# Performance evaluation of some tangential impact shelling devices for moringa seed shelling

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**Abstract:** The utilization of Moringa oleifera seed requires efficient shelling process and effective detachment of whole kernels from its shells. In this study, the effects of some Tangential Impact Shelling Devices (TISDs) and moisture content on Moringa oleifera seed shelling process were established. The moisture content of moringa seed was varied from 9.17% to 24.31% while three different configurations of flat bar-cylinders having inclination of 30$^o$, 60$^o$ and 90$^o$ were applied in the shelling process. The performance of the machine was evaluated based on capacity, shelling efficiency, percentage whole kernel recovered, percentage broken kernel recovered and separation efficiency. The capacity, shelling efficiency, percentage whole and broken kernels recovered and separation efficiency were found to have mean range values of 6.70-7.98 kg h$^{-1}$, 91.73%-94.77%, 58.72%-85.17%, 14.83%-41.28%, and 73.52%-82.10% respectively for the three cylinders. The moringa seed shelling machine had a maximum value of 8.44 kg h$^{-1}$, 97.97%, 85.17%, 75.98% and 82.10% for capacity, shelling efficiency, percentage whole kernel recovered, percentage broken kernel recovered and separation efficiency respectively. The variation of moisture content using three different Tangential Impact Shelling Devices (TISD) were found to influence the performance of the moringa seed shelling significantly ($p$<0.05). In moringa seed shelling machine where tangential impact shelling device is to be used, cylinder bar inclination of 30$^o$ would reduce broken kernel in moringa seed shelling. It is suggested that the shelling process of moringa seed should be optimized.

**Keywords:** moringa, moisture content, cylinder bar inclination, seed shelling, efficiency

**Citation:** Fadele, O. K., A. K. Aremu. 2017. Performance evaluation of some tangential impact shelling devices for moringa seed shelling. Agricultural Engineering International: CIGR Journal, 19(4): 170–180.

## 1 Introduction

Moringa oleifera is a monogenic shrub which belongs to moringaceae family, with provenance from Agra and Oudh in North Western region of India to South of the Himalayan Mountains. It is commonly known as horseradish tree or drumstick tree in English, and zogele in Hausa, ewe ile in Yoruba and ikwe oyibo in Igbo (Fadele and Aremu, 2016). Several parts of moringa plant have been discovered to be medicinal; the leaves of moringa plant have anti-diabatic, hypotensive, anti-tumorand hypocholesterolmic potencies. Moringa oleifera seeds contain flocculants, which could be used for water treatment. Seed kernels of Moringa oleifera are known to remove lead, iron and cadmium ions from contaminated water; moringa seed is a good source of protein and cooking oil. The seed oil is used as a raw material in the cosmetic industry and as lubricant for machineries (Rashid et al., 2011; Tende et al., 2011; Fadele and Aremu, 2016; Aviara et al., 2013). Moringa seed and oil are also used in the treatment of ailments such as arthritis, rheumatism, sexually transmitted diseases, hypertension and boils (Eilert et al., 1981). Many researchers have worked on performance evaluation of de-hulling and shelling processes of most industrial crops such as jatropha seed and fruits, safflower, cotton seed and sunflower seeds (Gupta and Das, 1999;

**Received date:** 2017-02-09 **Accepted date:** 2017-07-05

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Ting et al., 2012; Nunneleyet al., 2012, Figueiredo et al. 2013 and Aremu et al. 2015) but investigation shows there are still other crops of interest, including moringa seed which is yet to be fully mechanized. Moringa seed shelling machine is very important in moringa seed processing. In order to maximize the industrial utilization of moringa seeds, shelling devices with high performance have to be developed. Figueiredo et al. (2014) reported that partial dehulling of oil bearing seed have many advantages, such as a suitable bulk porosity for the oil extraction process, better quality of both raw oil (lower wax content) and de-oiled meal (higher protein content), as well as an increase of the life span of the machinery. It was revealed that waxes located in the hull of the seedstend to crystallize and cause turbidity when the oil is cooled, thus interfering with oil quality and marketing. Partial removal of the hull reduces the wax content of the raw oil, at the same time it decreases the fiber content of the meal and increases its protein content (Figueiredo et al., 2013). Moreover, Makanjuola (1975) investigated the impact of moisture content on shelling effectiveness of a melon shelling machine which revealed that the kernels could be separated more easily from the shells at low moisture contents. At these low moisture contents, the kernels do not fill completely the internal space of the shells and it is the little clearance between the kernels and the shells that facilitate the separation. It was established that the most appropriate moisture content for melon seed shelling was 8.6% moisture content (wet basis). Pradhan et al. (2010) studied the effects of moisture content on jatropha fruit decortications at four moisture content values viz 7.97%, 10.53%, 13.09% and 15.65% (d.b.). The best moisture content was found to be 7.97% giving a maximum percentage whole kernel recovered to be 67.94%±2.48%. It was also reported that this was due to the fact that at low moisture content the fruit become more brittle and susceptible to mechanical damage. Oluwole et al. (2007) also investigated the effect of different impeller designs on the performance of bambara nut decorticator and reported that the impellers with eight slots consistently gave the best performance. This shows that moisture content and design factors affect the performance of most shelling machines. Thus, in order to enhance recovery of moringa kernel with little or no damage, effective shelling devices are necessary as well as appropriate seed condition. Therefore, performance of shelling process of moringa seed based on different cylinder configurations is necessary. In this study performance evaluation of some tangential impact shelling devices and the effects of moisture content on moringa seed shelling process were assessed.

## 2 Materials and Methods

### 2.1 Sample preparation

Some moringa seeds were purchased from a local market in Kano, Nigeria and stored in polythene sacks at room temperature (28.0$^o$C±2.0$^o$C). The seeds were cleaned manually to get rid of foreign materials such as stone, pods, leaves and so on. The initial moisture content of the moringa seed was found to be 9.17% (w.b.) using recommended procedure by (ASABE, 2008). Samples of moringa seeds were conditioned to five moisture levels (9.17%, 13.49%, 17.42%, 21.01% and 24.31% w.b.) by adding calculated quantity of water to the moringa seed using Equation (1). The seeds were sealed in a polythene bag and left for three hours to enhance moisture stability and uniform distribution of moisture within the seeds (Sharmaet al., 2013; Fadele and Aremu, 2016).

$$Q = \mathrm{A}(b - a)/(100 - b) \quad (1)$$

where, $Q$ is the quantity of water added to the seed; A is the mass of the seed; $b$ is the final moisture content of the seed; $a$ is the initial moisture content of the seed.

### 2.2 Operation of the machine

The moringa seed shelling machine was designed to ease the process of shelling. The machine was put on and made to run for some minutes before loading with the seed. This is to ensure that all the components of the machine are properly fixed in order to reduce noise resulting from machine vibration. Thereafter, the seed was introduced into the machine through the hopper. The seeds moved from the hopper to the shelling chamber where shelling takes place. The seed remains on the screen until shelling takes place. The kernel-shell mixture drops from below the screen after shelling. A blower incorporated into the machine does the cleaning of the kernel-shell mixture by separation based on the difference between the aerodynamic properties of the kernel and the shell. The machine has two chutes (outlets); while the shell is being blown away through the upper chute, the kernel comes out through the lower chute. The moringa seed shelling machine applies the combination of impact and shear force to achieve shelling (Fadele and Aremu, 2016).

### 2.3 Performance evaluation

The performance of the moringa seed shelling machine in Figure 2 was assessed using three selected Tangential Impact Shelling Devices with cylinder bar inclination of 30$^o$, 60$^o$ and 90$^o$ as shown in Figure 1, Figures 3 and 4 show the isometric and orthographic views of the moringa seed shelling machine respectively. Clean moringa seed was shelled to obtain the kernels as shown in Figure 5.

The parameters determined during the machine evaluation were capacity, shelling efficiency, percentage whole kernel recovered, percentage broken kernel recovered and separation efficiency.

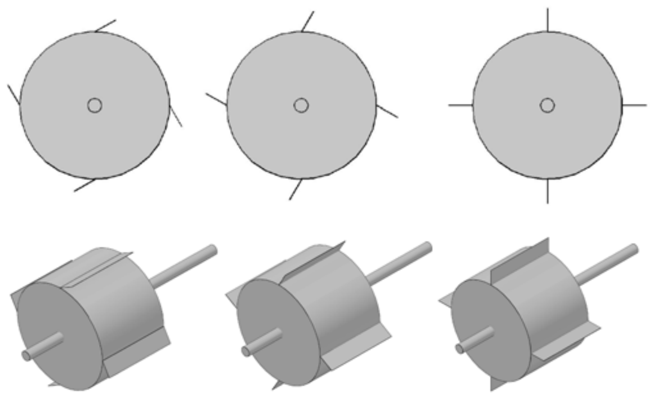
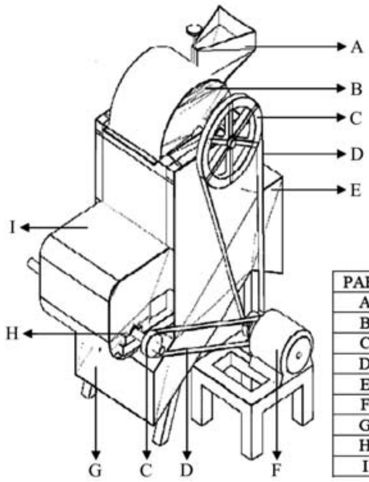


Figure 1 Side and 3-D views of some Tangential Impact Shelling Devices with cylinder bar inclination of 30$^o$, 60$^o$ and 90$^o$

Figure 2 Moringa oleiferaseed shelling machine




| PART | DESCRIPTION | QTY |
|---|---|---|
| A | Hopper | 1 |
| B | Shelling Chamber Head | 1 |
| C | Pulley | 3 |
| D | V-Belt | 2 |
| E | Shell Outlet | 1 |
| F | Electric Motor | 1 |
| G | Kernel Outlet | 1 |
| H | Ball Bearing | 4 |
| I | Fan Compartment | 1 |

Figure 3 Parts description of isometric view of the moringa seed shelling machine

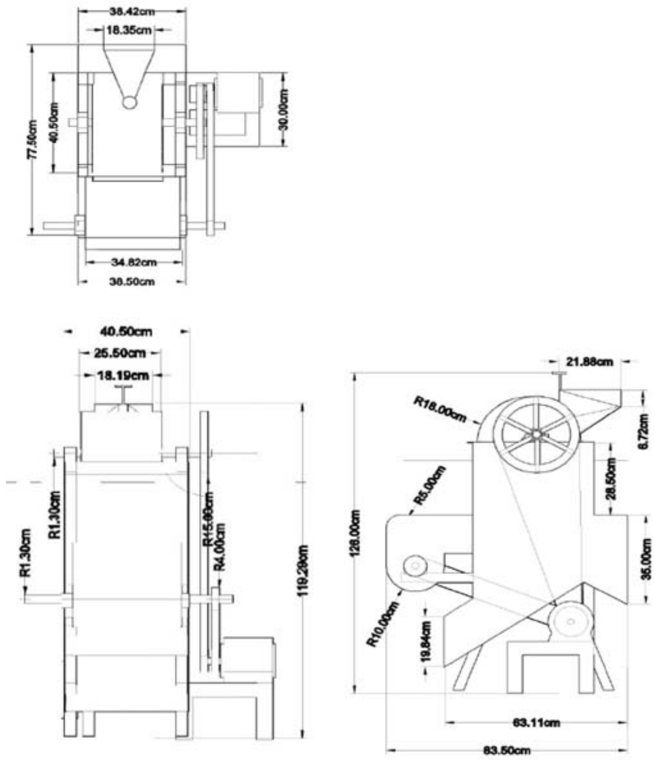



Figure 4 Orthographic views of the moringa seed shelling machine

a. Unshelled moringa seed b. Moringa kernel

Figure 5 Moringa seeds and kernels

#### 2.3.1 Capacity of moringa seed shelling machine

This is also referred to as the rate of shelling. The capacity of the machine was evaluated as the quantity of the moringa seed the machine could process within a recorded time. In this case 100 g of moringa seeds was introduced into the machine while the time for the shelling operation to complete was recorded. This was calculated using Equation (2).

$$C = \frac{M_o}{T} \tag{2}$$

where, $C$ is the capacity of the machine; $M_o$ is the mass of seed introduced into the machine; $T$ is the time taken for the shelling process.

2.3.2 Shelling efficiency of moringa seed shelling machine

The shelling efficiency of the machine was evaluated using the Equation used by Pradhan et al. (2010) and Atiku et al. (1999) as stated in Equation (3).

$$SE = \left[1 - \frac{M_3 + M_4}{M_o}\right] \times 100 \tag{3}$$

where, $SE$ is the shelling efficiency; $M_3$ is the mass of seed unshelled; $M_4$ is the mass of seed partially shelled; $M_o$ is the mass of the seed introduced into the machine.

2.3.3 Percentage whole kernel recovered

The percentage whole kernel recovered was also evaluated during the shelling process, using Equation (4). The percentage whole kernel recovered is a parameter which indicates the effectiveness of the Tangential Impact Shelling Device (TISD) in removing the outermost cover of the seed without any form of damage such as bruises, cuts, punctures, cracks, splitting and distortion on the kernel.

$$PWK = \frac{M_1}{M_a} \times 100 \tag{4}$$

where, $PWK$ is the percentage whole kernel recovered; $M_1$ is the mass of whole kernel recovered; $M_a$ is the actual mass of kernel present in the quantity of seed introduced into the machine.

2.3.4 Percentage broken kernel recovered

The percentage broken kernel recovered was determined after the shelling process. The broken kernels were separated from the whole kernel by hand picking immediately after the shelling process was completed. This was also evaluated using Equation (5).

$$PBK = \frac{M_2}{M_a} \times 100 \tag{5}$$

where, $PBK$ is the percentage broken kernel recovered; $M_2$ is the mass of broken kernel recovered; $M_a$ is the actual mass of kernel present in the quantity of seed introduced into the machine.

2.3.5 Separation efficiency

The separation efficiency also known as the screening efficiency is a measure of the overall efficiency of the separator in separating the kernels from the shells (Akubuo and Eje, 2002). The separation efficiency was computed using Equation (6) as done by (Akubuo and Eje, 2002).

$$V = 100\left[\frac{w}{w+x} \times \frac{y}{y+z}\right] \tag{6}$$

where, $V$ is the separation efficiency; $w$ is the mass of kernel in the product tray; $x$ is the mass of kernels mixed with the shells in reject tray; $y$ is the mass of shell in the reject tray; $z$ is the mass of shells mixed with kernel in product tray.

### 2.4 Statistical analysis

The data obtained were analyzed using Microsoft Excel (2007) and IBM SPSS Statistics version 23. The analysis of variance and regression models were computed at 5% level of significance. The coefficient of determination for the models was also established.

## 3 Results and Discussion

### 3.1 Capacity of the moringa seed shelling machine

The effects of moisture content and cylinder bar inclination on the capacity of the moringa seed shelling machine is depicted by Figures 6-8.

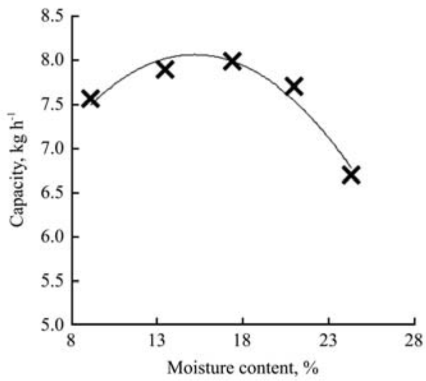



Figure 6 Variation of moisture content with capacity using 30° cylinder bar inclination

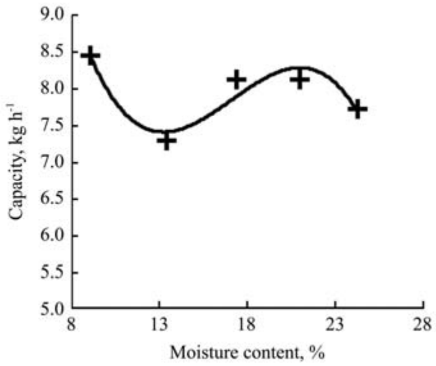



Figure 7 Variation of moisture content with capacity using 60$^o$ cylinder bar inclination

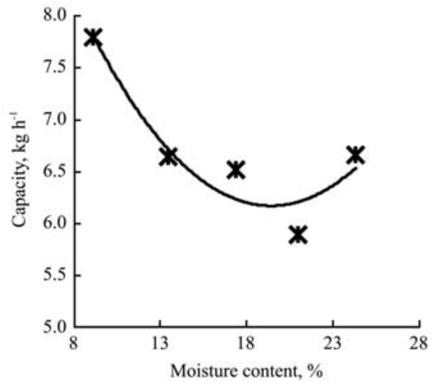



Figure 8 Variation of moisture content with capacity using 90$^o$ cylinder bar inclination

The capacity of the machine had a maximum value of 8.44 kg h$^{-1}$ at moisture content of 9.17% when a tangential impact shelling device with cylinder bar inclination of 60$^o$ was used as shown in Figure 7 and minimum value of 5.89 kg h$^{-1}$ at moisture content of 21.01% when the cylinder bar inclination was 90$^o$ as shown in Figure 8. The capacity of the moringa seed shelling machine was found to be affected by the three Tangential Impact Shelling Devices (TISDs) and moisture content. The capacity of the moringa seed shelling machine decreased and then increased with the moisture content when the cylinder bar inclination was 90$^o$ due to the area of contact between flat bar and moringa seed as shown in Figure 8. The impact force exerted on the seed was not sufficient to break the seed because of its toughness and elastic nature as a result of increase in the moisture content. However, the relationship between moisture content and the capacity followed a sinusoidal trend for cylinder bar inclination of 60$^o$ as shown in Figure 7. This is similar to the trend obtained by (Fadele and Aremu, 2016). This is due to the heterogeneous nature of moringa seed. Moreover, at cylinder bar inclination of 30$^o$, the capacity of the machine increased with moisture content up to a certain point and then decreased as shown in Figure 6. This is because of increase in the surface contact area of the flat bar with the moringa seed, thus more impact force was exerted on the seed. However, the capacity decreased with moisture content. The regression models depicting the relationship between moisture content and capacity for all the TISDs are shown in Equations (7)-(9).

$$C_{30}=4.51+0.47(MC)–0.015(MC)^2 \quad (R^2=0.95) \quad (7)$$

$$C_{60}=23.94–3.15(MC)+0.194(MC)^2–0.0038(MC)^3 \quad (R^2=0.88) \quad (8)$$

$$C_{90}=11.99–0.599(MC)+0.015(MC)^2 \quad (R^2=0.89) \quad (9)$$

where, $C_{30}$, $C_{60}$, and $C_{90}$ are capacities of the machine when the cylinder bar inclination are 30$^o$, 60$^o$ and 90$^o$ respectively while MC is moisture content.

Tables 1 and 2 show the Analysis of Variance and Duncan Multiple Range Test conducted to assess the interaction between kernel moisture content and shelling capacity for Moringa for all the TISDs. The capacity was found to be significantly ($\alpha$<0.05) influenced by moisture content at cylinder bar inclination of 30$^o$.

**Table 1 Analysis of variance for interaction between moisture content and capacity**

| Source | Sum of Squares | Df | Mean Square | F | Significance level |
|---|---|---|---|---|---|
| Model | 0.993 | 2 | 0.496 | 19.289 | 0.049 |
| 30$^o$ Residual | 0.051 | 2 | 0.026 | | |
| Total | 1.044 | 4 | | | |
| Model | 0.098 | 2 | 0.049 | 0.143 | 0.875 |
| 60$^o$ Residual | 0.687 | 2 | 0.344 | | |
| Total | 0.786 | 4 | | | |
| Model | 1.677 | 2 | 0.839 | 8.191 | 0.109 |
| 90$^o$ Residual | .205 | 2 | 0.102 | | |
| Total | 1.882 | 4 | | | |

**Table 2 Duncan multiple range test for Capacity**

| Cylinder bar inclination | Moisture content | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 90.00 | 5 | 6.7000 | |
| 30.00 | 5 | | 7.5660 |
| 60.00 | 5 | | 7.9380 |
| Significance level | | 1.000 | 0.311 |

### 3.2 Shelling efficiency

The relationship between shelling efficiency and moisture content using three Tangential Impact Shelling Devices are shown in Figures 9-11.

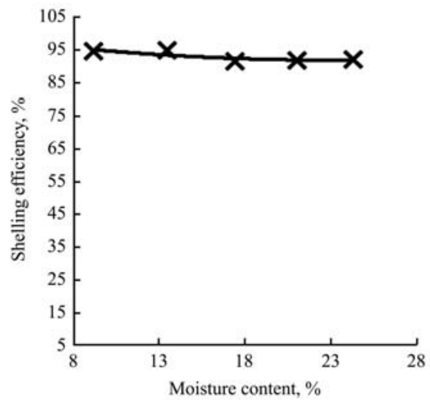



Figure 9 Variation of moisture content with shelling efficiency using 30$^o$ cylinder bar inclination

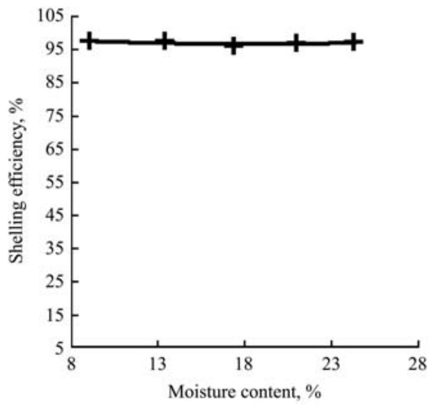



Figure 10 Variation of moisture content with shelling efficiency using 60$^o$ cylinder bar inclination

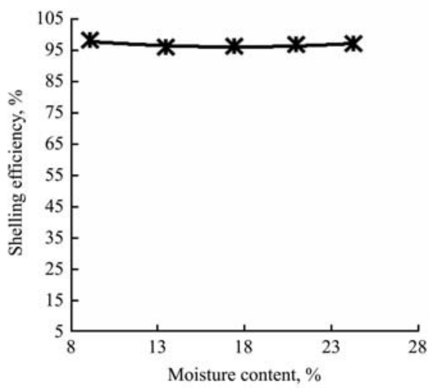



Figure 11 Variation of moisture content with shelling efficiency using 90$^o$ cylinder bar inclination

The shelling efficiency of the moringa seed shelling machine had a maximum value of 97.97% at moisture content of 9.17% when a tangential impact shelling device with cylinder bar inclination of 90$^o$ was used and minimum value of 91.3% at moisture content of 17.42% when the cylinder bar inclination was 30$^o$. The shelling efficiency of the moringa seed shelling machine followed closely the the same pattern for all the TISDs. The shelling efficiency tends to gradually decrease with increase in seed moisture content. However, sharp decrease was observed when the cylinder bar inclination was at 30$^o$. This is similar to the trend obtained by Kumar et al. (2016) for decortications of sal seed. The shelling efficiency was found to be higher at lower moisture content because moringa seed ruptures easily due to the brittleness of the enclosing shell and kernels being more loosely held in the seed without sticking to the shell. This observation is similar to that Pradhan et al. (2010), Subramanian et al. (1990), and Makanjuola (1975) observed the same trend for melon seed shelling that the kernels could be separated more easily from the shells at low moisture contents. At low moisture contents, the kernel does not fill completely the internal space of the shells and it is the little clearance between the kernel and the shells that facilitate the separation. The results obtained for interaction between shelling efficiency and moisture content compares favorably with that of Ogunsina and Bamgboye (2014), Fadele and Aremu (2016), Aremu et al. (2015) and Oluwole et al. (2007). The regression models depicting the relationship between moisture content and shelling efficiency for all the TISDs are shown in Equations (10)-(12).

$$SE_{30}=100.3–0.73(MC)+0.015(MC)^2 \quad (R^2=0.67) \quad (10)$$

$$SE_{60}=90.23+1.67(MC)–0.119(MC)^2+0.002(MC)^3 \quad (R^2=0.57) \quad (11)$$

$$SE_{90}=103.6+0.874(MC)+0.025(MC)^2 \quad (R^2=0.77) \quad (12)$$

where, $SE_{30}$, $SE_{60}$, and $SE_{90}$ are shelling efficiencies of the machine when the cylinder bar inclination are 30$^o$, 60$^o$ and 90$^o$ respectively while MC is moisture content.

### 3.3 Percentage whole kernel recovered

The relationship between percentage whole kernel recovered and moisture content using three different TISDs is shown in Figures 12-14.

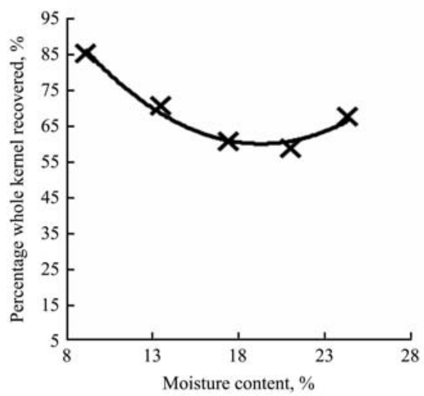



Figure 12 Variation of moisture content with percentage whole kernel using 30$^o$ cylinder bar inclination

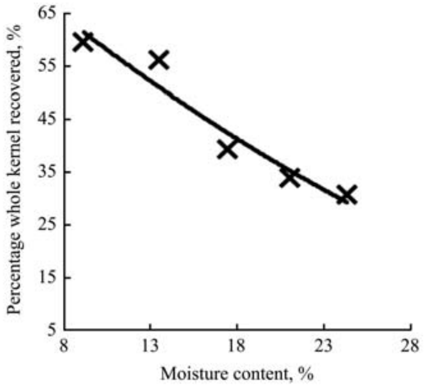



Figure 13 Variation of moisture content with percentage whole kernel using 60$^o$ cylinder bar inclination

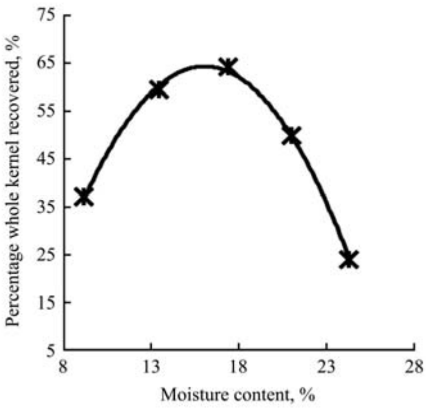



Figure 14 Variation of moisture content with percentage whole kernel using 90$^o$ cylinder bar inclination

The percentage whole kernel recovered was found to decrease with increasing moisture content when the cylinder bar inclination was at 30$^o$ and 60$^o$. This trend was similar to what was reported by Pradhan et al. (2010) for jatropha fruit decortication. However, in TISD with cylinder bar inclination of 90$^o$, the observation was contrary to that of 30$^o$ and 60$^o$. The percentage whole kernel recovered increased and decreased with moisture content. The percentage whole kernel recovered had a maximum value of 85.17% at moisture content of 9.17% when a tangential impact shelling device with cylinder bar inclination of 30$^o$ was used and minimum value of 24.02% at moisture content of 24.31% when the CBI of 90$^o$. The decrease in percentage whole kernel recovered with moisture content could be due to tightness of kernel to shell as it increases in size with the moisture content. Moreover, percentage whole kernel recovered decreased with increase in cylinder bar inclination because of reduced contact area of the cylinder flat bar as the cylinder bar inclination increased. The regression models depicting the relationship between moisture content and percentage whole kernel for all the TISDs are shown in Equations (13)-(15).

$$PWK_{30}=154.6-9.82(MC)+0.254(MC)^2 \quad (R^2=0.98) \quad (13)$$

$$PWK_{60}=86.36-2.96(MC)+0.025(MC)^2 \quad (R^2=0.94) \quad (14)$$

$$PWK_{90}=-86.33+18.77(MC)-0.585(MC)^2 \quad (R^2=1.00) \quad (15)$$

where, $PWK_{30}$, $PWK_{60}$, and $PWK_{90}$ are percentage whole kernel when the cylinder bar inclination are 30$^o$, 60$^o$ and 90$^o$ respectively while MC is moisture content. Percentage whole kernel recovered was significantly affected by moisture content using TISDs with cylinder bar inclination of 30$^o$ and 90$^o$ at 5 % level of significance except the cylinder bar inclination of 60$^o$ as shown in Tables 3 and 4.

**Table 3 Analysis of variance for interaction between seed moisture content and percentage whole kernel recovered using differentTangential Impact Shelling Devices**

| Source | Sum of Squares | Df | Mean Square | F | Significance level |
|---|---|---|---|---|---|
| Model | 429.188 | 2 | 214.594 | 40.834 | 0.024 |
| 30$^o$ Residual | 10.511 | 2 | 5.255 | | |
| Total | 439.699 | 4 | | | |
| Model | 646.424 | 2 | 323.212 | 15.214 | 0.062 |
| 60$^o$ Residual | 42.489 | 2 | 21.244 | | |
| Total | 688.913 | 4 | | | |
| Model | 1076.102 | 2 | 538.051 | 476.278 | 0.002 |
| 90$^o$ Residual | 2.259 | 2 | 1.130 | | |
| Total | 1078.362 | 4 | | | |

**Table 4 Duncan multiple range test for percentage whole kernel recovered**

| Cylinder bar inclination | Moisture content | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 60.00 | 5 | 43.8560 | |
| 90.00 | 5 | 46.8540 | |
| 30.00 | 5 | | 68.5540 |
| Significance level | | .733 | 1.000 |

## 3.4 Percentage broken kernel recovered

The relationship between percentage broken kernel recovered and moisture content using three different TISDs is shown in Figure15-17.

The percentage broken kernel recovered was found to increase with increase in moisture content and then decrease with increase in moisture content when the CBI was at 30$^o$. Similarly, percentage broken kernel recovered also increased steadily with increase in the moisture content in TISD with CBI of 60$^o$ without falling; this is contradictory to that of Pradhan et al. (2010) for Jatropha fruit decortications; Oluwole et al. (2004) for shea nut cracking. In TISD with cylinder bar inclination of 90$^o$, the observation was contrary to that of 30$^o$ and 60$^o$; the percentage broken kernel recovered decreased and increased with moisture content. The percentage broken kernel recovered had a maximum value of 75.98% at moisture content of 24.31% when a tangential impact shelling device with cylinder bar inclination of 90$^o$ was used and minimum value of 14.83% at moisture content of 9.17% when a TISD of CBI of 30$^o$.

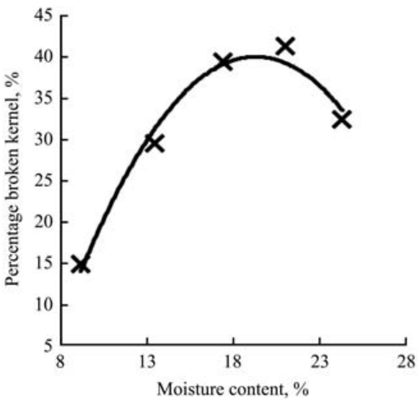



Figure 15 Variation of moisture content with percentage broken kernel using 30$^o$ cylinder bar inclination

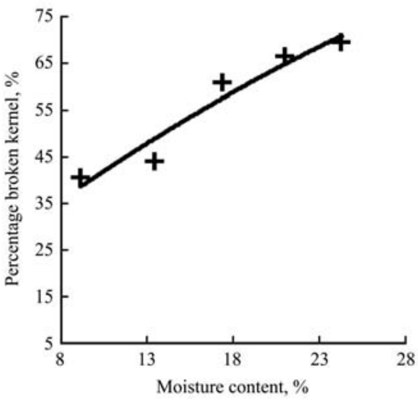



Figure 16 Variation of moisture content with percentage broken kernel using 60$^o$ cylinder bar inclination

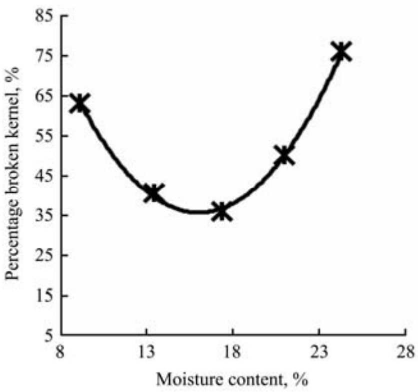



Figure 17 Variation of moisture content with percentage broken kernel using 90$^o$ cylinder bar inclination

Tables 5 and 6 show the analysis of variance and Duncan Multiple Range Test for regression models for percentage broken kernel recovered; this is alternate to that obtained for percentage whole kernel recovered. The regression models in Equations 16-18 showed the relationship between moisture content and percentage broken kernel recovered for all the TISDs. Sitkei (1986) reported that the condition for avoiding damage is that the maximum stress arising during impact should not exceed the permissible value. It was ensured that the impact force arising from cylinder bar at the design point did not exceed the permissible value for the breakage or rupturing of the moringa shell without damaging the kernel.

$$PBK_{30}=-54.66+9.82(MC)-0.254(MC)^2 \quad (R^2=0.98) \quad (16)$$

$$PBK_{60}=13.66+2.95(MC)-0.024(MC)^2 \quad (R^2=0.94) \quad (17)$$

$$PBK_{90}=186.30-18.77(MC)+0.585(MC)^2 \quad (R^2=1.00) \quad (18)$$

where, $PBK_{30}$, $PBK_{60}$, and $PBK_{90}$ are percentage broken kernel when the cylinder bar inclination are 30$^o$, 60$^o$ and 90$^o$ respectively.

Percentage broken kernel recovered was significantly affected by moisture content using TISDs with cylinder bar inclination of 30$^o$ and 90$^o$ at 5% level of significance except the cylinder bar inclination of 60$^o$ as shown in Table 3.

**Table 5 Analysis of variance for interaction between moisture content and percentage broken kernel recovered using different Tangential Impact Shelling Devices**

| Source | Sum of Squares | Df | Mean Square | F | Significance level |
|---|---|---|---|---|---|
| Model | 429.188 | 2 | 214.594 | 40.834 | 0.024 |
| 30$^o$ Residual | 10.511 | 2 | 5.255 | | |
| Total | 439.699 | 4 | | | |
| Model | 646.424 | 2 | 323.212 | 15.214 | 0.062 |
| 60$^o$ Residual | 42.489 | 2 | 21.244 | | |
| Total | 688.913 | 4 | | | |
| Model | 1076.102 | 2 | 538.051 | 476.278 | 0.002 |
| 90$^o$ Residual | 2.259 | 2 | 1.130 | | |
| Total | 1078.362 | 4 | | | |

**Table 6 Duncan multiple range test for percentage broken kernel recovered**

| Cylinder bar inclination | Moisture content | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 30.00 | 5 | 31.4440 | |
| 90.00 | 5 | | 53.1460 |
| 60.00 | 5 | | 56.1400 |
| Significance level | | 1.000 | 0.733 |

### 3.5 Separation efficiency of the moringa seed shelling machine

The relationships between separation efficiency and moisture content using three different TISDs are shown in Figures18-20.

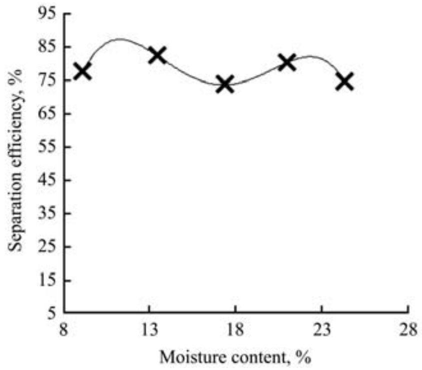



Figure 18 Variation of moisture content with separation efficiency using 30$^o$ cylinder bar inclination

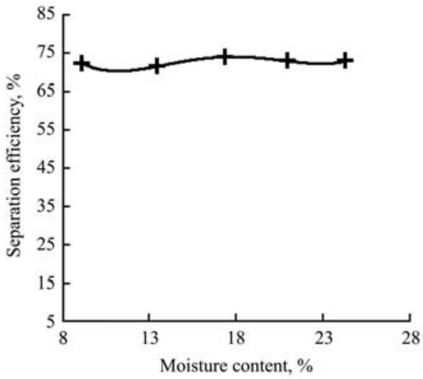



Figure 19 Variation of moisture content with separation efficiency using 60$^o$ cylinder bar inclination

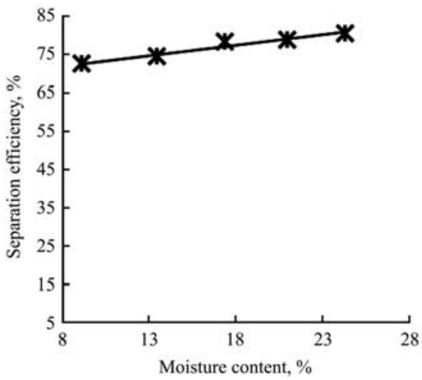



Figure 20 Variation of moisture content with separation efficiency using 90$^o$ cylinder bar inclination

The separation efficiency had a maximum value of 82.10% at moisture content of 13.49% when a tangential impact shelling device with cylinder bar inclination of 30$^o$ was used and minimum value of 71.49% at moisture content of 13.49% when a TISD of CBI of 60$^o$ was used. The variation of moisture content with separation efficiency followed a sinusoidal trend for all TISDs except CBI of 90$^o$ as shown in Figure 20. This indicated that separation efficiency of the moringa seed shelling machine is independent of seed moisture content. Table 4 shows the analysis of variance for regression model for relationship between separation efficiency and moisture content using three different TISDs. These values are similar to what Akubuo and Eje (2002) obtained for separation of palm kernel from its shell. The regression models in Equations 19-21 showed the relationship between moisture content and separation efficiency recovered for all the TISDs.

$$y_{30}=-678.4+202.8(MC)-19.39(MC)^2-0.79(MC)^3-0.011(MC)^4 \quad (R^2=1.00) \quad (19)$$

$$y_{60}=228.6-41.59(MC)+3.92(MC)^2-0.156(MC)^3+0.002(MC)^4 \quad (R^2=1.00) \quad (20)$$

$$y_{90}=0.542(MC)+67.52 \quad (R^2 = 0.96) \quad (21)$$

where, $y_{30}$, $y_{60}$, and $y_{90}$ are separation efficiencies when the cylinder bar inclination are 30$^o$, 60$^o$ and 90$^o$ respectively while MC is moisture content.

The relationship between moisture content and the separation efficiency of the machine was found to be significant at 5% level of significance when TISD with cylinder bar inclination of 90$^o$ was used while that of 30$^o$ and 60$^o$ were non-significant as shown in Tables 7 and 8.

**Table 7 Analysis of variance for interaction between moisture content and separation efficiency using different Tangential Impact Shelling Devices**

| Source | Sum of Squares | Df | Mean Square | F | Significance level |
|---|---|---|---|---|---|
| Model | 8.005 | 2 | 4.003 | .179 | 0.848 |
| 30$^o$ Residual | 44.804 | 2 | 22.402 | | |
| Total | 52.810 | 4 | | | |
| Model | .866 | 2 | .433 | .358 | 0.736 |
| 60$^o$ Residual | 2.417 | 2 | 1.209 | | |
| Total | 3.283 | 4 | | | |
| Model | 42.590 | 2 | 21.295 | 29.167 | 0.033 |
| 90$^o$ Residual | 1.460 | 2 | 0.730 | | |
| Total | 44.051 | 4 | | | |

**Table 8 Duncan multiple range test for separation efficiency**

| Cylinder bar inclination | Moisture content | Subset for alpha = 0.05 | |
|---|---|---|---|
| | | 1 | 2 |
| 60.00 | 5 | 72.6780 | |
| 90.00 | 5 | | 76.7840 |
| 30.00 | 5 | | 77.5600 |
| Significance level | | 1.000 | 0.679 |

## 4 Conclusion

The performance of a moringa seed shelling was evaluated using three Tangential Impact Shelling Devices with cylinder bar inclination of $30^o$, $60^o$ and $90^o$. The performance of the moringa seed shelling machine ranged from 5.89 kg $h^{-1}$ to 8.44 kg $h^{-1}$, 91.3% to 97.97%, 24.02% to 85.17%, 24.31% to 75.98% and from 71.49% to 82.10% for capacity, shelling efficiency, percentage whole kernel recovered, percentage broken kernel recovered and separation efficiency respectively. The moringa seed shelling machine had the best performance when the cylinder bar inclination was at $30^o$. However, the performance of the moringa seed shelling machine was suboptimal when the cylinder bar was at $90^o$ due to greater proportion of kernel breakage. Tangential Impact Shelling Devices are effective and suitable for moringa seed shelling when the cylinder bar inclination is between $30^o$ and $60^o$. It is recommended that the shelling process of the moringa seed shelling machine should be optimized.


## Acknowledgement

The authors wish to thank Forestry Research Institute of Nigeria for making their facilities available for this research. The support and assistance received from the department of Agricultural and Environmental Engineering, University of Ibadan Nigeria is also appreciated. The contribution of researchers in Federal College of Forestry Mechanization Afaka Kaduna, Nigeria is also appreciated.


## References


Akubuo, C. O., and B. E. Eje. 2002. Palm Kernel and Shell Separator. *Biosystems Engineering*, 81(2): 193–199.

Aremu, A. K., A. O. Adeniyi, and O. K. Fadele. 2015. Development and performance of a jatropha seed shelling machine basedon seed moisture content. *Journal of Biosystems Engineering*, 40(2): 137–144.

ASABE Standards, 2008. Moisture Measurement for Crops. St. Joseph, Michigan: ASABE.

Atiku,A., N. Aviara, and M. Haque. 1999. Performance evaluation of a bambara ground nut sheller. *CIGR Journal*, 7(VI): 1–18.

Aviara, N. A., P. P. Power, and T. Abbas. 2013. Moisture-dependent physical properties of Moringa oleifera seed relevant in bulkhandling and mechanical processing. *Industrial Crops and Products*, 42(1): 96–104.

Eilert, U., B. Wolters,andA. Nahrstedt. 1981. The antibiotic principle of seeds ofMoringa oleifera and Moringa stenopetada tala. *Journal of Medicinal Plants*, 42(1): 55–61.

Fadele, O. K., and A. K. Aremu. 2016. Design, construction and performance evaluation of a *Moringa oleifera* seed shelling machine. *Engineering in Agriculture Environment &Food*, 9(3): 250–256.

Figueiredo, A. K., L. M. Rodríguez,I. C. Riccobene,and Nolasco. 2014. Analysis of the Performance of a Dehulling System for Confectionary Sunflower Seeds. *Food and Nutrition Sciences*, 05(6): 541–548.

Figueiredo, A. K., L. M. Rodríguez, L. I. Lindström,I. C. Riccobene, and S. M. Nolasco. 2013. Performance analysis of a de-hulling system for safflower grains. *Industrial Crops and Products*, 43(5): 311–317.

Gupta, R. K., and S. K. Das. 1999. Performance of centrifugal dehulling system for sunflower seeds. *Journal of Food Engineering*, 42(4): 191–198.

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, New York. 2015.

Kumar, C. S., R. C. Pradhan, and S. Mishra. 2016. Fabrication, performance evaluation and optimization ofSal(shorea robusta) seed decorticator. *Journal of Food Process Engineering*, 40(3): 1–10.

Makanjuola, G. A. 1975. An Evaluation of some centrifugal impaction devices for shelling melon seeds. *Journal of Agricultural Engineering Research*, 20(1): 71–77.

Nunneley, J. L., W. B. Faulkner, M. V. Shimek, G. A. Holt, and T. C. Wedegaertner. 2012. Optimization of a Cottonseed Dehulling Process to YieldIntact Seed Meats. *Applied Engineering in Agriculture*, 29(5): 613–619.

Ogunsina, B. S., and A. I. Bamgboye. 2014. Pre-shelling parameters and conditions that influencethe whole kernel out-turn of steam-boiled cashew nuts. *Journal of the Saudi Society of Agricultural Sciences*, 13(1): 29–34.

Oluwole, F. A., N. A. Aviara, and M. A. Haque. 2004. Development and performance tests of a sheanut cracker. *Journal of Food Engineering*, 65(1): 117–123.

Oluwole, F. A., A. T. Abdulrahim, and M. B. Oumarou. 2007. Development and performance evaluation of impact bambara groundnut sheller. *International Agrophysics,* 21(3): 269–274.

Pradhan, R. C., S. N. Naik, N. Bhatnagar, and V. K. Vijay. 2010. Design, development andtestingof hand-operated decorticator for jatropha fruit. *Applied Energy*, 87(3): 762–768.

Rashid, U., F.Anwar, M. Ashraf, M. Saleem, and S. Yusup. 2011. Application of response surface methodology for optimizing transesterification of Moringa oleifera oil: Biodieselproduction. *Energy Conversion and Management*, 529(8-9): 3034–3042.

Sharma, V., R. C. Pradhan, S. N. Naik, N. Bhatnagar, and S. Singh. 2013. Evaluation of a centrifugal impaction-type decorticator for shelling tung fruits. *Industrial Crops and Products*, 43(5): 126–131.

Sitkei, G. 1986. *Mechanics of Agricultural Materials*. Elsevier Science Publishers: Hungary.

Subramanian, R., M. C. Shamanthaka Sastry, and K. V. enkateshmurthy. 1990. Impact Dehulling of Sunflower Seeds: Effect of Operating Conditions and Seed Characteristics. *Journal of Food Engineering*, 12(2): 83–94.

Tende, J. A., I. Ezekiel, A. A. U. Dikko, and A. D. T. Goji. 2011. Effect of ethanolic leaves extract of *moringa oleifera* on blood glucose levels of streptozocin-induced diabetics and normoglycemic wistar rats. *British Journal of Pharmacology and Toxicology*, 2(1): 1–4.

Ting, R. P., E. V. C. Peralta, and J. C. Elauria. 2012. Design, fabrication, and optimization of jatropha sheller. *International Journal of Optimization and Control: Theories &Applications*. 2(2): 113–127.