens, R.C. Mechanics of machines. Advanced theory and examples 2nd Edition, Viva Books Private Limited (Publishers) 200-208, 1999.
Klanjcar J., Kopac M., Kosem D. And Kozlovic K., Dawadaw www.bf.unilj.si/zt/biotech/seminar_abstract/zivil 2002
Oluwole, F.A., Aviara, N.A. and Haque, M.A.., Effect of moisture content and impact energy on the crackability of sheanut, Journal of Food Engineering, 65: 117-123, 2004.
Simeon, E.B., Caloric and protein intake in three villages in Northern Zaria Province. Samaru Agriculture Newsletter 18: 13-36, 1976.
Sina, S., Reproduction et diversite genetique chez *Parkia biglobosa* (Jacq) G. Don. PhD Thesis, Wageningen University, the Netherlands, 2006.
Steinkraus, K. H., Van-Buren, J.P., Hackler, L.R. and Hand, D.B., A pilot plant process for the production of dehydrated, Tempeh Food Technology, 19 (I): 63-68, 1965.