

DEVELOPMENT OF A CONCENTRIC CYLINDER LOCUST BEAN DEHULLER

Idriss Audu¹, A.O. Oloso² and Bobboi Umar¹
idrissaudu@hotmail.com, bobboiumar@yahoo.co.uk

¹Department of Agricultural Engineering, University of Maiduguri, Maiduguri, Nigeria

²Department of Agricultural Engineering, University of Ibadan, Ibadan, Nigeria

ABSTRACT

A locust bean dehuller was developed so as to reduce the amount of time and labour required in the traditional manual dehulling of African locust bean (*Parkia biglobosa*) seeds, which are processed into a food condiment and flavouring agent that is popular in many African countries. The dehuller principally consists of two concentric cylinders, a power transmission shaft and a prime mover. The space between the two cylinders constitutes the dehulling chamber. After design and construction, the dehuller was evaluated based on three parameters, namely moisture content of beans, length of the dehulling head and the speed of rotation of the inner cylinder. Tests showed that efficiency of the machine increased linearly with increases in all the three parameters. The throughput of the dehuller decreased with increases in moisture content and length of dehulling head, but increased with increase in dehulling speed. The maximum values of dehulling efficiency and throughput obtained were 70.3% and 0.51 kg/min. respectively. This paper describes the design and performance evaluation of the dehuller as well as the implication of the results obtained.

KEYWORDS: Locust beans, dehuller, dehulling efficiency

INTRODUCTION

African locust bean (*Parkia biglobosa*) is common around villages in the Savannah areas of West Africa where it is left standing when land is cleared, or sometimes planted and trees are individually owned (Dalziel, 1937). The tree is about 7 – 20 m high and bears pods that occur in large bunches and vary between 120 – 300 m in length (Odunfa, 1985). Each pod may contain up to 23 seeds (Hopkins, 1983).

The most important use of African locust bean is found in its seed, which is a grain legume, although it has other food and non-food uses. The locust bean, when dehulled

and cooked, is fermented to form a strong-smelling food condiment/flavouring agent in the entire Savannah region of West Africa. The condiment is called *dawadawa* in Niger and northern Nigeria and Ghana, *iru* in southern Nigeria and *soumbala* in Burkina Faso, Mali, Cote d'Ivoire and Guinea.

On a moisture-free basis, the fermented locust bean contains about 40% protein, 32% fat and 24% carbohydrate (Campbell-Platt, 1980). Thus, apart from being a food condiment the fermented bean also contributes to the calorie and protein intake. According to Diawara et al. (2000), it has essential acids and vitamins and serves as a protein supplement in the diet of poor families. *Dawadawa* is used in soups, sauces and stews to enhance or impart meatiness (Klanjcar et al., 2002).

The production of fermented locust bean has remained a traditional family art practised in homes with rudimentary utensils. The traditional processing method consists of steaming, dehulling and fermenting the beans by covering them with cloth or leaves. Some consumers further grind the fermented bean into a thick paste, which is finally moulded into balls or circular platelets and sun-dried. According to Beaumont (2002), spices and additives such as salt are incorporated before moulding the final product, while sun drying is undertaken to facilitate its stabilisation.

Beaumont (2002) identified several constraints to the production and consumption of the condiment. These include, among others, low production due to the use of rudimentary equipment, high wood fuel consumption and poor manufacturing practices. Dehulling of the locust beans is time consuming, laborious and inefficient. Consequently, the production of this food condiment has not increased substantially. Its declining popularity, especially among the growing urban population has led to rapid increase in the import of foreign soup flavours. In order to increase supply, it is necessary to modernise production techniques and optimise processing conditions.

Oloso (1988) gave a four-point suggestion on how to upgrade the production technology of fermented locust bean. According to him, a steamer should be designed to hasten the softening of the bean coat, a machine should be designed to remove the bean coat, optimum temperature and relative humidity should be provided to reduce the time required for fermentation and a better post fermentation technique is necessary to protect and prolong shelf-life and to render the fermented bean in a more presentable form. Other researchers reported on the effects of soaking duration, soaking water temperature and steaming on dehulling.

Reichert et al. (1979), Kon et al. (1973) and Despande et al. (1982) among others, carried out wet dehulling of various soaking duration of cowpea and found out that duration of soaking did not seem to have effect on dehulling efficiency. Water temperature and soaking time were found to increase efficiency of dehulling (Forbus and Smith, 1971).

In his attrition-type dehuller, Oloso (1988) observed that for locust beans, moisture content as well as dehulling efficiency increased with duration of steaming (up to four hours). He also observed that dehulling efficiency was higher at higher speeds. Ojo (1989) also obtained similar results in experiments with the same crop.

Currently, locust beans processing in Nigeria is done manually. This traditional method is laborious, time-consuming and inefficient. There is the need to develop a simple and relatively cheap machine that can lead to improved dehulling of the beans. The objective was to design, construct and evaluate a locust bean dehuller of the concentric cylinder type.

DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF THE DEHULLER

A number of points were considered during the design. Such points include the cost of construction, power requirement of the machine and labour requirement in operating the machine. Also considered in the design was the ease of replacement of component parts in case of damage or failure.

The dehuller consists of 4 principal parts, viz.: the outer cylinder, the inner cylinder, the power transmission shaft and the power source. The complete assembly of the dehuller is shown in Figure 1. It is 0.55 m wide, 0.70 m long and 0.85m high.

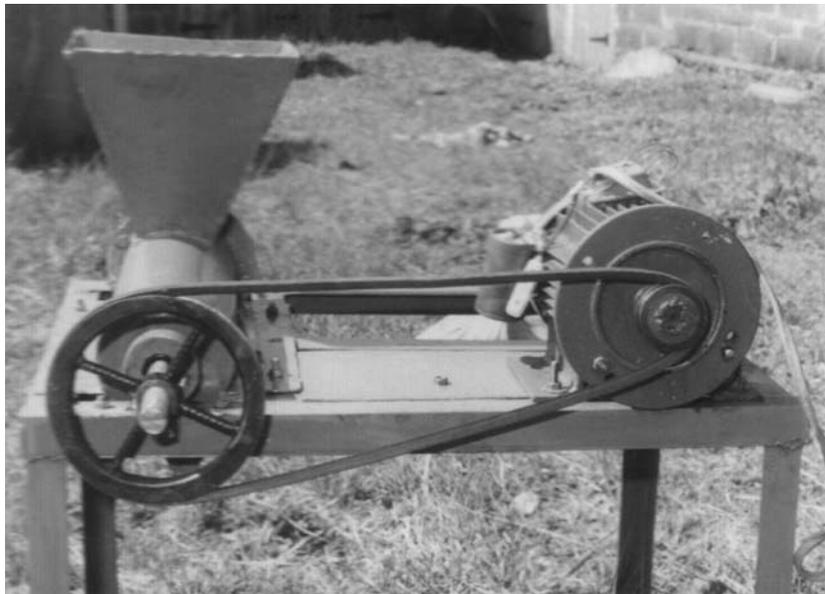


Figure 1. The complete assembly of the dehuller

The outer cylinder is made of gauge 16 steel (1 mm thick) 400 mm long and 127 mm in diameter. An outlet, 20 mm from one end, was provided at the lower surface and the inlet at the upper surface to which the hopper is welded is 10 mm from the other end (see Figure 1). The hopper is also made of gauge 16 steel sheet with 4 sides all slanting towards the inlet at an angle of 72° to the horizontal.

The inner cylinder is made of Ayan wood (*Distemonanthus benthamianus*). The density and modulus of elasticity of the wood were 704 kg/m^3 and 9500 N/mm^2 respectively (Oloso, 1988), and it is 114 mm in diameter and 280 mm long with the power transmission shaft (in two pieces) fixed to it tightly at both ends, so that both the wood and the shaft appear as a single unit and rotate together.

The first 100 mm length of the wood accommodates a screw type auger. The screw is made of 5 mm diameter iron rod with drilled holes to allow fastening to the wood with nails. The remaining 180 mm length of the wood was covered with roughened zinc sheets in 3 parts. The sheets can be replaced whenever the roughened surface is dulled. The inner cylinder can rotate freely inside the stationary outer cylinder when powered through the shaft via a V-belt/pulley arrangement. The gap between the two cylinders is 6.5 mm and this is enough to dehull the steamed beans whose average thickness is about 8 mm (Oloso, 1988).

The mild steel solid shaft for power transmission is 20 mm in diameter and 490 mm long. It is supported at both ends by ball bearings, which are in turn bolted to the stand.

Power Requirement

The power requirement, P , can be divided into three parts; (1) power required in dehulling, Ph ; (2) power required to drive the inner cylinder, Pc ; and (3) power required to drive the pulley, Pp .

The power required in dehulling was obtained from the following equations

$$Ph = T\omega \quad (1)$$

$$T = \pi D^3 t / 16 \quad (2)$$

where,

Ph = power needed to dehull	[W]
T = torque	[Nm]
D = diameter of inner cylinder = 0.114	[m]
t = shear stress	[N/m ²]

For steamed locust bean, t is 9086.86 N/m^2 (Oloso, 1988).

ω = angular speed; it is given by

$$\omega = 2\pi N / 60 \quad (3)$$

where,

N = speed in revolutions/minute.

Using the above equations, and for a cylinder speed of 500 rpm, Ph was found to be 139.3 W.

For the power needed to drive the cylinder, Pc , torque was first obtained using Equation 4.

$$T = W_c R \quad (4)$$

where,

W_c = weight of cylinder [N]

R = radius of cylinder [m]

Therefore, Pc was found to be 59.38 W.

To drive the pulley, the power required (Pp) was estimated to be 111.92 W (Oloso, 1988)

The total power P was then found as:

$$P = Ph + Pc + Pp = 286.85 \text{ W.}$$

To account for friction and other losses, a 746 W motor was selected for the machine.

Design of the Power Transmission Shaft

The shaft is subjected to both bending and torsional loads. The bending load comprises vertical and horizontal components. The vertical component is as a result of the weights of the pulley, wood and the two pieces of steel shaft, while the horizontal component is made up of the summation of tension T_1 and T_2 on the tight and slack sides respectively of the power transmission belt. The resultant bending and torsional moments were calculated and found to be 20.1 Nm and 5.48 Nm respectively. The diameter of the shaft was obtained from the following (Spotts, 1988);

$$d^3 = 16 [(K_b M_b)^2 + (K_t M_t)^2]^{1/2} / \pi S_s \quad (5)$$

where,

S_s = allowable combined shear stress for bending and torsion for steel shaft with keyway

$$= 40 * 10^6 \text{ N/m}^2$$

K_b = combined shock and fatigue factor applied to bending moment
= 1.5 - 2.0 for minor shock.

K_t = combined shock and fatigue factor applied to torsional moment
= 1.0 - 1.5 for minor shock.

The diameter was calculated and found to be 17.4 mm and a shaft of 20 mm was used in order to have a higher factor of safety. The designed shaft was checked and found to satisfy the deflection, torsional and critical speed criteria.

Power Source

A 746 W, 1435 rpm, single - phase electric motor served as the power source. Power is transmitted from the motor to the dehuller through a V - belt/pulley arrangement.

The Stand

Both the dehulling unit and electric motor were bolted firmly to the stand. The stand was made from 37.5-mm angle iron, 550 mm wide, 700 mm long and 500 mm high. The entire surface of the machine was painted to prevent corrosion and rusting.

PERFORMANCE EVALUATION

The constructed dehuller was tested in order to determine the optimum operating conditions at which maximum efficiency could be obtained.

It was shown that dehulling efficiency is affected by moisture content, duration of steaming and machine parameters such as speed and length of the dehulling head (Reichert et al., 1979; Oloso, 1988; Ojo, 1989). For the performance evaluation of the dehuller, three parameters were varied during its testing. These were steaming time, length of dehulling head (Lh) and speed of rotation (N), which were varied from 0 - 6 hours, 60 - 180 mm at 60 mm interval and 250 - 500 rpm respectively. The effects of these parameters on the dehulling efficiency were investigated.

The locust beans were steamed using a steamer of 0.53 m³ capacity constructed by Ojo (1989). For running the tests, 6kg of locust bean was used in the whole testing. A 1-kg sample was used for testing at each of the six periods of steaming. Each sample was further sub-divided into six equal sub-samples for dehulling at different lengths of dehulling head (Lh) and speeds of rotation (N). Thus, for the zero hour (control) steaming batch, two sub-samples were dehulled, each at 250 and 500 rpm with Lh of 60 mm. The next two samples were dehulled with Lh of 120 mm at 250 and 500 rpm, and the last two sub-samples were dehulled with Lh of 180 mm at speeds of 250 and 500 rpm.

At the end of the first, second, third, fourth and sixth hours of steaming, 1 kg each of steamed beans was collected and the steps carried out for the zero hour of steaming were repeated for each of these periods.

Dehuller Efficiency (*DE*)

For every experiment, the performance of the dehuller was evaluated by determining its efficiency, *DE* as follows (Oloso, 1988):

$$DE = 100(C_h \cdot C_w) \quad (6)$$

where:

$$C_h = 1 - (M_u/M_t) \quad (7)$$

and $C_w = \frac{k}{k + b}$ (8)

where:

C_h = coefficient defining the quantity of beans dehulled

C_w = coefficient of wholeness of beans defining the quality of beans recovered

M_u = mass of undehulled beans in the final product (g)

M_t = mass of sample before dehulling (g)

k = mass of whole beans in the final product (g)

b = mass of broken beans in the final product (g)

Dehuller Throughput (*Tp*)

The throughput of the dehuller (*Tp*) was evaluated using the following equation:

$$Tp = \frac{3.6M_t}{t_D} \text{ (kg/h)} \quad (9)$$

where t_D = time used in dehulling (s)

RESULTS AND DISCUSSION

Moisture content

Figure 2 shows the variation of moisture content (m.c.) of the beans with different steaming times. It can be seen from the graph that m.c. increased with duration of steaming. The minimum m.c. was 9.7 % dry basis and it was obtained just before the steaming commenced (zero hour). The maximum m.c. of 110 % was obtained after six hours of steaming. Initially, the rate of moisture absorption by the beans was slow from 0 - 4th hour of steaming, but thereafter there was a rapid increase. The initial slow rate may be due to the fact that moisture take up through the seed coat was slow and therefore, it took sometime for the seed coat to be permeable. On the other hand, the rapid increase of m.c. from the 4 - 6th hour duration might be attributable to the seed coat being softened to make it easier for the moisture to penetrate.

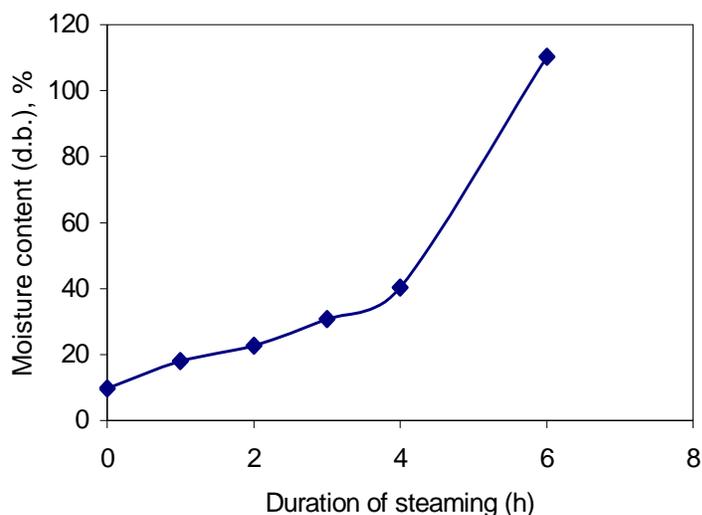


Figure 2. Variation of locust beans moisture content with steaming time

Dehuller Efficiency (*DE*)

The effects of m.c. and *Lh* on *DE* are shown in figures 3 and 4 respectively. *DE* increased linearly with m.c. Minimum and maximum efficiencies of 8 and 70.53 % were obtained at 9.8 and 110 % m.c (dry basis) respectively. The low efficiency obtained initially was probably due to the hard seed coats which were difficult to remove and thereby leaving many undehulled beans, and also greater part of the few cotyledons obtained were broken. At high m.c the seed coats were softened and less brittle, therefore it was easy for the machine to dehull most of the beans with minimum breakage. Wet beans cotyledons are more elastic than dry bean cotyledons, hence, they are not easily broken during dehulling.

The effect of *Lh* on *DE* (Figure 4) shows that the *DE* increased proportionately with *Lh*.

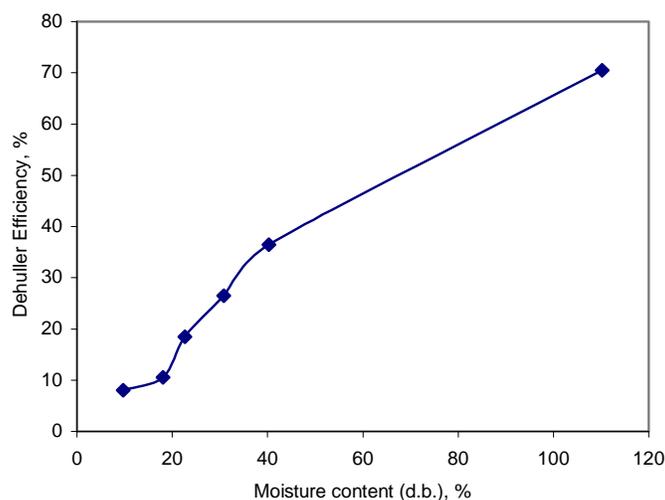


Figure 3. The effect of locust beans moisture content on dehuller efficiency

A minimum DE of 16 % was obtained with Lh of 60 mm, while the maximum was 36 % with Lh of 180 mm. The coefficient of the dehuller that defines the quantity of beans dehulled increased with Lh because as Lh increased the steamed beans were exposed to more roughened surface and hence experienced more abrasion before discharge.

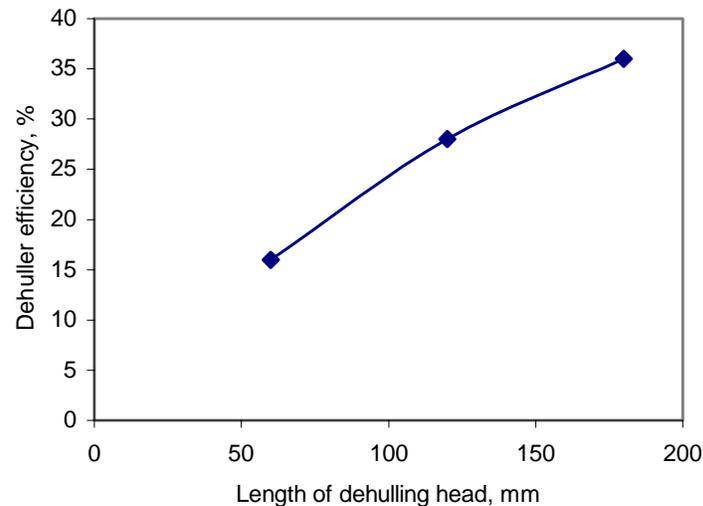


Figure 4. Variation of DE with lengths of dehulling head

It was observed that doubling the operating speed (N_s) from 250 to 500 rpm resulted in only 0.73% increase in dehulling efficiency (from 69.8 to 70.53%). The increase in DE may be due to the fact that at high speed, the steamed beans experienced more rubbing action before discharge. This increase was not high probably because at such high m.c. (110.2%), the bean coats were soft enough to be easily removed such that even when speed increased substantially only a few more beans would be dehulled.

Dehuller's Throughput (T_p)

The T_p of the machine varied inversely but not linearly with the m.c. (Figure 5). Increase in m.c. reduced the T_p . At 9.7% m.c., the T_p obtained was 0.42 kg/min, while at 110.2 % m.c. the T_p was as low as 0.06 kg/min. However, when aided by using water to flush out the beans, T_p (at 110.2 % m.c.) was greatly increased up to 0.5 kg/min.

The T_p decreased because at high m.c. the seed coats were sticky resulting in a high force of friction between the steamed beans and the walls of both the inner and the outer cylinders. This made the flow of beans very difficult during dehulling and hence the rate of dehulling/discharge was reduced. But at lower moisture content, the beans were less sticky and therefore were able to flow much more freely.

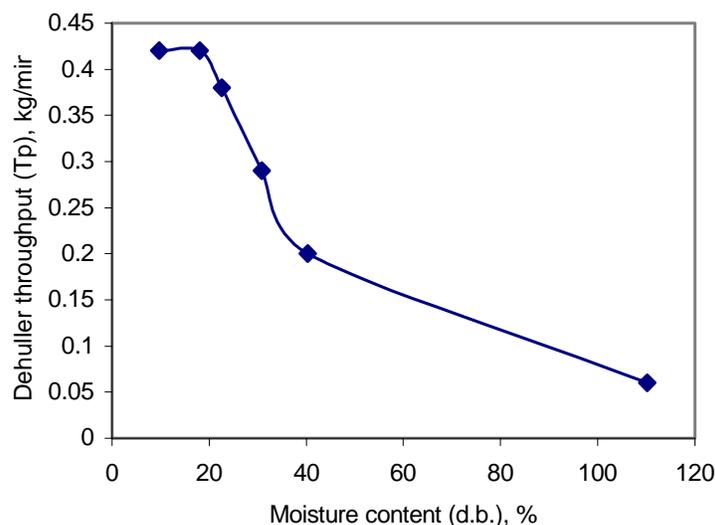


Figure 5. Variation of dehuller throughput with moisture content of locust beans

Increase in the length of dehulling head (L_h) had a negative effect on throughput (T_p). At 60 and 180 mm of L_h , the T_p obtained were 0.5 kg/min. and 0.42 kg/min respectively. This was perhaps because the restriction for bean movement increased as L_h was increased. The bean had to pass through greater length of restricted area before being discharged.

CONCLUSION

A locust bean dehuller was designed, constructed and tested. The following conclusions were arrived at after experimental testing of the machine:

- a) The dehuller works more efficiently as the moisture content of the beans increases. The machine attained an efficiency of 70 % when the moisture content of the beans was 110%, compared to a value of only 8% recorded when the beans were dry.
- b) The dehuller efficiency increased with length of dehulling head

- c) The best set of conditions under which the dehuller can be operated is a speed of 500 rpm, 180 mm length of dehulling head and 110 % moisture content at which the maximum efficiency of 70.3 % can be obtained

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