Development of a locust bean processing device

Oseni Kehinde Owolarafe · Dare Aderibigbe Adetan ·
Gbenga Adebayo Olatunde · Adebowale Oladeji Ajayi ·
Ile Kehinde Okoh

Revised: 25 February 2011 / Accepted: 2 March 2011 / Published online: 17 April 2011
© Association of Food Scientists & Technologists (India) 2011

Abstract A locust bean steaming, dehulling and separating machine was designed in this study by simulating the traditional processing operations. The machine consist of pressure cooking pot (as the cooking device) mounted on a separate stand and equipped with rocker- arm system to facilitate discharge of contents, a hopper made of mild steel sheet, the dehulling unit made of screwed shaft and abrasive barrel, a conical-shaped separating section equipped with paddles (made of aluminum material) and a standing frame to support the whole arrangement. The machine was evaluated by processing seed at cooking times of 30, 45, 60 and 90 min. The result indicated increase in dehulling efficiency with increase in cooking time from 30 to 60 min while it dropped at 90 min. The highest dehulling efficiency of 82% was obtained at cooking time of 60 min. The separation efficiency obtained at this optimal cooking time was 79%.

Keyword Locust beans · Nutritive value · Processing ·
Drudgery · Machine · Efficiency

The African locust beans (*Parkia biglobosa*, (Jacq.) G. Don) is a member of the *leguminosae* family. The tree is a 7–20 m tall perennial deciduous tree named *Parkia Biglobosa* after Mungo Park, Scot who made two remarkable journeys of exploration into the interior of West Africa (Adewumi and Igbeka 1993; Audu et al. 2004) The

multipurpose tree has seeds with a hard testa and these seeds are large with a mean weight of about 0.3 g/seed and the cotyledons form about 70% of the weight. These seeds are borne in pods that may carry up to 30 seeds embedded in a yellow pericarp and the colour of these pods change from pink brown to dark brown as maturity sets in. The tree also bears alternate, dark green bipinate leaves and hermaphrodite flowers. The seeds are brown-blackish. Each seed has a 0.5–1 cm funicle, spherical-ovoid and slightly compressed laterally. The testa is hard, smooth and glossy. Seed size varies within pod, with those at the centre being largest. It is widely used for its remarkable nutritional value and the dietary value it contains. The seeds are rich in protein, lipids and vitamin B2 and when fermented are rich in lysine. The fat in the beans is nutritionally useful (approximately 60% unsaturated). The seeds are which are particularly valued for their high protein are fermented for cooking. Fermented locust beans are commonly used in soups and stews. The embedding yellow pulp of the seeds sometimes called dozim which have a high energy value is used as a sweetener as it contains 60% sugar (Audu et al. 2004) It is also supposedly a water purifier and is taken for fevers. The fruit is a source of food during drought. The leaves are edible and sometimes mixed with cereal and are added in lotions for sore eyes burns, haemorrhoids and toothache. Medicinally, the bark is used as a mouthwash and also macerated in baths to cure leprosy. It is also used for a wide range of ailments such as malaria diarrhoea, jaundice and so on (Audu et al. 2004). The tree is a good source of timber though is rapidly spoiled by pests.

The traditional method of processing locust beans is usually a reference point from which mechanical devices are made. Adewumi and Olalusi (1995) reported that the processing of locust beans is mainly done locally by women in Africa. Processing of locust beans involves shelling of

O. K. Owolarafe (✉) · G. A. Olatunde
Department of Agricultural Engineering,
Obafemi Awolowo University,
Ile-Ife, Nigeria
e-mail: owolarafe@yahoo.com

D. A. Adetan · A. O. Ajayi · I. K. Okoh
Department of Mechanical Engineering,
Obafemi Awolowo University,
Ile-Ife, Nigeria

matured pods, boiling, dehulling, separation of the hull from the beans and fermentation into various forms of condiments. Women are the key player in locust bean processing. Traditional Boiling is carried out for cooking the beans with the hull for 8 to 10 h using firewood as fuel (Oyewole and Odunfa 1990). This initial stage of processing makes the process time consuming with the seeds usually degraded. Locust bean is dehulled by mashing the boiled seeds with bare feet near the riverside or using pestle in a mortar (Adewumi and Olalusi 1995). If a mortar is used some clean sand may be added to ease the removal of the hull. The process of ridding the edible seeds from the hull in locust bean processing is implied as separation. The separation process is carried out locally using the principle of buoyancy or by using a screen, most often a perforated calabash referred to by the Yorubas as 'Ajere'. The undeveloped beans are sorted out by washing in water. Proximity to water supply is required and for this reason the process is carried out in a stream.

The application of various, evolving technological methods have resulted in modern methods of processing the African locust bean (Audu et al. 2004, Adewumi et al. 1999). Boiling units such as steamers and pressurized vessel are employed in order to enhance good dehulling characteristics and high quality of the final product. The use of gas and charcoal as fuel has also been embraced since this provides clean operation and sustained heat input during boiling. In lieu of the impact loading and rubbing action against the wall of the mortar carried out traditionally on boiled seeds, dehullers are used to achieve the same end with rubbing action(force) against the wall of the dehulling chamber. Audu et al. (2004) reported that the guiding principles are very much the same as that of the traditional process; abrasion. This is usually accomplished with a mild steel rotating auger (conveyor) with coils of the same material (mild steel) wound about the perimeter with a gap of 6.5 mm clearance between the coil and the abrasive wall of the dehulling chamber. This is to allow the shear force act on the seeds whose average thickness is about 8 mm, thereby obtaining dehulled seeds. Separation of the hulls from the edible seeds has constituted a challenge due to the sticky nature of the seeds with the testa (Adewumi et al. 1999). Hydrocyclone separation has been used in separating locust bean from the hull but only 37% efficiency was recorded and therefore has not been adopted. Steaming and dehulling are still being handled by separate device and this induces a lot of handling and hence longer processing time is recorded. There is no information in literature on the combination of the key unit operations viz: boiling, dehulling and separation. The need for technological intervention that can handle these three operations as a component will go a long way to facilitate the seamless processing of locust bean. This study undertakes the development of a processor that combines the three operations for small scale locust bean processors.

Methodology

The guiding principles

The dehulling process is not feasible until appropriate boiling and separation processes are incorporated into the design. The boiling process is aimed at creating good dehulling characteristics which is achieved by the weakening of the bond between the testa and the cotyledons. This, when carried out using a pressure pot is ready for dehulling in 30–50 min between the temperature range of 121 °C and 151 °C (according to Oyewole and Odunfa 1990). Adewumi and Igbeka (1993) reported that when the bean is allowed to cool for 5 min after boiling, it poses a dual advantage of both increasing the dehulling characteristics of the dehulling surface and upon condensation, the water that migrated into the seed during the boiling process settles between the cotyledon and the testa thereby weakening the bond. Therefore the use of pressure-cooking system was chosen for the boiling process. The cooking pot which was used for the device was purchased from a market and it has a rated capacity of 5.5 l of water with maximum temperature of 121 °C and pressure of 81 kPa.

The dehulling process seeks to impact the seeds with a shear force for separation to occur. Dry dehulling is carried out in some areas but this, though done with the mortar and pestle gives an impact, also seeks to provide the major required shear force. The impact force is ensured not to exceed the compressive force on the seed otherwise, it may lead to crushing of the seeds to be dehulled. 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 vanes which helps create turbulence in the water. The result of this is that the heavier cotyledons are thrown down. According to Archimedes' principle, the lighter testa displaces its own weight in the flowing runoff water thereby achieving separation.

Component parts of the machine

The boiling unit is made up of different parts such as the boiling chamber and the source of energy. The boiling chamber is a pressure pot (purchased from the market has a capacity of about 0.5 kg of locust bean thus making it a batch type) which is equipped with the rocker system by which the content of the cooking pot is emptied into the hopper. The source of energy for this part of the device is gas. Apart from this being a clean and consistent source of heat, it is in the long run one of the cheapest. The fuel compartments can however be conveniently modified for the use of charcoal or wood.

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.

The separating unit can be described as a cylindrical bowl to collect the dehulled beans. The bowl has a slit by

the side with a protruding set of lips that permit exit of dirty water and the testa of the beans. It also has a spindle with paddles welded on it to create centrifugal motion that is necessary to effectively separate the testa from the dehulled

Fig. 1 Orthographic projection of the machine (a -Front elevation, b-side view, c-plan)

seeds in the fastest possible time. Figure 1 shows the plan and elevation of the machine and Fig. 2 shows the assembly of the machine.

Design for power requirement

Power required to drive the shaft, (P_s)

The power requirement P , can be divided into two parts

- Power required to drive the shaft (P_s) and,
- Power required to dehull (P_t)

The power required to drive the shaft, P_s was obtained using the relation below (Hall et al. 1983)

$$P_t = T\omega$$

$$T = \frac{bt d^a}{12}$$

Where

- P_t power needed to dehull [W]
 T Torque [Nm]
 b thickness [m]
 d breadth [m]
 t shear stress

for steamed locust beans, t is 9086.86 N/m² (Audu et al. 2004)

ω angular speed; it is given by

$$\omega = \frac{2\pi N}{60}$$

Where,

N speed in revolution / minute

Using the above equation, for a speed of 60 rpm (assumed in practice for a human being) P_t is found to be 11.2 W

To drive the pulley the power required P_s was assumed to be 74 W (i.e the human power as given by Owolarafe et al. 2002, 2007)).

The total power was then found as

$$P = P_s + P_t = 85.2W$$

Design of the dehulling chamber shaft

The properties of the selected shaft material are:

Allowable shear stress, $S_s = 4 \times 10^6$ N/m² (for shaft with a keyway)

Length of shaft $L_s = 700\text{mm} = 0.7\text{m}$

For a rotating shaft with gradually applied load, the bending fatigue factor,

K_b 1.5 and the tortional fatigue factor

K_t 1.0 (Hall et al. 1983)

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Frame	Galvanized Steel
2	1	Platform	Stainless Steel
3	1	Dehulling Chamber	Stainless Steel
4	1	Shaft	Stainless Steel
5	1	Hopper	Stainless Steel
6	1	Separation Chamber	Stainless Steel
7	1	Separation Shaft	Stainless Steel
8	3	Bearing house	Mild Steel
9	1	Bevel Gear1	
10	1	Bevel Gear2	
11	3	CSN 02 4645 - B 71905	Single row angular contact ball bearings
12	1	Delivery	Stainless Steel
13	1	Tripod Stand	Galvanized Steel
14	1	JIS B 2051 Screwed Gate Valve - 10K 2	Gate Valve
15	1	Pressure Pot	Pressure Cooking Pot
16	1	Handle	Galvanized Steel

Fig. 2 assembly of the machine

The loads on the shaft are due to

- Locust seed: the mass of locust bean was determined by weighing
 Mass of locust bean = 500 g = 0.5 kg
 Weight of locust bean = $0.5 \text{ kg} \times 9.81 \text{ m/s}^2 = 4.905 \text{ N}$
- Weight of the auger was estimated (Autodesk Inventor 2010)
 Mass of the auger = 520 g = 0.52 kg
 Weight of the auger = 5.10 N

Therefore,

Sum of clockwise moments = sum of anticlockwise moment as shown in Fig. 3

$$R_a = 15.3 \text{ N}$$

$$R_b = 19.7 \text{ N}$$

$$R_c = 1.5 \text{ N}$$

Maximum bending moment $M_b = 0.1975 \text{ Nm}$

But,

Fig. 3 Loading, bending moment and deflection for the shaft

Tortional moment, $M_t = 9550 \text{ kW/rev min Nm}$ (Hall et al. 1983)

$$\text{Human effort in watts} = 75 \text{ W} \\ = 0.075 \text{ kW}$$

$$\text{Expected rpm} = 60$$

$$\text{Therefore, } M_t = 9550 \times 0.075 / 60 \text{ Nm} \\ = 11.938 \text{ Nm}$$

The required shaft diameter is determined by employing the formula (Hall et al. 1983),

$$d^3 = \frac{16}{\pi S_3} \sqrt{(K_t M_t)^2 - (K_b M_b)^2} \\ d^3 = 1.52 \times 10^{-5} \text{ m} \\ d = 2.48 \times 10^{-2} \text{ m} \\ d = 24.8 \text{ mm}$$

Therefore the minimum diameter for the shaft should be 25 mm

Hopper design

Bulk density of locust beans seed = 538.02 kg/m^3 (Ogunjimi et al. 2001)

Max allowable mass of locust beans = 500 g

Required volume of hopper = maximum volume of locust beans seed that can be loaded at a time

$$= \frac{0.5 \text{ kg}}{538.02 \text{ kg/m}^3} \\ = 9.293 \times 10^{-4} \text{ m}^3$$

The hopper was made of stainless material with dimension is $250 \times 250 \times 270 \text{ mm}$ inclined at an angle of 73.6° to the base (based on the work of Ogunjimi et al. 2001). The total volume is 0.061 m^3 with maximum capacity of 0.5 kg.

Dehulling chamber

Dehulling chamber consist of a rectangular drum with an abrasive lining made of stainless steel and a helical shaft with a radial gap of 6.7 mm (the design specification was adopted from Audu et al. 2004)

Gear drive selection

The parameters considered for the gear selection is presented in Tables 1 and 2

Design of the separating unit

The separation unit consists of the separation bowl, loaded with specially designed spindle with paddles to create

Table 1 Some basic features common to the gears

Component	Parameter
Gear Ratio	1.00 ul
Tangential Module	3.00 mm
Helix Angle	0.00 deg
Tangential Pressure Angle	20.0 deg
Shaft Angle	90.0 deg
Normal Pressure Angle at End	20.0 deg
Contact Ratio	1.72 ul

centrifugal motion such that the coat of the seed will float and can be collected at the exit point (lip) at the top of the separation bowl. The separating chamber operates under the principle of floatation. The dehulled seed naturally sink in water while the coat floats. During operation, the turbulence in the separating chamber aids in detaching coats that are loosely attached to the seed. The rotating shaft is driven by the main shaft through bevel gear arrangement inclined at 90° . After the operation the tap at the base of the chamber shall then be opened for collection of clean locust beans seed.

Separating chamber shaft design

Volume required for separation

Bulk density of locust beans = 538.02 kg/m^3

Maximum load = 0.5 kg

The volume occupied will be $9.29 \times 10^{-4} \text{ m}^3$

However, since separation involve two layers: the top for the coat and the bottom for the cotyledon then the need for a design with a considerable height for the separation. From preliminary experiment, a minimum of 120 mm height will be sufficient. However, 126 mm was used for the machine.

An outlet at 105 mm for the coat to flush out was incorporated in a separating chamber with a height 386 mm,

Therefore the total volume of the chamber was estimated to be $7.01 \times 10^{-3} \text{ m}^3$

Table 2 Attributes of the gears

	Bevel Gear 1	Bevel Gear 2
Number of Teeth	30 ul	30 ul
Unit Correction	-0.2485 ul	0.2485 ul
Pitch Diameter at End	90.0 mm	90.0 mm
Pitch Diameter in Middle Plane	72.04 mm	72.04 mm
Outside Diameter at End	93.19 mm	95.3 mm
Outside Diameter at Small End	56.0 mm	57.3 mm
Root Diameter at End	83.8 mm	85.96 mm
Vertex Distance	43.41 mm	42.35 mm

For the separating shaft design there will be a centripetal force which will be acting toward the shaft at the center since the shaft is rotating.

$$\text{centripetal force} = \frac{mv^2}{r}$$

Where m is the mass

Velocity is 60 rpm = 3.143 m/s

R is the radius of the chamber = 0.114 m

Mass of water on the shaft = 7.01 kg

Mass of the locust beans = 0.5 kg

Mass of the shaft = 1.93 kg

Total mass of the paddle = 0.32 kg

The total mass acting on the shaft will be the summation of the masses exerted by the locust beans, paddle, shaft and water which is equal to 9.76 kg. Since this force are uniformly distributed in their effect over the shaft.

$$\begin{aligned} \text{The force exerted} = \text{centripetal force} &= \frac{9.76 \times 3.142^2}{0.112} \\ &= 860.29 \text{ N} \end{aligned}$$

Therefore, converting the weight to uniformly distributed load = $860.29/0.281 = 3.06 \text{ N/mm}$

The loading and bending moment diagrams are shown in Fig. 4.

Fig. 4 Loading and bending moment diagrams for the shaft of the separating chamber

Sum of clockwise moments = sum of anticlockwise moment

$$R_a = 48.83 \text{ N}$$

$$R_b = 58.50 \text{ N}$$

Maximum bending moment $M_b = 6.62 \text{ Nm}$

But,

Tortional moment, $M_t = 9550 \text{ kW/rev min Nm}$ (Hall et al. 1983)

$$\begin{aligned} \text{Human effort in watts} &= 75 \text{ W} \\ &= 0.075 \text{ kW} \end{aligned}$$

$$\text{Expected rpm} = 60$$

$$\begin{aligned} \text{Therefore, } M_t &= 9550 \times 0.075 / 60 \text{ Nm} \\ &= 11.938 \text{ Nm} \end{aligned}$$

The required shaft diameter is determined by employing the formula,

$$\begin{aligned} d^3 &= \frac{16}{\pi S_3} \sqrt{(K_t M_t)^2 - (K_b M_b)^2} \\ d^3 &= 6.37 \times 10^{-6} \text{ m} \\ d &= 1.85 \times 10^{-2} \text{ m} \\ d &= 18.5 \text{ mm} \end{aligned}$$

Therefore the minimum diameter for the shaft should be 19 mm but 25 mm shaft was used

Machine evaluation

About 0.3 kg of the locust bean was cooked for 45 min, 60 and 75 min based on a preliminary test to give the exact range of the preferred cooking time. Having cooled the beans for about 5 min to reduce the adhesive force between the testa and the cotyledons, it was introduced by raising the lever and tipping in that bid into the hopper. The time taken to process i.e. dehull each batch of the sample for each cooking time was noted. Data collected include the machine throughput, dehulling efficiency and separation efficiency.

The machine throughput was determined using the formula below

$$\text{Machine throughput} = \frac{W_p}{t}$$

where;

W_p = weight of material processed in kg

t = time taken in hr

The dehulling efficiency (η_d) was calculated with the following formula

$$\eta_d = \frac{\text{number of dehulled beans}}{\text{total number of processed beans}}$$

Fig. 5 Dehulling efficiency of the machine at different steaming time

The separation efficiency (η_s) was determined using the formula

$$\eta_s = \frac{\text{weight of testa collected through the slit}}{\text{total weight collected}}$$

Results and discussion of performance evaluation of the machine

Fig. 5 shows the dehulling efficiencies of the machine at different steaming time. It could be observed that the dehulling efficiency increased with increase in cooking time from 15 min to 60 min, this is due to the fact that the coat is softer and hence more coats are removable from the seeds that at as cooking time increased. It was however

Table 3 Materials for fabrication of components and projected cost

Materials	Components used for	Amount in NGN Naira(#)
Mild steel sheet	Body of the device, Hopper, Stool for the burner	5,600
Aluminum Sheet	Spindle with paddles, Separation bowl	3,900
Mild steel Rod	Rocker arm and tip	850
Mild steel	Motor stand, Mounting table	3,500
Angle Iron	Helical shaft	7,000
	Bevel gears	4,500
	Pulleys (2)	1,300
	Gate valve	1,200
	Journal bearings	3,800
	Electrodes	500
	Bolts and Nuts	900
Accessories	Pressure pot, Gas cooker	5,400
	Workmanship	5,000
Total		43,450*

This amounts to about \$300.00 or 15,000.00 Indian Rupees

observed that the dehulling efficiency dropped as cooking time was increased from 60 to 75 min and may be due to the fact that at a cooking time of 75 min, the coats were very soft and sticky, so they are difficult to remove from the seeds. At the optimal cooking time (60 min) the separation efficiency was found to be 79%. The throughput of the machine was found to be 0.5 kg/h.

Cost estimation

Table 3 gives the cost for the development of the prototype of the locust bean dehulling device that incorporates both the boiling process and the separation process. The cost of producing a copy of the machine was estimated by costing the material used for the fabrication including the workmanship.

Conclusion

A prototype device for cooking, dehulling and separation of dehulled beans and hulls was developed in this study. A preliminary evaluation of the machine in terms of efficiency and cost- effectiveness indicates that it has a high potential in substituting the manual method of carrying out the three unit operation. However there is still room for improving the efficiency of the machine which may be embarked on.

References

- Adewumi BA, Igbeka JC (1993) Note on the effect of steaming on the physical and dehulling characteristics of locust beans (*Parkia Biglobosa*). *Trop Agric (Trinidad)* 70(3):380–382
- Adewumi BA, Olalusi AP (1995) Performance of a manually operated concave type locust bean dehuller. *J of Agric Tech* 6(2):23–30
- Adewumi B, Adedokun A, Adebola EO (1999) Characteristics of an hydrocyclone for cowpea hull separation. *J of Applied Sci* 3 (3):1310–1326
- Audu I, Oloso A, Umar B (2004) Development of a concentric cylinder locust beans dehuller. *Agricultural Engineering international, the CIGR Journal of Scientific Research and Development, volume VI Article No. PM 04 003, August 2004.*
- Autodesk inventor (2010) 3D machine design and analysis professional edition, Autodesk Inc, 111 McInnis Parkway San Rafael, CA 94903 USA
- Hall AS, Holowenko AR, Laughlin HG (1983) *Schaum's outline series of theory and problems of machine design.* McGraw-Hill Publishers Incorporated, New York, pp 113–121
- Oyewole OB, Odunfa SA (1990) Effects of cooking method on water absorption and ease of dehulling in the preparation of the African locust beans for Iru. *Inter J of Food Sci and Tech* 25(4):461–463
- Ogunjimi LAO, Aviara NA, Aregbesola OA (2001) Some engineering properties of locust beans seed. *J of Food Eng* 55(2):95–99
- Owolarafe OK, Sanni LA, Ogunyomi OT, Edinowe AS, Faborode MO, Ajibola OO (2002) Development of a hand-operated palm fruit stripper for spikelets. *J Agric Eng Tech Nigeria* 10:59–64
- Owolarafe OK, Murtala OA, Ogunsina BS (2007) Development of an okra slicing device. *J Food Sci Tech Mysore India* 44 (4):426–429