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Research Article
Design, Fabrication and Testing of a Manually Operated Locust Bean Cubing Machine

Mohammed Gana Yisa, Adeshina Fadeyibi and Salman Abdul Hafeez

Department of Food, Agricultural and Biological Engineering, Kwara State University, Malete, Kwara State, Nigeria

Abstract

Background and Objective: Cubing is a process of consolidating bulk agricultural products to allow precise sizing prior to packaging and marketing. This research was undertaken to develop a locust bean cubing machine. **Materials and Methods:** The machine was designed to cube 2 kg of fermented locust beans with the help of a piston-connecting rod arrangement, as a conveying mechanism. A handle attached to the connecting rod provides the drive and force required for cubing and the resultant piston speed was computed empirically. **Results:** The results showed that the machine required a piston speed and pressure of 33 m sec^{-1} and 25.1 kN m^{-2}, respectively. Also, the machine was able to produce cubed locust beans of an approximate size of 0.06 m^2. **Conclusion:** Thus, the cubing of locust beans condiment can be successfully achieved with the help of this machine.

Key words: Cubing machine, consolidating bulk, fermented locust beans, piston speed, locust beans condiment

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Corresponding Author: Adeshina Fadeyibi, Department of Food, Agricultural and Biological Engineering, Kwara State University, Malete, Kwara State, Nigeria Tel: 070-348-67681

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Processing of fermented locust bean into food condiments is still largely dominated by the traditional method in Nigeria and often carried out using rudimentary utensils[1]. The production usually involves shelling mature pods, sorting into sizes of equivalent range, steaming and boiling in earthenware pots, dehulling by mashing with pestle and mortar, washing in a calabash and subsequently fermenting the beans by covering them with cloth or banana leaves[2]. The process of dehulling locust bean seeds using the traditional method is not only laborious and time consuming, but also yields a low quality product. It involves the cooking of the seeds to the point at which the coat splits. The cooked seeds are poured into a mortar with washed sharp sand. The mixture is then mashed in the mortar with pestles or feet and by the action of the gritty sand on the cooked seed, the seed coats are removed. The mixture is washed several times with clean water to remove the floating chaff and the denser sand settles to the bottom of the container. This is subsequently followed by fermentation to form the condiment commonly known as 'iru' in western Nigeria, 'soumbala' in Burkina Faso, Mali, Ivory coast and Guinea. The steps involved in processing locust bean seeds into the food condiment can be summarized in Fig. 1.

The traditional method described in Fig. 1 was usually associated with poor quality product and the people directly involved in the production could surfer drudgery, especially during dehulling and the fermentation processes. For this reason, efforts have been presented in the past to mechanize the processes. Research efforts of Olaoye[3], Audu *et al.*[4], Gbabo *et al.*[5] and Adamade and Oladipo[6] have already given credence on this and locust beans processing is now carried out with little or no drudgery involved. For instance, Audu *et al.*[4] developed a concentric locust beans dehuller to reduce the amount of time and labor required in the traditional manual dehulling of the seeds. Olaoye[3] developed a depulping machine for the seed to reduce time wastage in the process. Gbabo *et al.*[5] and Adamade and Oladipo[6], in separate researches, developed a dehuller and separator to remove the drudgery and constraints associated with the traditional dehulling and separating method of the seed before it is processed into food condiment. Despite all these efforts, the poor handling technique of the condiment together with its associated offensive odour and subsequent contamination are issues for health concern. Cubing and packaging are two possible ways of addressing these inherent challenges[3] and available research efforts in this area have not addressed the problem. In fact, the development of locust bean cubing machine has not been reported in literature.

African locust bean

↓

Boiling in water for 8 h

↓

Allowing to cool for 5 min

↓

Dehulling by pressing between palms

↓

Washing the cotyledons

↓

Discarding seed coats and un-dehulled

↓

Boiling cotyledons in water for 1-2 h

↓

Spreading in hot seeds in wide calabash

↓

Covering calabash and wrap with jute sacks

↓

Fermenting for 24 h or more

↓

Daddawa

Fig. 1: Flow chart for processing locust bean into *Daddawa* (fermented locust beans)

Hence, there is the need to design and fabricate a locust bean cubing machine for application in precise sizing of the food condiment prior to packaging. The objective of this research, therefore, was to develop locust bean cubing machine.

MATERIALS AND METHODS

Materials: Samples of the Locust bean seed (*Parkia biglobosa*) (2 kg) were bought from Oja-Oba Market in Ilorin, Kwara State, Nigeria on December 12, 2017. The seeds were then immediately transported to the Kwara State University, Malete, Nigeria for experimentation (Fig. 2). Foreign materials such as broken and immature seeds, stones, tree branches, leaves and sand were manually removed from the seeds[7]. The initial moisture content of the locust bean seed was determined using the air circulated oven method and found to be 6.5% (wb). The seeds were allowed to ferment and thereafter ground into paste (50-10 μm particle sizes) using a seed grater. This was to ensure the proper adhesion of the locust bean particles in the cubing process. The pastes were packaged in an air tight polyethylene bag and kept for the period of the experiment, which lasted 2 months from date the seeds were bought to the final date (January 15, 2018).

Fig. 2: Fresh locust bean seeds[3]

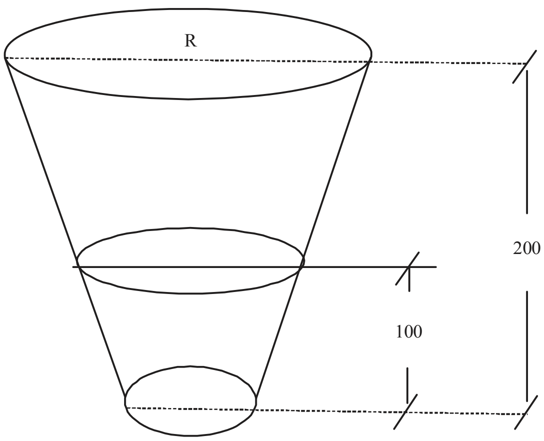

Fig. 3: Hopper geometry

Design considerations: Fabrication materials for the locust bean cubing machine were sourced locally. Locust bean cubing machine was designed considering its adaptability for ease of operation and affordability within the capacity of the intended users[8]. Also, the materials are chosen on the basis of their availability, suitability and viability in service among other considerations[8,9].

Design analysis: The analysis of the component parts of the locust bean cubing machine is as the follows:

- **Hopper volume:** This allows for convenient flow of the fermented locust bean seeds into the barrel of the machine. The volume of the hopper was computed according[9] to Eq. 1:

$$\rho = \frac{m_l}{v_h} \tag{1}$$

Where:

ρ = Density of locust bean seeds =1156.85 kg m^{-3}
m_l = Mass of locust bean seeds fed into the hopper = 2 kg
v_h = Required volume of the hopper (m^3)

Thus:

$$v_h = \frac{2}{1156.85} = 0.00173$$

Hence, the required volume of the hopper that will allow the flow of locust bean seeds without causing arching and ratholing[10] or any other flow problem was 0.00173 m^3.

- **Hopper capacity:** Assuming the hopper is in the form of a frustum, enclosing two concentric cones as shown in Fig. 3. The upper radius of the frustum was assumed 62.5 mm. Also, the height of the outer and the inner cones were assumed as 200 and 100 mm, respectively. All assumptions were made based on the study of existing hopper design and previous research experience. The base radius, r, of the hopper was computed from the expression in Eq. 2[11].

Using the formula for volume of a cone:

$$v_h = \frac{\pi r^2 h}{3} \tag{2}$$

Since the hopper is a frustum, we have to account for the two cones using the expression in Eq. 3:

$$v_h = \frac{\pi r^2 h_1}{3} - \frac{\pi R^2 h_2}{3} \tag{3}$$

Where:

v_h = 0.00173 m^3
π = 3.142
R = 62.5 mm
h_1 = 200 mm
h_2 = 100 mm
r = Based radius of the frustum

Thus:

$$v_h = \frac{3.142 \times r^2 \times 200}{3} - \frac{3.142 \times 62.5^2 \times 100}{3}$$

$$= 1.047 \times r^2 \times 200 - 1.047 \times 3906.25 \times 100$$

$$= 1.047 \times r^2 \times 200 - 408984.375$$

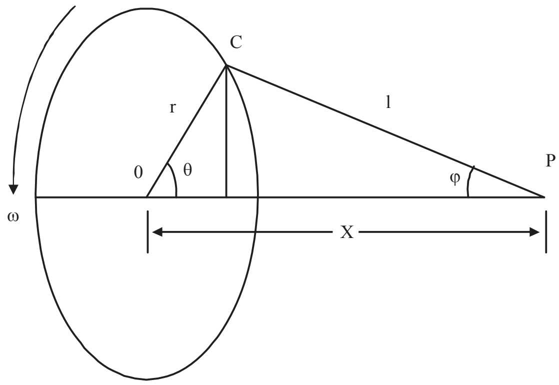

Fig. 4: Piston stroke analysis

$$0.00173+408984.375 = 1.047\times r^2\times 200$$

$$r^2 = \frac{408984.3767}{209.4}$$

$$= 1953.125$$

$$\therefore r = 44.19 \text{ mm}$$

Piston speed: The piston speed was computed as twice the piston stroke using the expression[12] in Eq. 4:

$$\text{Speed} = 2\times S \text{ (rpm)} \tag{4}$$

Where:
S = The stroke length (rev)

Assuming that the crank radius and crank angle are 150 mm and 45°, respectively, the law of cosines for piston stroke (Fig. 4), expressed in Eq. 5 was used to determine the stroke length in terms of the complete number of revolution[13]:

$$S = r\cos\theta + \sqrt{r^2\cos^2\theta - r^2 + b^2} \tag{5}$$

Where:
r = Crank radius (150)
b = Crank diameter (300)
θ = Angle at crank radius (45°)

Thus, substituting we have:

$$S = 30\cos 45° + \sqrt{30^2\cos^2 45° - 30^2 + 300^2}$$

$$= 21.21 + \sqrt{-263.60 + 90000}$$

$$= 21.21+2995$$

$$= 320.71 \text{ rev. (stroke length)}$$

However, the angular speed was:

$$\text{Angular speed} = 2\times 320.71$$

$$\therefore N = 641.42 \text{ rpm}$$

Now, since the acceleration of the piston is in linear motion, the linear speed was computed as thus:

$$\text{Angular speed} = 3.142\times\left(\frac{641.42}{60}\right) \text{m sec}^{-1}$$

$$\therefore \text{Piston angular speed} = 33 \text{ m sec}^{-1}$$

Piston force: The force of a piston is crucial when deciding how the component will work, its practical applications and its functionality in terms of performance. The force was evaluated using Eq. 6[13]:

$$F = \frac{2\pi Nmv}{60} \tag{6}$$

Where:
M = Mass of fermented locust beans fed into the hopper (2 kg)
N = Angular speed (641.42 rpm)
v = Linear velocity (33 m sec^{-1})

Thus:

$$F = \frac{2\times 3.142\times 641.42\times 2\times 33}{60}$$

$$= 4433.75 \text{ N}$$

Therefore, the force required by the piston to push the locust beans condiment was 4433.75 N.

Piston pressure: The piston pressure generated at the cubing region or compartment of the machine was determined using the expression[13] in Eq. 7:

$$P = \frac{F}{\pi\left(\frac{r}{2}\right)^2} \tag{7}$$

Where:
F = Piston force (4433.75 N)
r = Crank radius (0.15 m)
P = Required piston pressure (N m^{-2})

$$P = \frac{4433.75}{\pi\left(\frac{0.15}{2}\right)^2}$$

$$= \frac{4433.75}{0.01767}$$

$$= 250919.64 \text{ N m}^{-2}$$

Therefore, the pressure required by the piston to push the locust beans condiment was 25.1 kN m^{-2}.

Drive: The machine was manually operated to drive the piston. The human effort and speed generated are theocratically 0.075 kW and 60 rpm, respectively. This effort was used to drive the piston against the connecting rod and the pressure developed was transferred to cubing compartment of the machine[14].

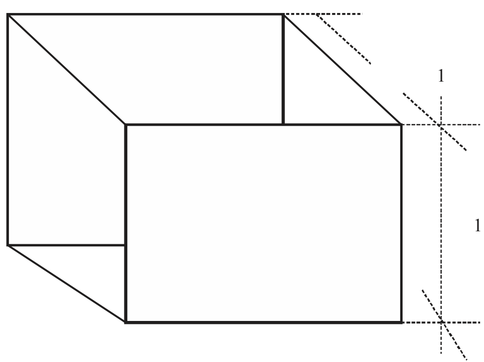

Fig. 5: Typical square hole, messing in cubing compartment

Cubing compartment: The cubing compartment is essentially made of wire mess, with many square holes each measuring approximately 100×100 mm in cross section, designed to take the shape of the cubed locust beans condiment (Fig. 5). The size of one of the holes in the mess was determined using the expression[15] in Eq. 8.

$$S = 6a^2 \tag{8}$$

Where:
a = Equal length of sides (100 mm)
S = Size of hole, messing the cubing compartment (mm^2)

$$S = 6\times100^2$$

$$S = 6\times10^4 \text{ mm}^2$$

Therefore, the size of each cubed locust beans condiment produced by the machine was 0.06 m^2.

Machine drawing: The assembly drawing of the component parts of the locust bean cubing machine was shown in Fig. 6.

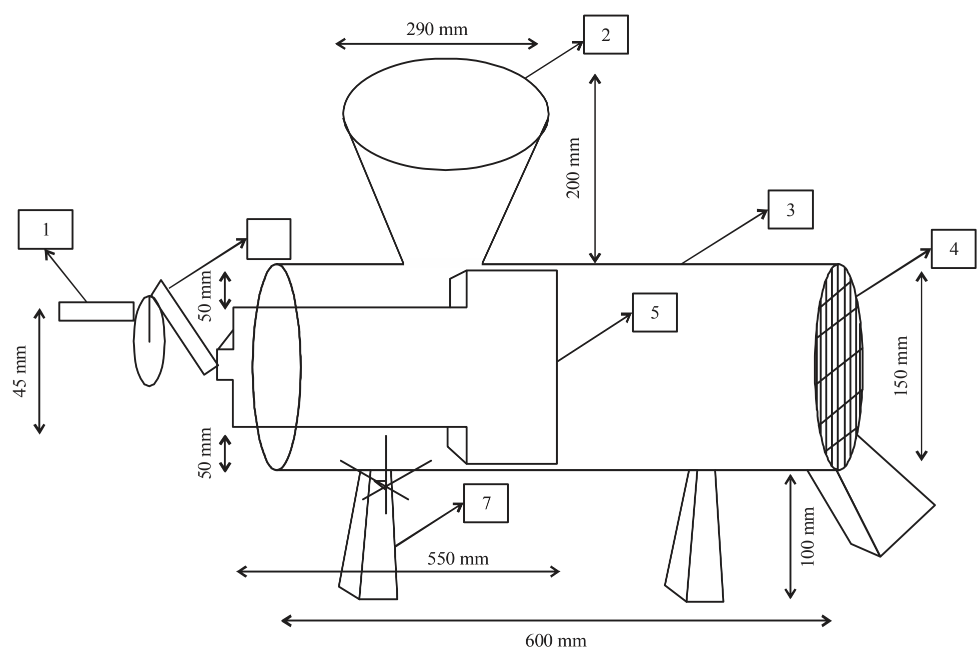

Fig. 6: Component assembly
1: Handle, 2: Hopper, 3: Barrel, 4: Cubing component, 5: Piston, 6: Connecting rod and 7: Stand

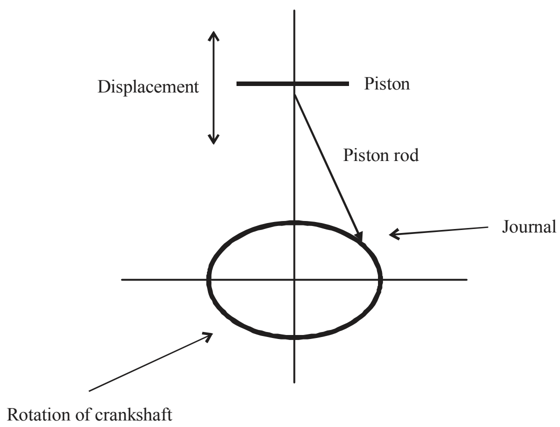

Fig. 7: Piston action in the barrel, causing pressure build-up

Table 1: Bill of engineering measurement and evaluation

Description	Quantity	Rate (₦)	Amount (₦)
Sheets of 1.5mm plate	1	2,000	2,000.00
1.5″×1.5″ angle iron	3	1000	3,000.00
1″×1″ angle iron	1	500	500.00
Stainless steel plates	3 sheets	2,000	6,000.00
Mild steel electrode	1 packet	1,100	1,100.00
Funnel	1	2,500	2,500.00
Bolt	3	50	150.00
18 mm diameter Rod	1	1200	1,200.00
Mess Net	1 sheet	2,000	2,000.00
Barrel pipe	1	5,500	5,500.00
Finger sheet	1	4,000	4,000.00
Stainless pipe	1	6,500	6,500.00
Mild steel plate	1 sheet	1,200	1,200.00
Thread	1"	1,530	1,530.00
Labor cost			6,500.00
Total			43,680.00

Fabrication and bill of measurements: The locust bean cubing machine was fabricated using the conventional workshop procedure, which involved bending, welding, cutting and drilling. The barrel, which houses the cubing compartment, was made from 3 mm thick stainless steel sheet of 500×190 mm cross section. The piston was made from 3 mm thick stainless steel material of 100×185 cross section. The hopper was made from a 1.5 mm thick mild steel material of 200×185 mm, which was bent to form a frustum. The thread inside the piston was made from a 24 mm thick mild steel material of 490×25 mm cross section. The action of the piston was hastened by a bearing at the entrance of the barrel with a cross section of 50×80 mm. The handle of the machine was made of 1.5 mm thick mild steel material of 150×18 mm cross section. The shaft supporting the thread was made from 3 mm thick stainless steel material of 450×45 mm cross section. The cubing compartment was made from a 2 mm thick stainless steal material, which has a cross section of 270×250 mm. Provisions were made for easy dismantling of the cubing compartment using bolts and nuts. The cost of fabrication of the machine is shown in Table 1.

Principle of operation of the machine: The machine was operated based on the action of the piston-connecting rod arrangement on the cubing compartment. It was equipped with a handle, which provides the drive required for the operation. The machine also has a crank-connecting rod- piston arrangement, which transferred the force from the handle drive via the piston rod to the cubing compartment. The connecting rod connects the piston to the crank end and pushes the piston forward by manually rotating the handle as shown in Fig. 7. In this investigation, 2 kg of fermented locust bean condiment was introduced, through the hopper, into the feed zone for the cubing operation. The reciprocating motion of the connecting rod was transformed into linear motion of the piston inside the barrel[9]. This then moved with a speed of 33 m sec^{-1} and conveyed the food condiment to the cubing compartment. The pressure developed by the action of the moving piston provides the force needed to push the locust bean condiment through the wire meshing arrangement at the cubing compartment. Thus, the product obtained as shown in Fig. 8, measures 0.06 m^2 approximate size per cube.

Testing of the locust bean cubing machine: The performance of the locust bean cubing machine was evaluated in terms of the throughput capacity with respect to the piston pressure for 1 h. The pressure developed at the die head was kept constant as the design pressure of 21.5 kN m^{-2}. About 2 kg of the fermented locust bean condiment was introduced into the hopper of the locust bean cubing machine. The machine was operated for 5 min and the mass of the output (cubed condiment) was measured and recorded. The procedure was repeated for 1 h machine operation at an interval of 5 min. The throughput capacity was thereafter computed[8,9] using Eq. 9:

$$Q = \frac{m}{t} \tag{9}$$

Where:

Q = Throughput capacity (kg min^{-1})
m = Mass of the machine output (kg)
t = Time of cubing (60 min, at 5 min interval)

Fig. 8(a-b): Cubed locust beans condiment (approximately 0.06 m^2)

RESULTS AND DISCUSSION

The result of the performance evaluation of the locust bean cubing machine was shown in Fig. 9. The performance of the machine is largely dependent on the power output of the operator, who in turn depends on his reserved energy to power the cubing compartment. Just as expected, it can be seen that the throughput capacity of the locust bean cubing machine decreases with an increase in the time of operation from 5-60 min. Consequently, the performance of the machine was higher during the first 20 min of the machine operation. The reason for this may be due to the dissipation of the reserved energy of the operator, who had continuously engaged the piston-connecting rod arrangement of the machine to power the cubing compartment for 1 h. This agrees with the work of Owolarafe *et al.*[8], who reported a decrease in the dehulling efficiency of a locust beans processing device with respect to the time of processing.

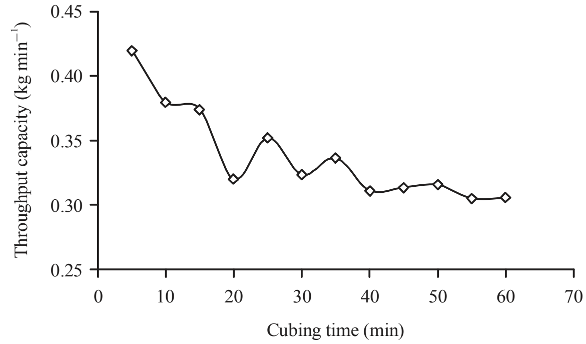

Fig. 9: Performance of the locust bean cubing machine

The research reports of Audu *et al.*[4], Gbabo *et al.*[5] and Adewumi and Olalusi[16], who developed a locust bean dehuller, also corroborate this finding. It is also possible that the natural adhesion property of the locust bean condiment was responsible for the decrease in the throughput and performance with an increase in the time of cubing. The research findings of Folami *et al.*[17], who work on the performance evaluation of a rice processing machine, has given credence to the fact that the adhesion property could be responsible for the decreasing throughput capacity of the machines use for food processing. In fact, the adhesion property in the locust beans paste is so pronounced that it is sometimes used in the preparation of fish meal[8,18], hence, this could be strong enough to cause a resistance to the piston pressure. Thus, the adhesion property together with the fluctuating reserved energy of the operator could be responsible for the decrease in the throughput of the manually operated locust bean cubing machine.

CONCLUSION

A machine for cubing locust beans has been developed in this investigation. The design piston speed and pressure developed for the cubing operation were 33 m sec^{-1} and 25.1 kN m^{-2}, respectively. The size of cube locust beans condiment measures 0.06 m^2 approximately. The cost of fabrication was considerably low (₦ 43,680) and can be afforded by the local producers. The cubing operation of locust bean condiment was successfully carried out with the help of this machine. The performance of this machine is largely dependent on power output of the operator and decreases with the increase in time of operation.

SIGNIFICANCE STATEMENT

The locust bean cubes are not common in the market like the other cube seasoning like the knorr cube largely due to lack of technology for its production. Available research efforts in this area have only addressed locust beans depulping, dehulling, soaking, steaming and drying operations. The cubing operation of the seed has not been reported in the previous studies. This research therefore reports the locust bean cubing technology so as to fill the deficit knowledge gap.

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