Development of a Bush Mango (Irvingia Gabonensis) Nutcracker

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Abstract: This research work involves the design and fabrication of Irvingia nut cracking machines. It operates using impact technique which involves collision between the seednut and stationary wall. The procedures employed the design stage, fabrication and testing. The machine components are: impact drum, shaft, impeller (rotor), electric motor, driver and dri-ven pulley and hopper. The cracking chamber consists of the impeller and impact drum. The seednuts were pre-treated before testing by sun-drying to improve its crack ability. The ma-chine gave a better performance at the speed of 2600 r/min with average cracking efficiency, percentage kernel breakage and capacity of 88%, 17.5% and 916 nuts/h. The improvement in the design can be achieved by incorporating a kernel and shell separator along the chute.

Keywords: design, construction, irvingiagabonensis, nut, cracking, efficiency

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1 Introduction

Irvingia is a genus of African and South West East Asia trees in the family of *irvingiaceae*, sometimes known by the common names, wild mango, African mango or bush mango (Burkill, 1994). It is abundant on the Eastern region of Nigeria such as in Imo State and Enugu State. It is also abundantly found on some parts of Cross River State such as in Ikom, Betim and Biase. This genus of plant is found in AkwaIbom State in less abundant and mainly within interior villages (Etukudo, 2003). The bush mango tree grows naturally in the humid low land forests of tropical Africa but is widely planted in central and western Africa (Ladipoet al., 1994).

Irvingia comprises of seven species, six on the tropical Africa and one on south-east Asia. The species are *irvigiagabonensis, irvingia excels, irvingiawombolu, irvingiaorbor, invingiasmithil and irvingiamidbr*. However, two common species of the tree are: *irvingiagabonensis*, which has a sweet edible pulp and *irvingiawombulu*, which has a bitter inedible pulp (Ejiofor, 1994). Kernels from both species exhibit 50 similar valuable food properties (Omogbai, 1990 and Ejiofor, 1994).

Irvingiagabonensis has its fruiting period on the rainy season, which is ripen, in June and August (Chudnoff, 1980). The fruits are green, which turn pale-yellow at ripening stage. It is about 3-5cm long. on size and spherical or ellipsoidal in shape. The fruit comprises fleshy mesocarp and the nut which is made up of a hard shell and flattened kernel and seed (FAO, 1982). Its seeds have an outer brown testa (hull) and two white cotyledons. *Irvingiagabonensis* in addition to bush mango is called wild mango and African mango (Okafor, 1975).

Fruit maturity of *irvingiagabonensis* is barely three to four months. Harvesting is done manually by gathering the fallen ripe fruit by the villages' processors or mechanically using harvester, which stakes the stem and collects the fallen fruits through its tray collector to avoid bruising of themesocarp. The fruit is stored in a controlled atmosphere storage system when the temperature is made a little below room temperature but not freezing.

Etukudo (2003) stated that the optimum temperature for the fruit storage is 25°C. He further noted that above this temperature, rapid fruit ripening leading to spoilage

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is induced. Then, below this stated temperature, the pulp starts decaying. The fruit can be stored for as long as four to five months provided the atmospheric parameters favorable to the storage are maintained (Sedgley and Grafin, 1989).

1. The fruit is grown for food and foreign exchange purposes. It is used as sauces and thickener in soups to achieve a desirable glutinous consistency. It also serves as a complement to “fufu’ “gari” and “cocoyam”. In processing *Irvingiagabonensis* fruits to kernel, the fibrous pulp is eaten raw because of its sweetness or used for the production of juice, jelly and jam (Okafor, 1973). The nut can be sundried, drumdried or smoked to aid the extraction of the kernel. The kernel can be extracted from the nut by the use of matched to crack the nut or striking it against stone.

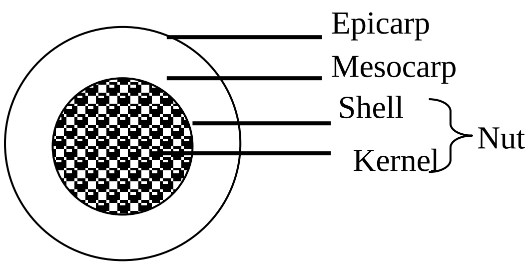

Figure 1A Cross section of *Irvingia Gabonensis* fruit showing the layers.
Source: Okafor, 1975

The kernels are processed by grinding and crushing after drying to be used as soup and stew thickener, they are made into cake called “*dika bread*” for year round preservation and easy use. Despite the productivity, nutritional and medicinal potentials of the kernel of *Irvingiagabonensis*, there has been a hindrance to the use of the kernel in the production of edible oil. This is as a result of the inability to crack nut to meet the capacity required for industrial use over a specified period of time.

Cracking has become the greatest challenge on utilization of *Irvingia* nut. In a previous work on cracking by Ogunsina*et al.*,(2008) on the deformation and fracture of *Irvingia nut* under uniaxial compressive loading, the nut evolved pronounced elastic deformation prior to a brittle failure. The cracking force was lower when loaded along the transverse axis. In comparison, roasted or steam boiled cashew nut, cooked walnut and conditioned balanitis experienced lower deformation prior to nutshell fracture (Oloso and Clarke, 1993; Koyuncu, 2004 and Mamman*et al.*, 2005).

Consequently, the proprietary nutcrackers (for palm nuts, and cashew nuts) are not appropriate for *Irvingia* nuts, which have a stony shell. Also, existing palm nut crackers do not appear suitable for cracking *Irvingia* nut because the nutshell is weaker than that of the palm nut and the embedded is more brittle than palm kernel (Koya and Faborode, 2005). This work is therefore undertaken to develop and test an efficient mechanical cracker for *Irvingia* nut with a view to reducing the drudgery involved in manual cracking.

1.1 Some physical and mechanical properties of *Irvingia*nuts

Okokon*et al.* (2007) reported on investigation into some properties of Bush mango seednuts relevant to its cracking. The physical characteristics as studied by Okokon et al. (2007) include shape, size, volume, weight, density and surface area. The average moisture content of *Irvingia* nut was found to be 50.1 % (wet basis) using oven dry method. The average major, intermediate and minor diameters were found to be 36.3, 36.2, 30.1 and 21mm respectively. They suggested the shape to be scalene ellipsoid with sphericity of 0.79.

The geometric mean of the nuts was 28.3 and average mass and density were found to be 10.71g and 16.01 kg/m^3. The average volume of the seed nut was found to be $11.8\times10^3 mm^3$ by water displacement method and 12.4×10^3mm when computed using axial dimensions. Furthermore, surface area of the nuts were reported to be 32.7×10^{10} and 27.3 $\times10^2$ mm^2 respectively be experimentation and using axial dimension methods (Okokon et al., 2007).

Alonge and Tom (2013) studied the frictional properties of *Irvingia* nuts. Moisture content is an important parameter that affects cracking of seednuts. The frictional properties studied include internal friction angle, coefficient of friction and angle of repose on different structural surfaces. The summary of the result of all frictional properties obtained are shown in Table 1.

He reported that moisture content has a great influence on the frictional properties of *Irvingiagabonensis* nuts. They noted that during mechanical processing of *Irvingia* nuts, moisture content of the nut should be reduced to minimum about 11.56% (wet basis) to reduce coefficient of friction on contact surface.

Table 1Frictional properties of *Irvingia* nut at different moisture and contact surfaces

s/n	Moisture cont. (MC (w.b)%	Internal friction Angle (Θ)				Frictional coefficient (µ)			Angle of Repose (^{0})	
		Glass (silica)	Plastic polyvinyl (chloride)	Plywood	Galvanized Iron	Glass (silica)	Plastic (polyvinyl chloride)	Plywood	Galvanized Iron	Mild steel
1	11.56 (3.44)	14	15	21	22	85.90	86.21	87.37	87.73	23.20
2	16.32 (2.85)	14	15	21	22	85.90	86.21	87.50	87.48	23.20
3	20.01 (3.01)	15	18	27	20	86.18	86.182	87.87	87.13	24.19
4	23.80 (3.56)	24	25	31	26	87.61	87.70	88.15	87.79	42.27
5	26.30 (3.70)	25	28	33	33	87.71	88.01	88.40	88.40	43.60

Note: Alonge and Tom (2013)

1.2 Cracking of *IrvingiaGabonensis*

Traditionally, cracking of nuts involves striking the nut against a stone, throwing the nut against rocks or using sharp objects to hit the nut until it cracks. But in recent times, many cracking device and machines have been developed. These include centrifugal nut crackers, walnut cracker, palmnut cracker etc. The endocarp of *Irvingia* needs to be cracked open after harvesting to extract the kernels.

The several techniques observed by Ladipo and Anegbe (1995) for the extraction of these kernels include;

1. The kernel can be extracted from fruits in the fresh state.
2. The fruits can be soaked in water, allowed to ferment and then the kernels extracted wet.
3. Alternatively, the seeds can be fermented and then the kernels extracted wet and sun dried.

Either of these methods is observed before extracting, packaging or marketing. All these methods are difficult, hazardous and time consuming. This has resulted to its being expensive in the market (Ladipo and Anegbe, 1995).

2 Materials and Method

2.1 Design Considerations

An *Irvingia* nut cracking machine is designed based on the following considerations:

(i) Affordability: It should be low-cost and within the buying capacity of the common man or local farmers.

(ii) The *Irvingia* nut must be dried to about 6.6% moisture content (w.b) for greater cracking efficiency (Ogunsina 2008).

(iii) The *Irvingia* nut must be feed through the hopper to the cracking chamber at lateral positions.

(iv) The impeller rotational speed must be uniform.

(v) The speed of rotation of the shaft should be relatively high in order to increase impact force since *Irvingia* nut is less brittle when compared with other nut such as palm kernel nut.

(vi) The assembly of the machine is made simple for easier maintenance.

(vii) The machine should be made with easily and readily available materials.

(viii) The capacity should be high when compared to manual operations.

2.2 Description of the machine

Figure 2 and Figure 3 show the first angle projection and the picture of the bush mango nut cracker respectively. The *Irvingiagabonensis* cracking consist of the hopper, cracking chamber, impeller, impact drum, shaft, pulley and electric motor. The machine is made up of two sections, the hopper, and the cracking chamber, which consists of the impeller and impact drum. A 2hp, 1400r/min single phase electric motor is recommended for machine. The motor shaft is connected in linked to a v-belt, which reduces the operational speed of the cracker. The frame is the support on which the machine rests i.e. acting as a stand that supports the entire machine. The frame is made up of mild steel with four legs and dimensions of 450 × 300 × 450.The working principle of the machine is based on the principle of energy absorbed by a seed as a result of impact (collision) between the seednut and stationery wall which will cause the cracking and removal of the seedcoat.

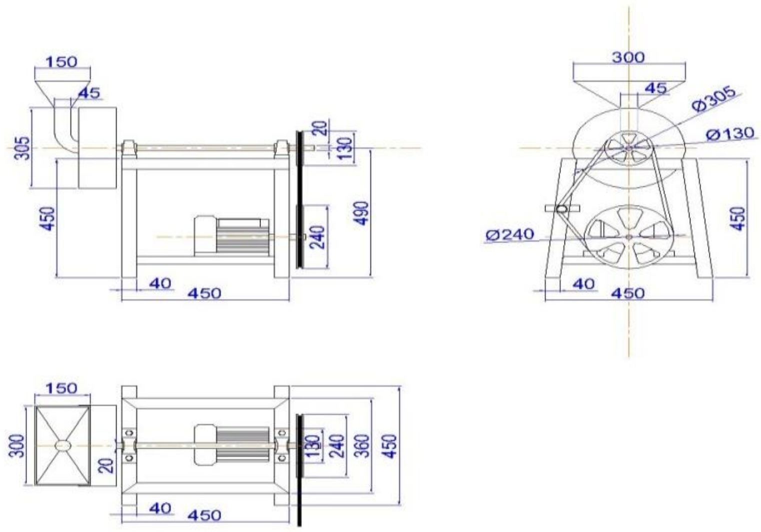

Figure 2 Angle projection of the Bush mango nut cracker

Figure 3 Picture of the Bush mango nut cracker

2.3 Design methodology and calculations

The design calculations of the *Irvingia* nut cracker have been done with reference to Khurmi and Gupta (2006), Akubuo and Eje (2002) and Ogunsina (2008). The physical, mechanical and frictional properties studied by Okokon et al. (2007), Alonge and Tom (2013) were also used for the design. The designed *Irvingia* nut cracker consists of the hopper, impeller (rotor), impact drum, shaft, ball bearing, pulley and the electric motor

2.3.1 Component design

The design of proper sizing of the various components is expected to be subjected to on service. The following assumptions were made for the design;

(i) The average mass, density, surface area and volume are 10.71g, 16.01 g/cm^3, 32.2 × $10^2 mm^2$ and 12.4 × $10^3 mm^3$ (Okokon (2007).

(ii) The estimated fracture energy along transverse axis for small size nuts 8.70kJ; medium, 9.76kJ; and large, 14.11kJ. The nuts were conditioned to moisture content of 6.6% to 11.56% (w.b) (Ogunsina2008and Alonge and Tom, 2013).

2.3.2 Design of hopper

The angle of repose is the most important criteria in the design of hopper. As reported by Alonge and Tom (2013), the angle of repose of *Irvingia* nut at 26.30% moisture level is 43.60 (w.b). It follows that the angle of inclination of the hopper to the horizontal is 53.60^o as recommended by Richey *et al.* (1961) that angle of inclination will be 10^o higher than the natural angle of repose of the stored materials.

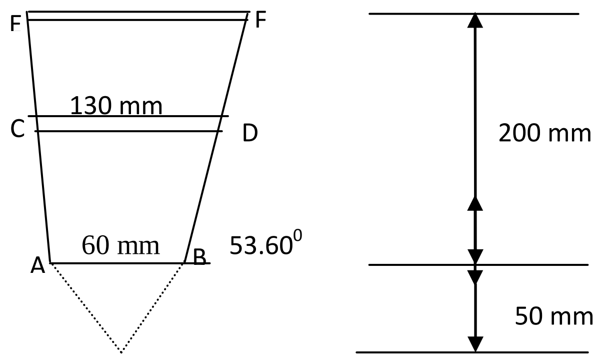

Figure 4:Hopper dimension

The following conditions are to be made satisfied to ensure that arching (where no flow occurs) and funneling (where flow may reduce) do not occur (see Equation 1 and Equation 2).

r/z≥N+ ϴ (1)

r ≥ Ntan(ϴ + β) – tan β (2)

where:

r= radius of hopper outlet

z= vertical height of hopper

ϴ= angle of internal friction

B= angle of inclination of the side of hopper to the vertical

ϴr = angle of friction of feed material on the hopper wall.

ϴr = 43.60; β = 90 - 53.60 = 36.4^o

$$N = \frac{\cos\theta}{2} = \frac{\cos 43.60}{2} = \frac{0.724}{2} = 0.362$$

N tan ϴ = 0.362 tan 43.60^0 = 0.345

Ntan (ϴ + β) – tan β = 0.362 tan (33^0 + 36.4) – tan 36.4 = 0.9631-0.737=0.226

Considering the selection ABCD of the hopper

r = 60/2 =30mm

Then r/2 = 30/100 = 0.30

Hence the condition r/z NtanϴΘ and r/z >Ntan (ϴ + β) - tan β be satisfied for the section

r 130/12 = 65mm

if r/z = 65/200 = 0.325

Also, this satisfies the two given conditions.

2.3.3 Hopper capacity

The volume of a pyramidal frustum is the volume of the solid before slicing the apex off, minus the volume of the apex:

$$V = \frac{h_2B_2 - h_1B_1}{3} \quad (3)$$

whereB_1 as the area of one base, B_2 is the area of the other base, and h_1, h_2 are the perpendicular heights from the apex to the planes at the two bases.

From Figure 4

$h_2 = 200mm$

$h_1 = 50mm$

$B_1 = 200x200 = 40{,}000mm^2$

$B_1 = 60x60 = 3600mm^2$

Substituting the values into equation 3

$$V = \frac{200\ x\ 40000 - 50\ x\ 3600}{3} = \frac{782000}{3}$$

$$= 2606666.7\ mm^3$$

The hopper capacity, in terms of number of nuts is volume of the hopper divided by average volume of *Irvingia* nuts. As reported by (Okokon 2007), the average volume of *irvingiagabonensis* is 11.8x10^{3}mm^3

$$Throughput = \frac{2606666.7\ mm^3}{11800\ mm^3} = 220\ nuts$$

Throughput in terms of weightis number of nuts times the average mass

$$i.e\ 220 \times 10.71 = 2356.2\ g$$

$$= 2{,}36\ kg\ of\ irvingia\ nuts$$

where 10.71g = average mass of *Irvingia* nut (Okokon 2007)

3 Results and Discussion

3.1 Performance testing of the *Irvingia* nuts cracking machine

The performance evaluation of the machine was carried out using 150 sundried *Irvingia* nuts which were randomly selected from a lot obtained from local markets in Abak, AkwaIbom State of Nigeria. The moisture content of the nuts was determined by oven-drying at 130^{o}C for 6 h (ASAE, 2003). The nuts were then fed into the cracker through the hopper and stop watch was used to measure the time taken for the cracking process. The machine performance was quantified in terms of its cracking efficiency, percentage kernel breakage and capacity of the machine in terms of number of number of nuts cracked per unit time. Three replications were made.

Cracking efficiencies a measure of successfully cracked nuts, with or without kernel breakage, compared with the total number of nuts in the sample. It was expressed as:

$$Cracking\ efficiency = \frac{successfully\ cracked\ nuts}{Total\ number\ of\ nuts} \times \frac{100}{1}$$

Percentage kernel breakage assesses the quantity of broken kernels in the cracked nuts sample. It was define as

$$Percentage\ kernel\ breakage = \frac{broken\ kernels\ in\ the\ cracked\ nuts}{total\ number\ of\ cracked\ nuts} \times \frac{100}{1}$$

Capacity of the machine was defined as

$$Capacity = \frac{number\ of\ nuts\ cracked}{Time\ taken}$$

3.2 Determination of the operational efficiency of the machine

The operational efficiency is determined as shown below:

$$Cracking\ efficiency = \frac{cracked + partially\ cracked\ nuts}{number\ of\ nuts}$$

$$= \frac{40+4}{50} \times \frac{100}{1} = 0.88 = 88\%$$

The percentage kernel breakage is estimated as:

$$\%\ Kernel\ breakage = \frac{broken\ kernels}{cracked\ nuts} \times \frac{100}{1} = \frac{7}{40}$$

$$= 17.5\%$$

3.3 Determination of the capacity of the machine

The capacity of the machine was estimated as shown below:

$$Machine\ capacity = \frac{number\ of\ nuts\ cracked}{Time}$$

$$= \frac{40\ nuts}{2.62\ min}$$

$$Hence, Machine\ capacity = \frac{15.27\ nuts}{min} \times \frac{60\ min}{1\ h}$$
$$= 916\ nuts/h$$

3.4 Discussion

The results obtained from the performance evaluation of the *Irvingia* nuts cracker are presented in Table 2. The performance characteristics of the machine estimated are: cracking efficiency (88%); kernel breakage (17.5%) and machine capacity (916nuts/h). The preliminary test result carried out suggested that the performance of the machine was highly depended on the rotor speed, moisture content of the nuts and quantity of the nuts passing through the machine with cracking operation probably better at around 2600r/min. At higher speed, the kernel breakage increases and lower speed and higher moisture level the cracking efficiency decreases.

Table 2 Performance data for Irvingia nuts cracker

Cracking operation sequence	Number of nuts	Cracked nuts	Partially cracked nuts	Uncracked nuts	Full kernels	Broken kernel	Time taken (min)
1	50	37	6	7	29	8	2.40
2	50	42	2	6	34	8	3.00
3	50	41	4	5	31	10	2.47
Average	50	40	4	6	31	7	2.62

The moisture content of the nuts at the time of the testing was 9.6% (wet basis). It was observed that some of the kernels were audibly shaking inside the nutshell, indicating that the kernel had shrunk away from the shell wall as earlier reported (Ogunsina, 2008). This enables a reduction in kernel breakage during the cracking process. The sun-drying of the *Irvingia* nuts before test-running the machine was necessitated in order to improve its crackability. This is in line with the suggestion of (Ogunsina and Bamgboye, 2007) during shelling of cashew nut. The nuts were subjected to certain pre-treatment to improve the crackability of the nutshell. Oluwole et al. (2007) also conditioned Bambara groundnuts to various moisture levels to improve its crackability in a centrifugal cracker. Similarly, in the dehulling of melon seed, which has a thin hull embedding a brittle kernel, the dried seeds were rewetted to improved shelling efficiency (Odigboh, 1979). *Irvingia*nut also requires some pre-treatment to improve crackability and wholesomeness of the kernel.

4 Conclusion

Mechanization of *Irvingia* nut processing is feasible; cracking the nut using impact techniques are easier and safety than the prevailing manual cracking. The *irvingia* nut cracking machine was developed from the available locally sources materials. The machine is very applicable for local production, operation, repair and maintenance. The operation saved energy and did not require high skilled labour. The operational and process performance showed that the equipment cracked well over 74% of *Irvingia* seednuts in three successive cracking operations and percentage of broken kernels in any cracking operation was less than 24%. Also, an*Irvingia* nut cracking plant based on this technology could provide employment and at the same time make available quality kernels at low cost for domestic use and for *Irvingia* oil process industry.

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Table 3: Cost Analysis

S/N	Material	Quantity required	Unit Cost (N)	Total Cost (N)
1	Frame	8	500	4,000
2	Hopper	1	4,500	4,500
3	Impact drum	1	5000	5000
4	Impeller	1	2,500	2,500
5	Shaft	1	5000	5000
6	Bearings	2	2000	4000
7	Pulley	2	1500	3000
8	Keys	2	100	200
9	Bolts	10	50	500
10	Belt	1	500	500
11	Electric Motor	1	21,000	21,000
				50,200 ($300)