# Development and Quality Evaluation of Cubing Machine for Fermented African Locust Beans (*Parkia biglobosa*)

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## ABSTRACT

Food prepared with chemical additives and preservatives is susceptible to chronic and non-communicable diseases. The global shift for naturally processed food calls for indigenous processing techniques that will guarantee food safety, healthy living, and storability. In view of this, the focus of this research is to develop a manually operated machine that converts naturally processed fermented African locus bean powder to cubes. Average efficiency and capacity of the machine is 92.42% and 191 cubes/hr, respectively. Moisture content, crude fat, crude protein, crude fiber, total ash, and carbohydrate content for un-cubed and cubed locust beans are 6.43% and 5.43%; 12.13% and 12.12%; 80.25% and 80.18%; 0.48% and 0.86%; 0.61% and 0.92%; and 0.12% and 0.50%, respectively.

Using $\bar{\bar{x}}$ control chart, the weight of cubes produced from different batches is in a state of statistical control and no assignable variation was detected. The machine is economically viable, easy to maintain, and user friendly.

(Keywords: design, fabrication, production, analysis, efficiency, capacity, statistical chart)

## INTRODUCTION

African locust bean (*Parkia biglobosa*) is a perennially grown leguminous plant with fruits containing sweet pulp and seeds (Olorunmaiye and Fatoba, 2011). All parts of the tree have shown to confer therapeutic benefits to human and are recognized for commercial value (Ojewumi, 2018). African locust bean is consumed after fermentation, increase sensory appeal of foods and are used as a cheap alternative to conventional condiments (Zakari, *et al.,* 2015).

West African food cultures are rich in spontaneously fermented foods, the majority of which have been passed down from one generation to another. The fermentation of food in West Africa is said to account for 40% of the population's diet, a percentage that increases with decreasing income (Koss, 2017). Africans usually ferment cereal-based foods like sorghum, millet, and maize; roots such as cassava; fruits, and vegetables; and less commonly meat and fish (Raji and Orelaja, 2014). Fermentation in different parts of West Africa, most especially in Nigeria covers leguminous plants and oilseeds, to produce fermented condiments that are used as flavorings in soups. Such fermented condiments include 'ogiri' from castor bean (*Ricinus communis*), 'dawadawa' from African locust beans (*Parkia biglobosa*) and 'ugba' from African oil bean (*Pentaclethra macrophylla*).

One of the major advantages of fermentation is the enhancement of both nutritional and sensory quality of foods by the conversion of macronutrients such as proteins and sugars into easily digestible compounds and the development of flavor compounds. Fermented African locust bean seeds are a rich source of protein and consist of oil, dietary fiber, vitamins, (vitamin B, riboflavin and vitamin A) and minerals (Olowokere, *et al.,* 2018). The most common groups of micro-organisms involved in food fermentation are bacteria, yeasts, and molds (Olanbiwoninu and Odunfa, 2018).

Spices and condiments are plant-derived substances (from dried seeds, fruit, root, bark, and leaves) used in minute quantities as food additives to stimulate flavor and taste in foods, beverages, and drugs (Oboh, 2006); improve color; in some cases serve as preservatives (Garcia-Casal, *et al.,* 2016); and improve the overall sensory acceptability of foods (Oladunmoye, 2007). Condiments are applied in the form of a sauce powder to contribute calories and protein intake and are generously added to soups as low-cost meat substitutes by low-income families in part of Nigeria (Asagbra, *et al.,* 2012). Thus, the awareness of the benefits of eating food products with little or no chemical food additives or preservatives for healthy living and life expectancy should be promoted.

Currently in Nigeria, fermented African locust beans are processed locally and sold as whole seeds or in particulate form which hampers its marketability and shelf-life. Thus, there is need to develop a system to improve the packaging and significantly boost the commercialization of the fermented product. Therefore, this research is aimed at design, fabricate, and performance of a quality evaluation of a low cost manually fabricated cubing machine for the production of fermented African locust beans cubes for low and medium scale processors.

## MATERIALS AND METHODS

### Material Selection and Design Consideration

African locust bean (*Pankia biglobosa*) seeds were purchased at Ilesha, Osun State, Nigeria. The materials used in the fabrication of the cubing machine were purchased at Owode Onirin along Ikorodu Road in Lagos State, Nigeria. The processing and analyses on locust bean seeds were carried out in the Food Technology Laboratory while fabrication of the machine was done in the Mechanical Engineering Workshop, Bell University of Technology, Ota, Nigeria. The dried locust beans were inspected and removal of immature seeds, broken, and damaged locust beans took place to avoid poor quality and unsafe finish products.

Prewashing was done before the locust beans were placed in a clean pot. It was allowed to boil for six hours to partially de-shell the locust beans. The boiled locust beans were drained and allowed to cool for easier mashing. The cooled locust beans were placed in the mortar and they were hand mashed with the addition of ashes. The de shelled locust beans were handpicked, washed with water, and placed inside a calabash containing a washed banana leaves and allowed to ferment for 24 hours. In other to facilitate the fermentation process, little amount of salt was added. The locust beans were dried using hot air oven at 60$^{o}$C for 24 hours to reduce the bulkiness by 29%. The dried locust beans were dried milled by using the milling machine, the resulting milled locust beans were sieved to obtain a homogenous size. The locust beans powder was divided into two equal parts. One of them was subjected to cubing machine with addition of lecithin which serves as the binding agent in ratio 3:1 (locust bean powder: lecithin).

The powder locust beans, and cubed locust beans were package for further analyses. In the design of cubing machine, various factors were considered in the selection of material, these include: durability, availability, suitability, and cost of materials for the desired quality performance. A flowchart for the production of dried fermented African locus beans is shown in Figure 1.

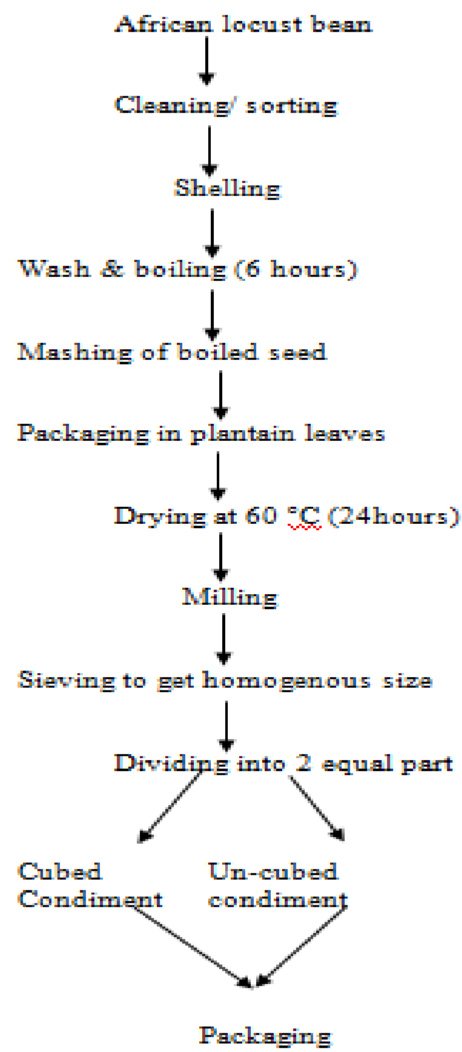



**Figure 1:** Flowchart for the Production of Fermented African Locus Beans.
Source: Egwim, *et al.* (2013).

## Machine Description

The major components of the machine are u-beam, cubing unit, mould, cylinder, and the frame. The u-beam made from mild steel was cut and shaped into 1500mm × 210mm × 26mm; the cubing unit consists of a cutting blade made from stainless steel, cylinder spring and handle; the mould houses the blade and is made from stainless steel with dimension 110mm × 100mm × 21.5mm and capable of producing 200 cubes per hour; the cylinder consist of iron rod 10mm tall and 2mm radius made from mild steel. Outer part of the cylinder is lined with flat metal connected to the handle and as the handle moves downward, presses the spring while the mould in contact with the condiment on the table to form cubes. The frame unit made from angle iron provides support to other components of the machine. Upper part of the frame is the working table that has direct contact with food made from stainless steel. The snapshot of the machine is shown in Figure 2.

**Figure 2:** Snapshot of Cubing Machine.

## Design Calculation and Performance Evaluation

The design analysis for the spring, power requirement, machine capacity and efficiency were considered as follows:

## Design Analysis for Spring Support

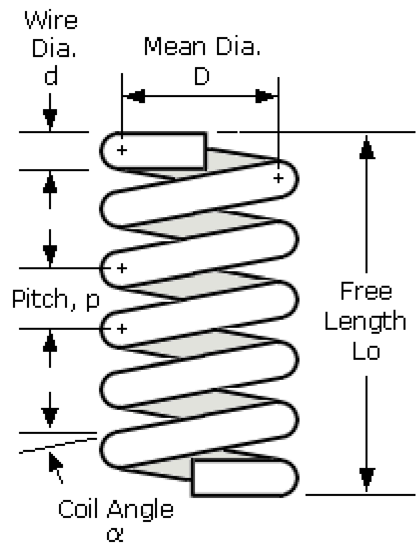



**Figure 3:** Typical Helical Spring.

Selected design data are as stated:

Spring free length, L = 120 mm
Diameter of the wire, d = 2.5 mm
Number of active coils, N = 14
Diameter of the coil, D = 28 mm
Mass of the handle, m = 170 g
Mass of the connecting rod = 550 g
Allowable stress ($\delta_s$) induced in the spring due to twisting for industrial spring = 6.25 x $10^5$ $Nm^{-2}$ (Thompson, 1999).

The compression load of the spring, F was obtained using the relationship reported by Rahat *et al.,* (2015)

$$F = \delta_s 2\pi r L \qquad ...........................(1)$$

Where r = $\frac{d}{2}$

F = 6.25 x $10^5$ x 2 x $\frac{22}{7}$ x 0.00125 x 0.12

F = 589 N

Selected weight of the handle,

W = mg ................(2)

Where m is the mass in kg and g is the acceleration to gravity.

Therefore, W = 0.170 x 9.81
W = 1.67 N

Machine compressive force,

$$F_s = F + W \qquad \text{....................(3)}$$

$F_s$ = 589 + 1.67

$F_s$ = 590.67 N

The maximum deflection of the spring, E was obtained from the relationship given by Shigley, (1989).

$$L - E = (n+2)d \qquad \text{...............(4)}$$

Where n is the number of active coils

E = 0.12 – E = (14 + 2) 0.0025

E = 80 mm

Therefore, the maximum deflection of the spring is 80 mm.

The Torque T required to overcome friction in spring was obtained using the relationship as stated by Rahat *et al.,* (2015).

$$T = \frac{\pi \delta_s d^2}{16K} \qquad \text{....................(5)}$$

Where K is stress concentration factor = 1.225 Joseph and Charles, (1986).

$$T = \frac{\frac{22}{7} \mathrm{X} 6.25 \mathrm{X} 10^5 \mathrm{X} (0.0025)^2}{16 \mathrm{X} 1.225}$$

T = 0.63 Nm

Therefore, the torque required to overcome friction in spring is 0.63 Nm.

Stiffness of spring was obtained from the relationship given by (Thompson, 1999).

$$\sigma = \frac{\pi R^4 G}{2L} \qquad \text{...................(6)}$$

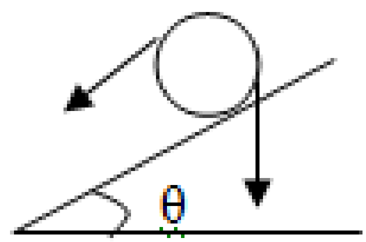
Where σ = Stiffness of spring in $Nm^{-1}$
R = Radius of coil in m
G = Mild steel modulus of rigidity
= 8.2 x $10^6$ $Nm^{-2}$ (Adewumi, 2007).

$$\sigma = \frac{\frac{22}{7} \mathrm{X} (0.014)^4 \mathrm{X} 8.2 \mathrm{X} 10^6}{2 \mathrm{X} 0.12}$$

σ = 4.13$Nm^{-1}$

Therefore, stiffness of the spring is 4.13 $Nm^{-1}$

**To Determine Machine Power Requirement**




$$\mu = Tan\theta \qquad \text{....................(7)}$$

Where μ is the coefficient of friction and θ is the angle of deflection.

$$Tan\,\theta = \frac{x}{y} \qquad \text{....................(8)}$$

Where x is the maximum compressive force and y is the weight of handle + weight of connecting rod.

$$Tan\theta = \frac{590.67}{1.67 + 5.40}$$

$$Tan\theta = 83.55$$

$$\theta = Tan^{-1} 83.55$$

$$\theta = 89^o$$

To calculate angular speed, S

$$S = \frac{r\theta}{t} \quad ..................(9)$$

Where θ is in radian, r is the length of plate base = 100 mm, and t is the time of deflection = 1 second.

$$S = \frac{0.1X89\pi}{180}$$

S = 0.16 $ms^{-1}$

To calculate machine power requirement for cubing, P

$$P = F_s S \quad ..................(10)$$

P = 590.67 x 0.16

P = 94.51 W

Conclusively, the power required by the machine for effective cubing falls within sustainable human potential power, 70 – 500 W (Jimoh, *et al.,* 2020)

## To Determine Machine Efficiency

$$Efficiency = \frac{Output}{Input} \times 100 \quad ...........(11)$$

(Ogunmoyela, *et al.,* 2016)

During machine evaluation, 5 batches in triplicate were carried out and average value for each batch was recorded as shown in Table 1. Weight of cube was determined by analytical weighing balance and time taken for each experiment was taken by stopwatch.

**Table 1:** Machine Performance Evaluation.

| Input (g) | Output (g) | Eff. (%) | No of cube produced | Time taken (sec.) |
|---|---|---|---|---|
| 500 | 422 | 84.40 | 84 | 1500 |
| 400 | 358 | 89.50 | 72 | 1320 |
| 350 | 326 | 93.14 | 65 | 1200 |
| 300 | 290 | 96.67 | 58 | 1110 |
| 250 | 246 | 98.40 | 49 | 1020 |

Average Machine Efficiency = 92.42%

## To Determine Machine Capacity

$$Capacity = \frac{N}{t} \quad ..........(12)$$

Where N is the number of cubes produced and t is the time taken in the production.

Average Machine Capacity = 191 cubes/hr

## Product Weight Control Measure

The weight of fermented African locus beans cube produced is slightly different from one another even from the same batch production. This variation could be from the mixing or machine setting among others and there is need to investigate the cause of the problem, provide solution using statistical control chart design.

## Procedure for $\bar{\bar{x}}$ Control Chart

Below is the step-by-step procedure to determine control limit using $\bar{\bar{x}}$ chart

(i). Draw a sample $\{x_1, x_2, x_3, .........\ ...x_k\}$ of size k at a stage of the production process

(ii). Repeat (i) for n samples at equal interval of time

(iii). Calculate the sum $\sum x$ for each sample

(iv). Calculate the mean $\bar{x} = \frac{\sum x}{k}$ for each sample

(v). Calculate the mean of the mean ($\bar{\bar{x}}$) in (iv) for all observation where $\bar{\bar{x}} = \frac{\sum \bar{x}}{n}$

(vi). Calculate the variance $s^2 = \frac{\sum (x - \bar{x})^2}{k}$ for each sample

(vii). Calculate the standard error (S) for every $S^2$ in (vi) (viii). Calculate the mean $\bar{S} = \frac{\sum S}{n}$ for all standard errors in (vii)

(ix). Obtain the control limit for x as follow:

(a) $\bar{\bar{x}}$ - Central control limit

(b) $\bar{\bar{x}} + \frac{3\bar{s}}{\sqrt{n-1}}$ - Upper control limit

(c) $\bar{\bar{x}} - \frac{3\bar{s}}{\sqrt{n-1}}$ - Lower control limit

Table 2 shows triplicate weight of fermented African locust beans cube for each batch production and other parameters as illustrated in the procedure so as to determine control limits.

**From the table:**

$$\bar{\bar{x}} = 5.012$$

$$\overline{S_i} = 0.0162$$

**Control limits:**

Central control limit = 5.012
Upper control limit = 5.024
Lower control limit = 4.989

## Determination of Nutritional Composition of Samples

The proximate composition of the samples was carried out by the methods described by AOAC, (2005). Nutritional compositions determined were moisture content, crude fat, crude protein, crude fiber, total ash, and carbohydrate content.

## RESULTS AND DISCUSSION

## Performance Evaluation of the Cubing Machine

The machine design analysis reveals that some parameters were selected while some were calculated using mathematical relations. Those that were calculated includes: Compression load of the spring, F = 589 N; Machine compressive force, Fs = 590.67 N; Maximum deflection of the spring, E = 80 mm; Torque, T = 0.63 Nm; Stiffness of the spring, σ = 4.13 Nm$^{-1}$; angle of deflection of the machine, ϴ = 89$^{o}$; angular speed of the machine, S = 0.16 ms $^{-1}$; machine power requirement, P = 94. 51 W; average efficiency of the machine = 92.42%; and average capacity of the machine = 191 cubes/hour.

However, as the input of the machine increases from 250g – 500g, efficiency of the machine decreases from 98.40% – 84.40% and machine capacity increases from 175 cubes/hr – 200 cubes/hr. In other word, at higher input, more residence time is spent and the rate at which efficiency dropped implies that more losses could be incurred.

**Table 2:** Statistical Batch Production of Fermented African Locust Beans Cube

| Batches | Cube Weight (g) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | $\sum x_1$ | $\bar{x}$ | $S^2$ | $S$ |
| 1 | 5.01 | 5.02 | 5.03 | 15.06 | 5.02 | $6.70\times10^{-5}$ | 0.0082 |
| 2 | 4.98 | 4.99 | 5.03 | 15.00 | 5.00 | $4.67\times10^{-4}$ | 0.0216 |
| 3 | 4.99 | 5.02 | 5.04 | 15.05 | 5.02 | $4.33\times10^{-4}$ | 0.0208 |
| 4 | 4.98 | 5.00 | 5.02 | 15.01 | 5.00 | $2.67\times10^{-4}$ | 0.0163 |
| 5 | 5.01 | 5.01 | 5.04 | 15.06 | 5.02 | $2.00\times10^{-4}$ | 0.0141 |
| | | | | | **25.06** | | **0.081** |

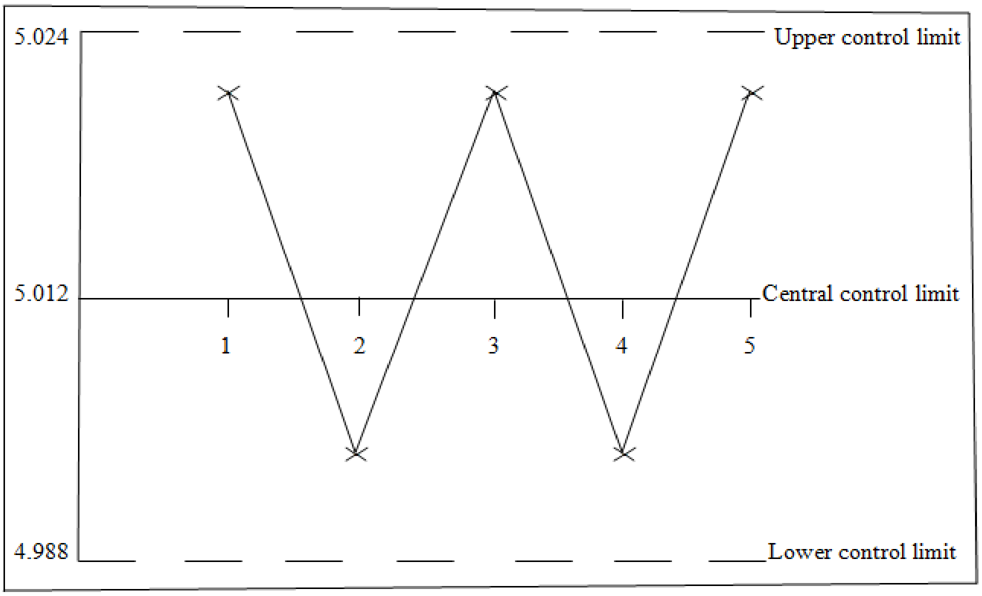



**Figure 4:** Production Control Chart.

**Figure 5:** Cube Production from Different Batches

**Effect of Statistical Control Measure on Standard Weight**

Figure 4 shows production of African locus beans cube control chart. From the chart, in all the batches, production process is in a state of statistical control. No significant assignable variation is detected. A slight difference in the weight of product discovered is as a result of chance variation and it is inherent and inevitable variation in any production process.

Figure 5 shows cubes produced from different batches as it comes out from the cubing unit.

## Effect of Processing Method on Product Quality

Table 3 shows the results of moisture content, crude fat, crude protein, crude fibre, protein, ash, and carbohydrate content of cubed and un-cubed African locust beans.

**Table 3:** Proximate Composition of Un-Cubed and Cubed Fermented African Locust Beans.

| Nutrient | Un-cubed locust beans (%) | Cubed locust beans (%) |
|---|---|---|
| Moisture content | 6.43 | 5.43 |
| Crude Fat | 12.13 | 12.12 |
| Crude Protein | 80.25 | 80.18 |
| Crude Fiber | 0.48 | 0.86 |
| Total Ash content | 0.61 | 0.92 |
| Carbohydrate content | 0.12 | 0.50 |

The moisture content of the un-cubed (powder) is 6.43% while the cubed locust beans is 5.43%. The values show rapid decrease compared with 42.65% reported by Oladunmoye, (2007). The reduced moisture content could be the result of the drying process at 60ºC for 24 hours and this might improve the storability of the condiment.

The crude fat content of the un-cubed sample is 12.13% while that of cubed sample is 12.12%. These values are closely related to 10.65% reported by Zakari *et al.,* (2015). The results show that the values of crude protein for un-cubed African locus beans sample is 80.25% while cubed sample is 80.18%.

Investigation revealed that protein content of naturally fermented African locust beans is 37.32% as reported by Oladunmoye, (2007). The wide difference in protein content could be seen to be the resultant effect of the processing method.

The crude fiber for un-cubed sample is 0.48% while that of cubed sample is 0.86%. These values are lower than 6.80% and 8.30% stated by Omafuvbe *et al.,* (2004) and Oladunmoye, (2007) respectively. Heating process reduces crude fiber content as revealed by Esenwah and Ikenebomeh, (2008), Thus, this might be reason for decrease in fibre content of both un-cubed and cubed samples. However, increase in the fibre content of cubed sample over the un-cubed sample could be traced to be effect of hydrophilic and lipophilic tendency in lecithin (Van Boekel, *et al.,* 2010).

The ash content for un-cubed sample is 0.61% while that of cubed sample is 0.92%. This is in variance with 4.31% naturally fermented African locust bean reported by Agbobatinkpo, *et at.,* (2019). The difference in the ash content could be as a result of oven drying for 24 hours.

The carbohydrate content of the condiment samples ranged from 0.12% in powder (un-cubed) to 0.50% in cubed African locust beans. The reason for low carbohydrate content compared to other researchers finding; 17.07% and 15.34% as reported by Oladunmoye, (2007); and Abbas and Ahmad, (2018) might likely be on the fact that protein and fat content were on the high side.

## CONCLUSIONS

A manually operated fermented African locus beams cubing machine was design, fabricated and evaluated. The following conclusions were drawn from the study:

1. Nutritional composition of the cube is slightly different from the powder product

2. Processing methods adopted enhances good nutritional value of the products and promote healthy living

3. All samples mean lie within upper and lower control limit. Hence, the production is in a state of statistical control

4. The machine is affordable, easy to operate, maintain and durable. Thus, it is recommended for small and medium scale processors.

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