Performance evaluation of a bush mango (*irvingia gabonensis*) nut cracking machine

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Abstract: A bush mango (*Irvingia gabonensis*) nut cracking machine was designed to ease the tedium involved in the cracking operation and enhance the efficiency of separating the kernels from hulls. The machine consists of a hopper, cracking unit barrel, electric motor, blower, tool frame, hull outlet and kernel outlet. It operates on the principle of impact using centrifugal force from the baffles on a spinning disc. Results of performance tests carried out on a fabricated unit of the machine, using nuts at four moisture levels in the range of 7.52%-20.6% (d.b) showed that percent effective cracking decreased, while percentage kernel breakage increased with increase in feed rate, moisture content and resident time of nuts in the cracking chamber. Winnowing efficiency increased with feed rate and resident time, but decreased with increase in moisture content. Highest percent effective cracking and percentage kernel breakage was 92.32% and 9.71%, respectively, at 7.52% (d.b) moisture content, 8.47 kg h^{-1} feed rate and 1 and 3 min respectively, resident time. Winnowing efficiency was highest (67.07%) at 10.6% (db) moisture content, feed rate of 8.47 kg h^{-1} and resident time of 3 min. The capacity of the machine was dependent on the nut moisture content.

Keywords: Bush mango nut, design and construction, performance evaluation, cracking, efficiency

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1 Introduction

Irvingia gabonensis is a genus of African and South Western Asia trees in the family of *irvingiaceae*. It is also known by some common names as Wild mango, African mango, Bush mango, Bread tree, Dika nut, Odika, Kaka and Etima nut (Burkill, 1994). In Nigeria, it is known as *oro* (Yoruba), *ogbono* (Igbo), *goron, biri* (Hausa), and *manguier sauvage, bobo* (French). The tree (*irvingiacea spp*) is very valuable for its edible mango-like fruits, nuts and kernels (Figure 1) and the termite – resistance of its wood (Ayuk et al., 1999). The fruit comprises fleshy mesocarp and nut which has a hard shell and contains a flattened kernel (FAO, 1982). Bush mango nut is about 3-5 cm long in size and has the shape of an oval spheriodal disc (Iyilade et al., 2018a).

Harvesting is carried out manually by gathering the fallen ripe fruits by the village processors or using mechanical harvester, which shakes the stem and collects the fallen fruits through its tray collector to avoid getting the mesocarp bruised. The fruit is stored in a controlled atmosphere storage system but the temperature is not to freeze (Alonge and Idung, 2015). The fresh fruits of *Irvingia gabonensis* have a shelf life of less than 2 days if picked when ripe and not more than 10 days if harvested at the mature green stage due to high respiration rate, moisture loss and microbial attack (Joseph and Aworh, 1992).

Traditionally the fruits are piled up in heaps and left to ferment before the nuts are extracted (Ejiofor, 1994). Alternatively, the fruits can be cut through with a cutlass to reveal the hard nut (Ladipo et al., 1996; Ayuk et al., 1999). Its kernels are traditionally extracted from the nuts by cracking with stones or pestle and mortar. The kernel is usually processed by grinding and crushing after drying,

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and used as thickening agent in soup and stew. It can be made into cake called ‘dika bread’ for year round preservation and ease of use (Alonge and Idung, 2015). Ogunsina et al. (2012) reported that bush mango kernel contains about 8.9% of crude protein and 68.37% of crude fat largely made up of saturated fat comprising about 62% and 28% of myristic and lauric acids respectively. Osagie and Odutuga (1986) had earlier reported that bush mango kernels contain 19.7% carbohydrate, 5.3% dietary fibre and 3.2% ash by weight. Apart from being a source of energy in human nutrition, some saturated fats carry fat – soluble vitamins A, D, E and K and may serve as valuable nutraceuticals in moderate use (Enig, 1995).

(a) Fruits

(b) Nuts

(C) Kernels

Figure 1 Irvingia gabonensis fruits, nuts kernels

Despite the productivity, nutritional and medicinal potentials of the kernel of *Irvingia gabonensis*, there has been a hindrance to the use of the kernel in the production of edible oil. This has been due to the inability of processors to crack nuts to meet the capacity required for industrial use over a specified period of time. The drudgery involved in cracking the nut has therefore, constituted a great bottle neck to the utilization of *Irvingia gabonensis*. Ogunsina et al. (2008) studied the deformation and fracture characteristics of *Irvingia* nut under uniaxial compressive loads and developed a table mounted device for cracking the nut. The cracking force was lower when the nut was loaded along the transverse axis. In comparison, roasted or steam boiled cashew nut, cooked walnut and conditioned *Balanites aegyptiaca* experienced lower deformation prior to nutshell fracture (Oloso and Clarke, 1993; Koyuncu et al., 2004 and Mamman et al., 2005). The device developed by Ogunsina et al. (2008) could not separate the kernel from the shell and that has to be done manually. Also, it takes a lot of time in cracking small quantity of dried bush mango *(Irvingia gabonensis)* nuts. 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 kernel is more brittle than palm kernel (Koya and Faborode, 2005). Olaniyan (2012), developed a small scale machine for recovering bush mango kernel from bush mango nut that had cracking and winnowing efficiencies of 57.3% and 49.8%, respectively, so that it was considered to be of poor performance. Alonge and Idung (2015) developed a bush mango (*Irvingia gabonensis*) nut cracker and tested the machine with nuts at the moisture content of 9.6% (w.b). The hopper was not fitted with a feed rate control device and there was no system for separating the kernels from hulls. Therefore, there is the need to develop a cracker for the nut that has improved efficiencies and feed rate control system.

Adigun and Oje (1993) reported that nuts whose shells/pods cannot be easily broken by the roller cracker are commonly cracked using a centrifugal cracker. Makanjuola (1975) evaluated some centrifugal impaction devices for shelling melon (*egusi*) seeds and found that a centrifugal impact method can be effectively used to shell the melon seeds. Odigboh (1979) developed and tested a prototype impact melon (*egusi*) shelling machine that gave about 96% shelling efficiency and 100% winnowing efficiency. Oluwole et al. (2004) developed and tested a shea nut cracker working on the principle of impaction and pneumatically separating the kernels from the shells. Akani et al. (2000) determined the optimum impact energy for shelling bambara groundnut at pod moisture content range of 5%-8% (wb) and found that the impact energy ranged from 0.24 to 0.59 J. Iyilade et al. (2018b) studied the effect of moisture content and loading orientation on strength properties of bush mango nuts and noted that the properties decreased with increase in moisture content and had lower values under lateral loading.

Okokon et al. (2007) reported investigation into some properties of bush mango nuts relevant to its cracking operation. The physical characteristics studied by Okokon et al. (2007) included shape, size, volume, weight, density and surface area. The average fresh state moisture content of *Irvingia* nut was found to be 50.1% (wet basis). The average major, intermediate and minor diameters were found to be 36.3, 30.1 and 21.0 mm, respectively. They suggested the shape to be scalene ellipsoid with sphericity of 0.79. The above findings were corroborated by Iyilade et al. (2018a) in their study of the variation of the physical properties of the nut with moisture content. Alonge and Tom (2013) studied the frictional properties of *Irvingia* nuts. Aviara et al. (1999) noted that moisture content is an important parameter that affects the adjustment, operation and performance of processing machines. Therefore, the main aim of this study was to evaluate the performance of a centrifugal impact cracker that was designed and fabricated for bush mango (*Irvingia gabonensis)* nut. Specially, the performance indicators considered were percentage effective cracking, percentage kernel breakage and winnowing efficiency at different nut moisture contents and feed rates.

2 Materials and methods

2.1 Material procurement and conditioning

The bulk quantity of fresh fruits of bush mango (*Irvingia gabonensis*) used in this study, was bought from Iware market near Fiditi in Afijio Local Government Area of Oyo State, Nigeria. The fresh fruits were kept inside sacks to decay at room temperature for the nut removal to be made easy. Thereafter, the nuts were removed manually, washed several times in clean water and sun dried to lower the moisture content. The physical and mechanical properties of bush mango nut that would influence the adjustment, operation and performance of the cracker (Aviara et al., 1999) were obtained from Iyilade et al. (2018a, 2018b).

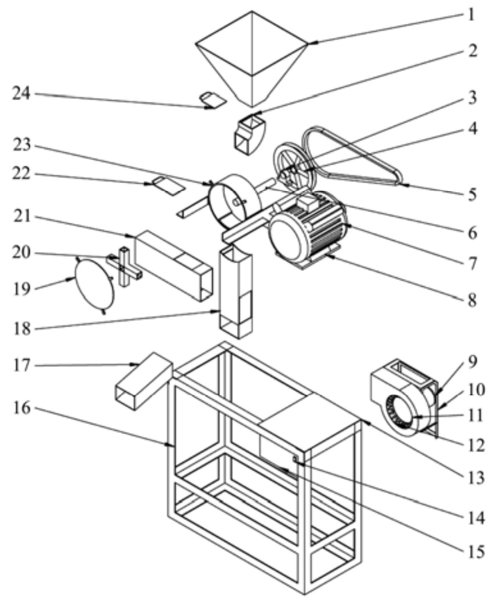
2.2 Design consideration, description and operation of cracking machine

The machine functional requirements were established and working elements designed in consideration of the nut physical and mechanical properties as affected by moisture content. The machine is to cracker *Irvingia gabonensis* nuts by impact, release the kernels from the shells and winnow off the hulls to enable clean kernels to be collected. The available fabrication technology and materials of construction as well as ergonomics and costs were also considered.

The nut cracker (Figure 2) designed to operate on the principle of impact, consists of a feed hopper, cracking unit, electric motor, blower, tool frame, kernel and hull outlets. The hopper is pyramidal in shape and connected to the cracking chamber through the nut flow channel to facilitate proper and easy feeding of nuts into the chamber. The cracking chamber consists of a cracking drum and impellers or baffles on a disc rotating in the vertical axis on a shaft at 620 rpm. Graduated locking devices were located between the hopper and the cracking drum and at the base of the cracking drum for use in metering the nuts into the cracking chamber at a selected feed rate, and in enabling the nut to remain resident in the cracking chamber so that un-cracked nuts could be cracked before the kernels and hulls are dropped from the chamber for winnowing.

Figure 2 Photograph of fabricated bush mango (*Irvingia gabonensis*) nut cracker

The fan running at 1250 rpm blows the hulls through the hull outlet while the kernels fall under gravity into the kernel outlet. A 3 hp electric motor mounted on the motor seating supplies the power needed to run the cracker through pulley and belt arrangement. The blower motor which was mounted beneath the main drive electric motor has switch by which it can be turned on or off. The machine components were assembled and mounted on a rectangular tool frame that gave it a compact design and sturdy outlook. The part list and detailed assembly drawing of the cracker are shown in Figures 3 and 4.



1. Hopper 2. Nut channel 3. Pulley 4. Pillow bearing 5. Transmission belt 6. Shah 7. Electric motor 8 Fngine base 9. Blower engine 10. Blower Case 11. Blower 12. Blower blades 13. Engine seat 14. Blower switch 15. Switch plate 16. Frame 17. Cracked nuts outlet 18. Discharge chute for both nuts and hull 19. Cracking drum cover 20. Impeller shaft 21. Hull outlet 22. Locking device 2 23. Cracking drum 24. Locking device 1

Figure 3 Bush mango (*Irvingia gabonensis*) nut cracker part list

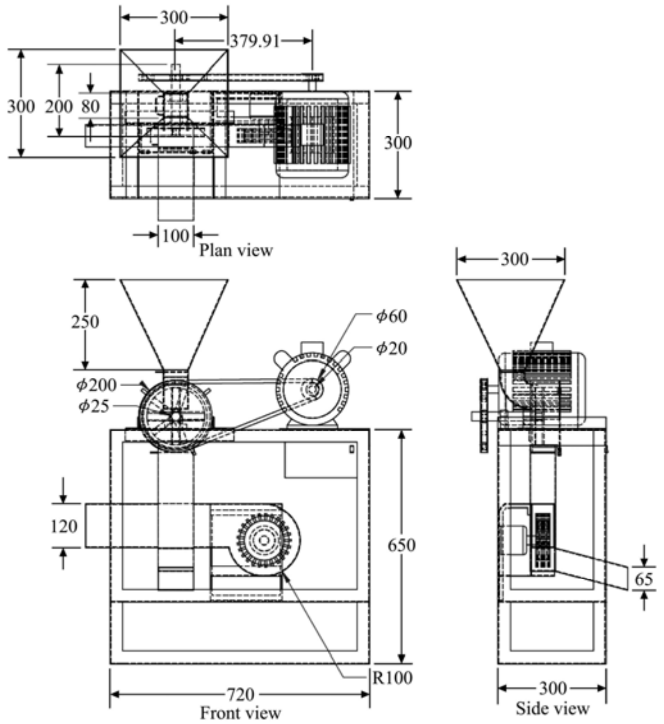


Figure 4 Bush mango (*Irvingia gabonensis*) nut cracker assembly

To operate the cracker, the hopper base gate opening would be shut completely by means of the flow rate control device. The hopper would then be filled with nuts and the main switched on to actuate the electric motor, which runs the impellers in the cracking chamber and the blower of the winnowing unit. The gate opening that delivers the desired feed rate would be selected using the flow rate control device and nuts will be allowed to flow into the cracking chamber and to fall upon the impeller. The centrifugal force developed by the impeller exerts impact on the nuts as they roll and slide on the impeller, thereby throwing them against the impact surface (cracking drum) and causing them to crack. The mixture of kernels and broken hulls flow down the inclined transition channel into the winnowing chamber. Here the hulls, which are lower in density than the kernels are pneumatically separated from the mixture and blown out through the hull outlet. The denser kernels fall through the air current into the kernel collection chute.

2.3 Performance tests and evaluation

Tests were conducted to evaluate the performance of the bush mango nut cracker. The flow rate control device was calibrated to establish the hopper gate opening that will deliver various nut feed rates into the cracking chamber. This was carried out by closing the hopper base opening using the flow rate control flap pushed through a slot. A graduated stem was used to determine the size of gate opening indicated by a number that ranged from 0 to 1. The hopper was filled with nuts and the stem was adjusted to read gate opening number $\frac{1}{2}$. The nuts were allowed to flow freely through the gate and the time taken to discharge a known mass of nuts was taken. The process was repeated with gate opening number 1 and was replicated thrice at each gate opening. The rate of flow of nuts through the gates also taken as the feed rate was calculated using the Equation (1).

$$\varphi \approx \frac{m_n}{t_s} \tag{1}$$

where, φ is nut flow rate (kg h^{-1}); m_n is mass of nut (kg) and t_s is time taken (h).

To carry out a performance test, the hopper base was completely closed with the flow rate control device. The hopper was filled with nuts at particular moisture content and the total number of nuts (N_t) was determined by counting. The nuts were poured back into the hopper, the main was switched on to run the electric motor and set the working components of the cracker in motion, the flow rate control device was adjusted to select the gate opening that will deliver a particular feed rate and the nuts were allowed to flow into the machine and get cracked until the hopper was emptied.

The mass of nuts that were completely cracked with unbroken kernels, completely cracked but with broken kernels, partially cracked with unbroken kernels, partially cracked but with broken kernels and mass of un-cracked nuts were determined at the end of each run. The quantity of hulls winnowed out and those collected with the kernels were noted. The tests were conducted using factorial design involving four moisture levels in the range of 7.52% to 20.6% (dry basis), two feed rates of 8.47 and 9.18 kg h^{-1} and three resident times of 1, 2 and 3 min. Each test was repeated three times and average values of the above masses were recorded. The data obtained were analysed to determine the effect of moisture content, feed rate and resident time on the performance of the cracker expressed on the basis of the following indices:

2.3.1 Effective cracking efficiency

This was determined in accordance with Alonge and Idung (2015) and defined as mass of successfully cracked nuts, with or without kernel breakage compared with total mass of nuts fed into the cracker, expressed as percentage. The percentage effective cracking of nut was expressed as follows:

$$\text{Cracking efficiency, } \in_c = \left\{ \frac{C_1 + C_3}{C_1 + C_2 + C_3} \right\} \times 100\% \quad (2)$$

where, C_1 is mass of cracked nuts (g); C_2 is mass of uncracked nuts (g); C_3 is mass of partly cracked uts (g).

2.3.2 Percentage kernel breakage

The percentage kernel breakage was determined using Equation (3) similar to that due to Alonge and Idung (2015), and was defined as mass of broken kernel compared to the summation of mass of un-broken kernel and mass of kernel in hull.

Percentage kernel breakage,

$$\in_b = \left\{ \frac{C_4}{C_5 + C_6 + C_7 + C_8} \right\} \times 100\% \quad (3)$$

where, C_4 is mass of broken kernel (g); C_5 is mass of kernel in hull outlet (g); C_6 is mass of un-broken kernel (g); C_7 is mass of kernels in partially cracked nuts (g); C_8 is mass of kernels in uncracked nuts (g).

2.3.3 Winnowing efficiency

The efficiency of winnowing was defined according to Olaniyan (2012), as percentage of mass of hull from hull outlet to the sum of masses of hull from hull outlet, hull from kernel outlet, hull in partially cracked nuts and hull in uncracked nut.

$$\text{Winnowing efficiency, } \in_w = \frac{C_9}{C_9 + C_{10} + C_{11} + C_{12}} \times 100\% \quad (4)$$

where, C_9 is mass of hull from hull outlet (g); C_{10} is mass of hull from kernel out let (g); C_{11} is mass of hull in partially cracked nuts (g) and C_{12} is mass of hull in uncracked nuts (g).

3 Results and discussion

The results of performance tests and analyses of the bush mango nut cracker are presented in Table 1. From the Table 1, it can be seen that feed rate of 8.47 kg h^{-1} consistently gave the best cracking performance. Similar finding was reported by Makanjuola (1975) in an evaluation of some centrifugal impaction devices for shelling melon seeds. However, a different finding was reported by Odigboh (1979) in the performance evaluation of an (*egusi*) melon shelling machine. Differences in variety, physical and mechanical properties of the test materials as well as machine operational speed may have been responsible for the different responses reported by the above investigators. Table 1 also reveals that the moisture content of the nut that gave the highest cracker performance was 7.52% (db).

The cracking efficiency at moisture content of 7.52% (db) was a maximum of 92.32%. This implies that the cracking machine was efficient. Also, the maximum breakage percentage was 9.63% which occurred at the resident time of 3 min, showing that little damage was done to the kernels. Maximum winnowing efficiency was 65.21%. This occurred at the feed rate of 9.18 kg h^{-1} and 3 min resident time. From the Table 1, it can be seen that the cracking efficiency decreased with increase in moisture content, feed rate and resident time. Percentage breakage increased with increase in moisture content and was not in agreement with Makanjuola (1975) and Odigboh (1979) that reported percentage of breakage as decreasing with increase in moisture content. This may be due to fibrous nature of the nut and decrease in its strength properties with moisture content (Iyilade et al., 2018b). Winnowing efficiency decreased with increase in moisture content and increased with increase in resident time and feed rate.

Table 1 Performance indices of bush mango (*Irvingia gabonensis*) nut cracker

Feed rate, kg h^{-1}	Performance indicator (%)	Resident time (min)	Moisture content, % (db)			
			7.52	10.6	15.62	20.6
8.47	Percentage effective Cracking	1	92.32	90.18	88.45	86.66
		2	90.93	87.93	85.60	83.92
		3	90.30	86.89	84.72	82.86
	Percentage of breakage	1	4.24	5.78	6.82	6.85
		2	6.42	6.79	7.20	7.76
		3	9.63	7.59	7.63	7.87
	Winnowing efficiency	1	58.63	57.12	56.12	55.95
		2	59.84	58.93	58.89	59.10
		3	60.04	67.07	58.76	54.96
9.18	Percentage effective Cracking	1	91.59	88.46	88.50	87.48
		2	88.65	87.28	86.71	85.87
		3	87.31	86.41	85.54	83.50
	Percentage of breakage	1	6.72	6.59	6.10	5.60
		2	7.83	6.75	7.41	6.72
		3	9.71	6.70	6.41	5.77
	Winnowing efficiency	1	62.39	58.85	58.41	56.26
		2	64.37	59.71	57.82	58.21
		3	65.21	64.77	60.59	61.15

4 Conclusion

The performance evaluation of a bush mango (*Irvingia gabonensis*) nut cracker operating on the principle of impact using centrifugal force from impellers revealed the following.

The nut feed rate and moisture content that gave the highest performance indices for the machine operation was found to be 8.17 kg h^{-1} and 7.52% (db), respectively. Cracking perfomance of the machine on bush mango nuts was moisture dependent. The cracking, breakage and winnowing efficiencies ranged from 82.86%-92.32%, 4.24%-9.71% and 54.96%-65.21%, respectively, in the moisture range of 7.52%-20.6% (db), feed rates of 8.47 and 9.18 kg h^{-1} and resident time of 1 to 3 min, respectively. The values of cracking efficiency, percentage breakage and winnowing efficiency indicated that the design of the machine has met the engineering requirement of better performance, when compared to those obtained from literature. The use of this machine can completely eliminate the drudgery involved in the manual cracking of bush mango nuts. Future work would be directed towards modeling the machine performance on the bases of material moisture content, feed rate, machine speed and mechanics of its operation.

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