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Research Article

Design, fabrication and testing of a machine for shelling *Jatropha curcas* seed

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Abstract: *Jatropha curcas* is a non-edible drought-resistant seed rich in oil. The seeds are usually shelled to obtain the kernels prior to the oil extraction. This research was undertaken to design, fabricate and evaluate a sheller for jatropha seed at different moisture contents. The moisture content of the seed was varied in the range of 6.8−12.2% (wb) and the machine performance was evaluated. Empirical relationships between the machine performance and the moisture content were established. The results showed that the shelling and machine efficiencies decreased with an increase in the moisture content. A quadratic relationship was established between the cleaning efficiency and the moisture content of the seed. The data obtained are found to fit the established equations with 65% R sq. value, and so can be used for predicting the machine performance within the specified moisture range. The power required to shell the seed was found to be 1 HP, and the technology was affordable compared to the ones reported in the previous designs. The machine can therefore be used for *Jatropha curcas* seed shelling at different moisture contents.

Keywords: Design; evaluation; shelling; *Jatropha curcas*; oil seed

1. Introduction

Processing of biological materials into oil for the production of biodiesel has gained renewed impetus in the renewable energy industry recently. This is partly because of the availability of the raw materials and the constant decline in the global amount of stored non-renewable resources. Many biological materials like the jatropha seed has been studied for their oil potential and later use. Interest in *Jatropha curcas* as a source has risen partly due to its economic benefit and partly due to its perceived ability to grow in the wild (Achten *et al.*, 2008). The oil content of the seed has been reported to be as high as 40% with characteristics properties matching its industrial application (Achten et al., 2008; Kheiralla et al., 2015; Amoah, 2012).

Non-edible seed species like the *Jatropha curcas* seed have numerous uses especially in the production of cosmetics and biofuel for internal combustion engines. Many researchers have reported the application of *Jatropha curcas* seed in biodiesel production. For instance, Folaranmi (2012) and Datta and Mandal (2014) reported high prospects of obtaining biodiesel fuel from the *Jatropha curcas* seed. The medicinal and cosmetic soap production potentials of the *Jatropha curcas* seed has also been reported by Shahinuzzaman et al. (2016) and Moniruzzaman et al. (2016). Raja et al. (2011) investigated the oil properties of the *Jatropha curcas* oil and reported 37.4% oil content from the whole seed and 49% oil content from the kernel. Also, Adebowale and Adedire (2006) reported 67% oil content from *Jatropha curcas* seed processing. Hence, in order to maximise the oil yield, shelling of the *Jatropha curcas* seed to obtain the kernel is very essential.

Meanwhile, the production of oil from the seed requires high level of technology in the shelling and

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in the oil extraction processing. Kheiralla et al. (2016) reported that the production of oil from the *Jatropha curcas* seed lacks the development of specialised machine. Although Ting et al. (2012) and Aremu et al. (2015) in their separate researches developed a *Jatropha curcas* seed shelling machine working at different speeds of the rotating shaft, the technology they described is highly capital intensive and difficult to replicate on a small scale. But the present design is cheaper to produce and easier to operate when compared with other existing designs. Also, a hand-operated decorticator for *Jatropha curcas* fruits has been developed and tested by Pradhan et al. (2010), but this does not address the issue of drudgery since the machine depends on human-drive-effort to operate and was reportedly low in efficiency. There is therefore the need to redesign the technology of shelling *Jatropha curcas* seed in order to address the obvious challenges. This research was therefore carried out to design, fabricate and test an affordable machine for the shelling operation of the *Jatropha curcas* seed at different moisture contents.

2. Materials and methods

2.1. Sample preparation

A freshly harvested, ripe dark-brown colour, *Jatropha curcas* fruits were obtained from the wild in Bida local government area of Niger State, Nigeria. The collected fruits were then cleaned manually to remove all foreign materials in it, dehulled, wrapped in polythene bags and stored in clean containers for further analysis (Fadeyibi et al., 2018).

2.2. Moisture content determination

A standard hot air oven method was used to determine the initial moisture content of the fruits. A 200 g of the *Jatropha curcas* seed was measured using standard scale. The sample was dried in an oven at 105±1°C for 24 h. The initial moisture content of the seed was calculated according to the method described by Fadeyibi et al. (2012). The moisture of the seed was varied to three other moisture contents by adding calculated amount of distilled water to obtained 6.8%, 9.5%, 11.0% and 12.2% (wb).

2.3. General machine description and component parts

The model of the *Jatropha curcas* seed sheller and its component parts are shown in Figure 1 and Figure 2, respectively. The machine comprises the feed hopper, shelling and cleaning units, which consist of a fan, a belt and pulleys for transmitting motor power to the fan. The main frame of the sheller is made of angular mild steel. The sheller housing was made of galvanised metal sheet and the hopper was constructed using a galvanised iron sheet. Shelling was achieved as the *Jatropha curcas* seeds rub against a stationary plate in the barrel. The waste product from the shelling operation was blown away with the help of the fan to obtain the clean kernels.

2.4. Design analysis

A detailed design analysis of each of the component parts of the machine for the shelling of the *Jatropha curcas* seed is described hereunder.

2.4.1. Design of the hopper

The volume of the hopper was calculated using Eq. (1) as reported by Ibrahim et al. (2016).

$$v_{ac} = v_b + (v_b \times 0.5) \tag{1}$$

where,

v_b is the volume of *Jatropha curcas* seed to be processed per batch

v_{ac} is the volume of the hopper (m^3)

Substituting the values into Eq. (1), then:

$v_{ac} = 0.0363 m^3$

The height of the hopper was calculated using Eq. (2) (Ibrahim et al., 2016)

$$v_{ac} = \frac{1}{3}(a^2 + ab + b^2)h \tag{2}$$

where,

v_{ac} is the volume of the hopper (m^3)

a is the length of the smaller side of the hopper (0.22m assumed)

b is the length of the bigger side of the hopper (0.33m assumed)

h is the height of the hopper

Substituting the values into Eq.(2), then: h = 0.474m

2.4.2. Energy required

The energy required to crush the seed was calculated using Kick's law which can be applied to coarse crushing and is given by Eq. (3).

$$E = K_k f_c \log_e\left(\frac{L_1}{L_2}\right) \tag{3}$$

where:

E = Energy required to shell a seed

K_K = Kick's constant, 1.2

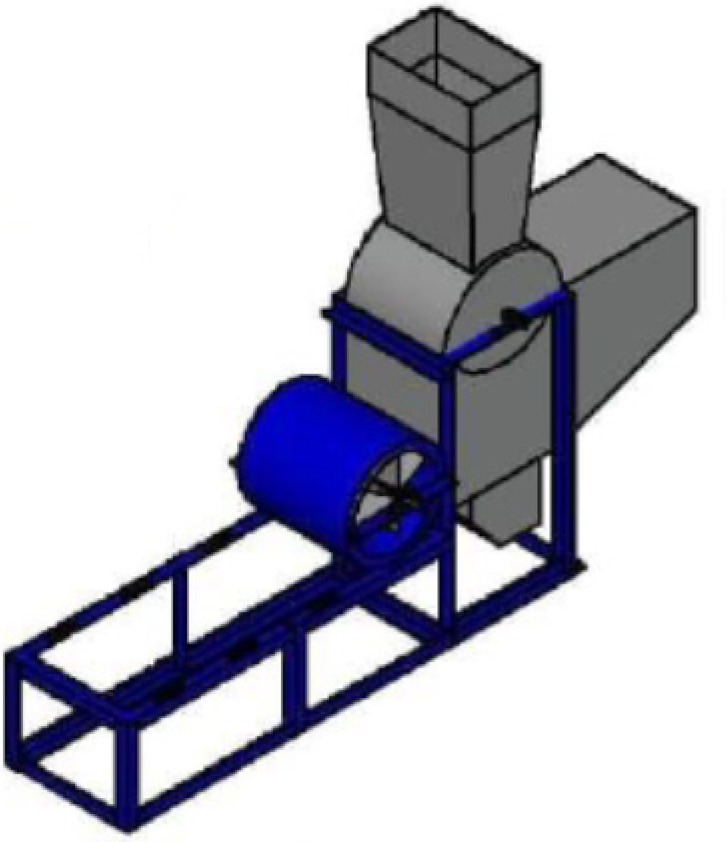

Figure 1: Model of the *Jatropha curcas* seed sheller

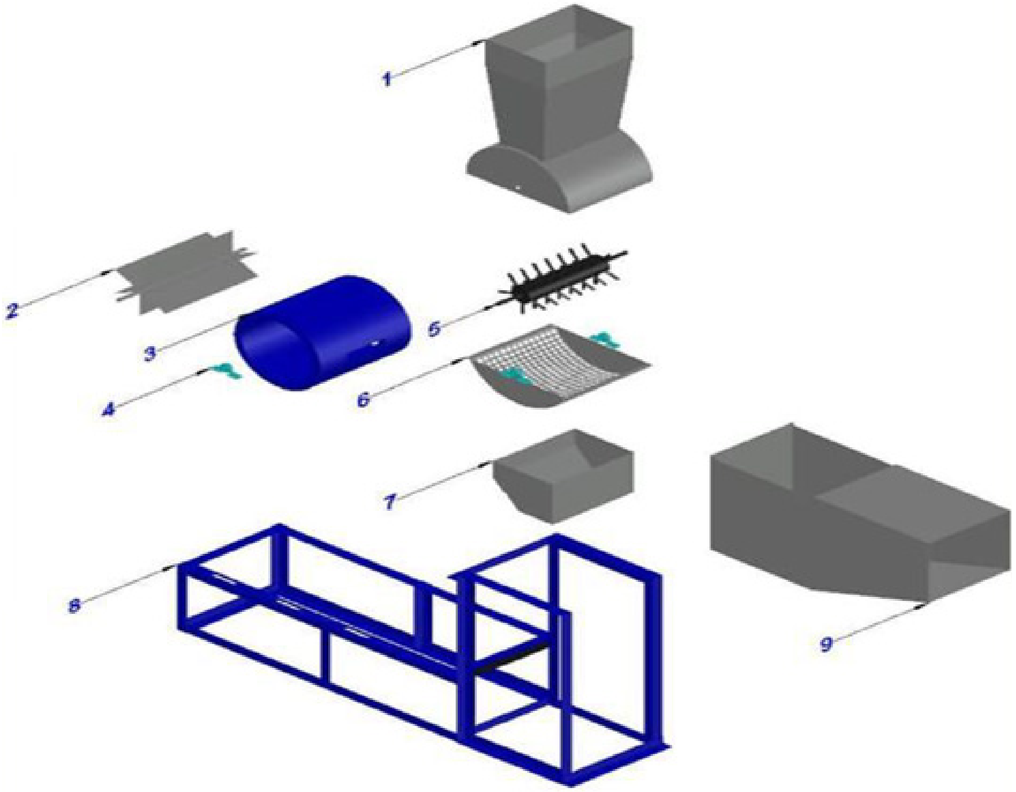

Figure 2: Machine component parts (1-hopper, 2-blower fan, 3-fan housing, 4-pillow bearing, 5-shelling spike, 6-shelling concave, 7-seed guard, 8-main frame, 9-chaff guard)

f_c = Crushing strength of *Jatropha curcas* -38.1 kgm^{-2}, (Pradhan et al., 2010); Bamgboye and Adebayo, 2012).

L_1 = average length of unshelled *Jatropha curcas* seed (18.56mm)

L_2 = average length of shelled *Jatropha curcas* seeds (15.23mm)

Substituting the values into Eq. (4), then: $E = 9.09$ kJ

2.4.3. Power required for shelling the seed

The required power in the shelling unit was determined using Kick's law as given by Eq. (4).

$$P = \dot{m} K_k f_c \log_e\left(\frac{L_1}{L_2}\right) \quad (4)$$

where,
$\dot{m}$ = we assumed a capacity of 50 kg/h.

Substituting values into Eq. (4)

$P = 0.126$kW

Considering the transmission efficiency, the required motor power (P_m) was computed according to Eq. (5). Assuming the power transmission efficiency is 80% for effective machine operation (Fadeyibi et al., 2018), we have:

$$P_m = \frac{P}{\text{Efficiency}} \quad (5)$$

Substituting values into Eq. (7), then:P_m= 0.1575 kW = 0.211 HP

2.4.4. Power required by the fan

This is given by the expression in Eq. (6)

$$p_f = \frac{2\pi N \tau}{60} \quad (6)$$

where,

P_f = power required by the fan (W)

N = speed of the fan (650 rpm)

τ = torque developed (Nm)

The torque developed by the sheller shaft was obtained from the relation given in Eq. (7).

$$M_t = \frac{9550}{N_m} \quad (7)$$

where,

M_t = Torsional moment (Nm)

N_m = Motor speed (1400) rpm,

Substituting values in Eq. (7), the value of the tensional moment obtained is 6.8 Nm.

Therefore power required to drive the fan is:

$$p_f = \frac{2 \times \pi \times 650 \times 6.8}{60} = 462.6\text{ w} = 0.4626\text{ kW} = 0.62\text{ HP}$$

The total power required by the machine is given as:

$$p = p_m + p_f$$

where,

P = total power required by the machine (HP)

p_m = power needed for shelling (HP)

p_f = power needed for cleaning (HP)

Hence

P = 0.211 + 0.62 = 0.831 HP

For safety and considering the power required to drive the fan, a 1 HP motor of 120 Watts was selected at a speed of 1400 rpm.

2.4.5. Design of belt

(i) Drum speed

In order to ensure effective power and torque transmission from the electric motor, two v-belts were connected to the motor to drive the shaft, which rotates the shelling drum and the fan in the cleaning unit. According to the velocity ratio, the diameter and drum speed were computed using Eq. (8).

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (8)$$

where,
N_1 = speed of driver pulley (1400 rpm)
N_2 = speed of driven pulley
D_2 = Effective diameter of driven pulley (300 mm)
D_1 = Effective diameter of drive pulley (80 mm)

From Eq. (9), the velocity ratio is 3.75 and the driven pulley speed was found to be 373 rpm

(ii) Length of belt

The belt length was determined according to the expression in Eq. (9) as given by Srivastava et al. (2006).

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{2C} \quad (9)$$

where,

C is the center distance between two pulleys (240mm), assumed.

D_2 = Effective diameter of driven pulley (300 mm)

D_1 = Effective diameter of drive pulley (80 mm)

The value of the belt length obtained using Eq. 6 is 1.18m.

(iii) Angle of contact

The angle of lap of the belt between the pulleys was computed using the expressions giving by (Khurmi & Gupta, 2005) in Eq. (10) and Eq. (11).

$$\theta = (180 - 2a) \times \frac{\pi}{180} \quad (10)$$

$$a = \sin^{-}\left(\frac{r_2 - r_1}{c}\right) \quad (11)$$

where,

θ is the angle of contact between two pulleys

r_1 is the radius of the shaft pulley (150mm)

r_2 is the radius of the motor pulley (40mm)

c is the center distance between two pulleys (240mm), assumed.

Substituting the values into Eq. (10) and Eq. (11), the angle of contact between the two pulleys was 3.13 rad.

(iv) Determination of the belt velocity

The velocity of the belt was determined using Eq. (12) (Khurmi & Gupta, 2005)

$$v = \frac{\pi N_1 D_1}{60} \quad (12)$$

where,

v is the velocity of the belt

N_1 is the speed of the motor pulley (1400 rpm)

D_1 is the diameter of the motor pulley (80mm)

Substituting the known values into Eq. (12), the velocity of the belt was found to be 5.87m/s.

2.4.6. Design of the shelling mechanism

The shelling mechanism consists of the shelling bar and shelling drum. The mass of the shelling mechanism was determined from the expression in Eq. (13) (Ibrahim et al., 2016).

$$m_{SM} = \left(m_S + m_J + m_b + m_p\right) \quad (13)$$

where,

m_{sm} is mass of shelling mechanism (kg)

m_s is mass of the shelling drum (kg)

m_j is mass of the *Jatropha curcas* seed to be shelled at a time (kg)

m_b is mass of the shelling bars (kg)

m_p is mass of the pulley (kg)

(i) Mass of shelling bars

The mass of the shelling bars was computed using the expressions in Eq. (14) and Eq. (15) (Ibrahim et al., 2016).

$$m_b = \rho_{sd} V_{sd} \quad (14)$$

$$m_b = \rho_{sd}(\pi r^2 L_b) N_{sb} \quad (15)$$

where,

m_b is the mass of the shelling bars (kg)

ρ_{sd} is the density of the shelling bars for mild steel materials (7850kg/m^3)

N_{sb} is the number of bars (4)

L_b is the length of the shelling bars (0.30m)

r is the radius of the bar (0.006 m)

π is constant

Substituting the values into Eq. (17), then:

$$m_b = 7850\,(3.142 \times 0.006^2 \times 0.30 \times 4) = 1.07\text{ kg}$$

(ii) Mass of the shelling drum

The mass of the shelling drum was computed using Eq. (16) as reported by Gbabo and Gana (2016).

$$m_{sd} = \rho_{sd}(2\pi r_{sd} \times L_{sd} T_{sd}) + N_c(\pi r_c^2 T_c) \quad (16)$$

where,

m_{sd} = mass of the shelling drum (kg)

ρ_{sd} = density of the shelling drum (7850kg/m^3)

r_{sd} = radius of the shelling drum (0.15m)

L_{sd} = length of the shelling drum (0.5m)

T_{sd} = thickness of the shelling drum (0.002m)

N_c = number of the circular plate. In this design, we assumed N_c = 4 in order to ensure effective shelling.

r_c = radius of the circular plate (0.12m)

T_c is the thickness of the circular plate (0.002m)

By substituting the values into Eq. (16)

$$m_{sd} = 7850\,(2\pi \times 0.15 \times 0.5 \times 0.002) + 3.142 \times 0.12^2 \times 0.002 \times 4$$

$$= 10.24\ \text{kg}$$

(iii) Mass of material to be processed at a time

Since the capacity of the machine was 50 kg/h. The mass of the *Jatropha curcas* seed to be shelled (m_j) after 60 min resident time of machine operation was obtained as 0.0875 kg.

(iv) Mass of the shelling unit

The mass of the two pulleys was measured to be 0.486kg. Substituting the values into Eq. (17), the mass of the shelling unit was found to be

$$m_{SM} = (1.07 + 0.0875 + 10.24 + 0.486)$$

$$m_{SM} = 11.88\text{kg} \qquad (17)$$

2.4.7. Design of the shaft

The diameter of the shaft was determined using Eq. (18) (Khurmi & Gupta, 2005).

$$d^3 = \frac{16}{\pi s}\sqrt{[(k_b M_b)^2 + (k_t M_t)^2]} \qquad (18)$$

where,

d = Diameter of the shaft (mm)

S= Allowable stress for mild steel = 42 MN/m (ASME)

M_b = Shaft bending moment, 13.3 Nm

k_b= Combined fatigue factor in bending (1.5)

k_t= Combined fatigue factor in torsion (1.0)

M_t= Torsional moment of the shaft (6.8 Nm).

Substituting the values in Eq. (18), the shaft diameter was found to be 12.3 mm. But, using a factor of safety of 50% the diameter of the actual shaft was 20 mm.

2.5. Technical specification of the sheller

The technical specification of the *Jatropha curcas* seed shelling machine is shown in Table 1. This summarises the values obtained from the design analysis.

2.6. Bill of engineering measurement and evaluation

The bill of engineering measurement and evaluation showing all the parts, specification and their costs is shown in Table 2.

2.7. Technical drawing of the sheller

The isometric and orthographic and projections of the *Jatropha curcas* seed sheller are shown in Figure 3.

2.8. Performance evaluation

Performance evaluation of the machine was carried out at the Agricultural Engineering Teaching Laboratory of the Kwara State University Malete, Nigeria. Random samples (3 kg each) of the *Jatropha curcas* fruits with different moisture contents were used for the evaluation. The sample with 6.8% (wb) moisture content was first fed into the shelling machine through the hopper, as shown in Figure 4. The time taken to shell the sample, the seeds weight, the husks weight, and the weight of the husks mixed

Table 1: Technical specifications of the developed shelling machine

S/n	Item	Specification	SI Unit
1	Machine overall dimensions	1100 × 450 × 1150	mm
2	Diameter of larger pulley	300	mm
3	Diameter of small pulley	80	mm
4	Power requirement	1.0	HP (1400 rpm)
5	Shelling speed	373.33	rpm
6	Motor pulley circumferential speed	5.87	m/s
7	Belt length	1.18	m
8	Mass of shelling mechanism	11.88	kg
9	Shaft diameter	20	mm

Table 2. Bill of engineering measurement and evaluation of the *Jatropha curcas* seed sheller

S/n	Part	Specifications	Quantity	Cost (₦)	Total Price (₦)
1	Shaft, Steel	300 × 300 mm	1	2,000	2,000
2	Shaft, Steel	250 × 600 mm	1	3,500	3,500
3	Flat bar, Mild steel	800 mm	2	1,000	2,000
4	Pulley, Cast iron	60, 80, 180 mm	3		6,000
5	Bearing, cast iron	P205	2	3,000	6,000
6	Bearing, cast iron	P204	2	2,000	4,000
7	Metal sheet, mild steel	1.2mm	1½	9,000	13,500
8	Angle bar, mild steel	2”	2	3,500	7,500
9	Bolt and nuts, mild steel	10, 13, 17	50		1,500
10	v-belt, rubber	A-33, A-65	2	400	800
11	Electrode	E12	1 pack		2,500
12	Paint	Oil paint	3 cans	800	2,400
13	Cutting and grinding disc		2	750	1,500
14	Machining				5,000
15	Pipe, mild steel	100× 300mm	1	1,000	1,000
16	Plate, mild steel	220× 120mm	1	1,000	1,000
17	Rod, steel	1.2mm	1	1,150	1,150
19	Labour and Miscellaneous				37,000
				Grand total	103,350

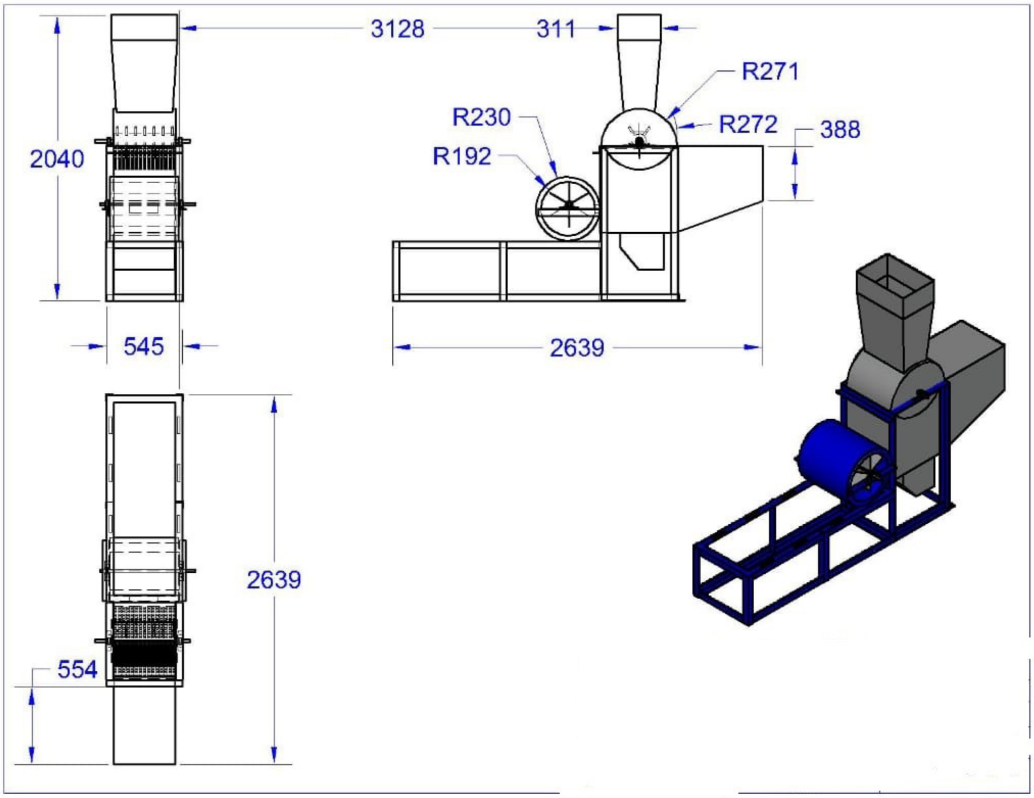

Figure 3: Isometric and orthographic projections of the jatropha curcas seed sheller

with the seeds were measured and recorded. The procedure was replicated three times for each of the other moisture contents, namely 9.5% (wb), 11.0% (wb) and 12.2% (wb).

Figure 4: Fabricated *Jatropha curcas* seed sheller

2.8.1. Determination of shelling efficiency

The shelling efficiency was computed using Eq. (19) (Pradhan al., 2010).

$$E_s = \left[1 - \frac{M_v + M_p}{M_o}\right] \times 100 \qquad (19)$$

where,

E_s = Efficiency of shelling (%)

M_v = mass of unshelled seed recovered after shelling (kg)

M_p = mass of partially shelled seed recovered after shelling (kg)

M_o = mass of the original sample introduced into the machine (kg)

2.8.2. Determination of the efficiency of the machine

The efficiency of the machine was computed using the expression in Eq. (20)

$$E_m = \left[1 - \frac{M_v + M_p}{M_o}\right] \times \left[\frac{M_W}{M_W + M_B}\right] \times 100 \qquad (20)$$

where,

E_m = Efficiency of the machine (%)

M_w = the mass of whole kernel (kg)

M_B = the mass of broken kernel (kg)

2.8.3. Cleaning efficiency

A machine cleanliness can be measured by the ability of the blower to effectively separate the husks from the seeds. Cleaning efficiency (%) was determined by Eq. (21).

$$\text{Cleaning efficiency} = 1 - \left(\frac{\text{Mass of husk in output}}{\text{Total mass of the husk in the sample}}\right) \qquad (21)$$

3. Results and discussion

3.1. Effect of moisture content on the machine efficiency

The effect of moisture content on the machine efficiency is shown in Figure 5. It can be seen that machine efficiency decreased with an increase in the moisture content of the seed. This behaviour may be associated with the sticky nature of the *Jatropha curcas* seeds at high moisture content thereby leading to a high friction force in the wall separating the shell and the seed. However, at lower moisture content, the seeds were less sticky and required less force to split and therefore separation or shelling becomes much easier. In related investigations, Ting et al. (2012) and Aremu et al. (2015) reported that the force of cracking the *Jatropha curcas* shells increased with an increase in the moisture content of the seed. Therefore, just as expected, the machine efficiency is higher for the 6.8% (wb) moisture content than the other moisture contents of the seed.

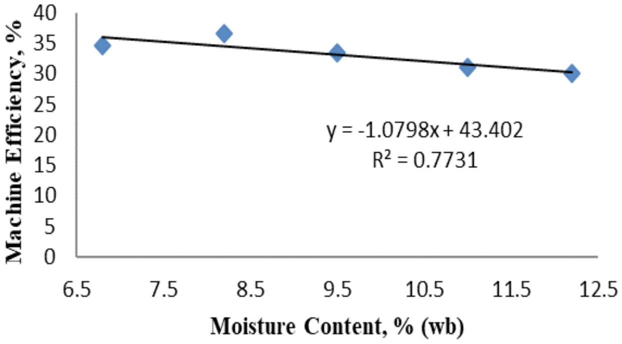

Figure 5: Effect of moisture content on the machine efficiency

3.2. Effect of moisture content on the shelling efficiency

The effect of moisture content on the shelling efficiency is shown in **Figure 6**. It can be seen that the shelling efficiency decreased with an increase in the moisture content of the seed. The maximum value of the shelling efficiency occurred at 6.8% (wb) moisture content and the minimum value occurred at 12.2% (wb) moisture content. The values obtained are close to the values for shelling *Jatropha curcas* seed shell using the roller mechanical mechanism reported by Ting et al. (2012). The reason for this behaviour may be attributed to the increase in the volume of the seed as the kernel absorbed more and more moisture, thereby requiring more effort for the shelling operation. Similar results were reported by Pradhan et al. (2010). Therefore, just as expected, the shelling efficiency is lower for the 12.2% (wb) moisture content than the other moisture contents of the seed.

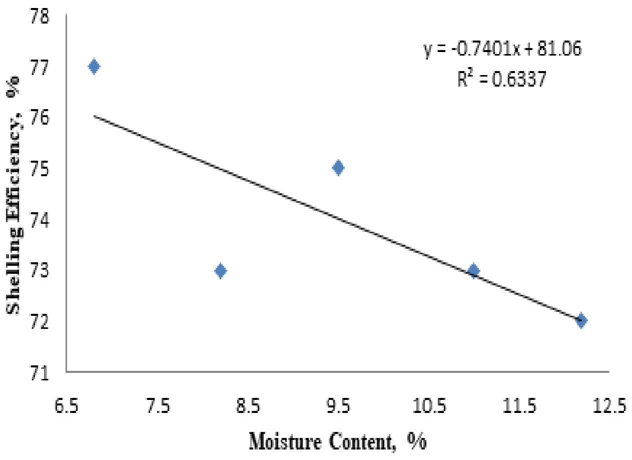

Figure 6: Effect of moisture content on the shelling efficiency

3.3. Effect of moisture content on the cleaning efficiency

The effect of moisture content on the cleaning efficiency is shown in Figure 7. It can be seen that the relationship between the cleaning efficiency and the moisture content is quadratic. There is also optimal moisture content on the curve where the machine will be able to shell the *Jatropha curcas* seed with a high cleaning efficiency. The research results of Aremu et al. (2015) corroborate this finding when they reported a sinusoidal relationship between moisture content and cleaning efficiency of a *Jatropha curcas* seed shelling machine. The minimum moisture content can be determined by taking the slope of the tangent on the curve between 6.8− 8.5 % (wb) whereas the maximum moisture content is found between 10.5− 12.5 % (wb).

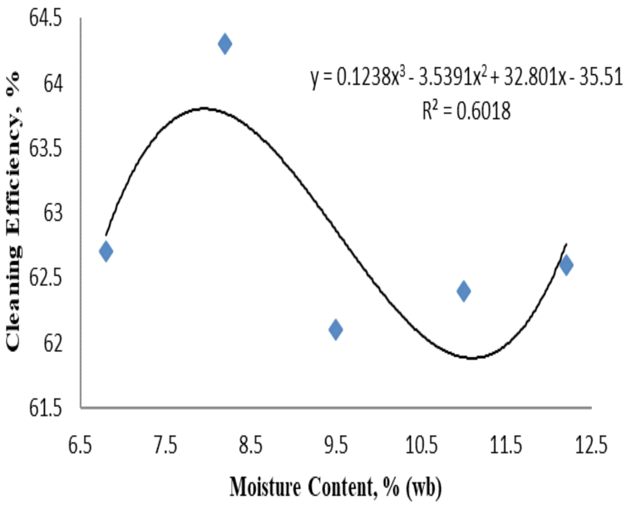

Figure 7: Effect of moisture content on the cleaning efficiency

4. Conclusion

A small-scale machine was developed for shelling *Jatropha curcas* seed shells at different moisture contents. The shelling and cleaning efficiencies decreased with an increase in the moisture content of the seed. The machine efficiency also decreased with increase in the moisture content. The highest shelling, cleaning and machine efficiencies were found to be 77%, 63% and 35% at the 6.8% (wb), respectively. The machine required 1 HP electric motor to drive the shelling and the cleaning units. The overall cost of the machine was ₦ 103,350, and this far less than the cost of the previous designs. The machine can therefore be used for Jatropha seed shelling at different moisture contents.

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