



DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A MUCUNA BEAN SEED CRACKER

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A cracking machine was developed for Mucuna bean seed. Design considerations and calculations were made using relevant equations and data from some engineering properties of the seed. A 2 hp electric motor running at a speed of 1400 rpm was used to transmit power to the gear mechanism. The cracker was fabricated using locally available materials to promote the possibility of replacing damaged parts. The performance of the machine was evaluated at various moisture levels since traditional post-harvest processing of the seed is moisture-dependent. The feed rate of the machine decreased as the moisture level increased. A significant decrease of 17.31 % was observed across the various moisture levels tested as the feed rate of the machine decreased from 8.01 to 6.59 kg/hr. At a moisture content level of 5.31 % (dry basis), the throughput capacity of the machine was obtained as 12.02 kg/hr, while between 9.14 to 11.52 % moisture content, it decreased by 3.5 %. The efficiency of cracking of the seed increased from 56.6 to 66.1 % as moisture content increased from 5.31 to 18.38 % (dry basis). The percentage of seed breakage also increased with moisture level. The seeds were observed to crack more efficiently when moisture was reduced. An average of 500 seeds were cracked within an hour, as against a minimum of 48 hours that would have been spent if the seeds were to be soaked in water before manual cracking.

1.0 Introduction

Mucuna Bean seed is a tropical tree crop widely available in Africa and Asia. It is harvested and consumed as food and used in the production of traditional medicine for treatment of kidney-related diseases, blood purification, expulsion of excessive gases, expelling of worms, menstrual cycle balance and blood pressure stabilization. The seed is harvested, processed, and utilized as a soap thickener, taste modifier and spice for confectionaries. After harvesting, the seeds are usually soaked in warm water for a period of two to four days, for effective moisture penetration and softening, before they can be manually cracked and utilized. The cumbersome process of traditionally processing the seed has resulted in increased loss of interest in processing and use of the oil seed, despite its huge nutritional and medical prospects.

A machine for cracking the seed was considered for development based on values of some engineering properties of the seed obtained and established machine design equations (Alonge and Etim, 2017). The machine was designed to evaluate the efficiency of cracking the seed in variation to moisture content since moisture plays a vital role in the traditional method of cracking the seed. Agricultural products can either be cracked in wet or dry form, depending on specific function (Antia *et al.*, 2014). Mahmoud and Elkaoud (2019) also highlighted the relevance of engineering properties of agricultural products in the design of processing machines.

Many authors have developed machines for cracking of different products such as dika nut (Owolarafe *et al.*, 2013), palm nut (Ibikunle *et al.*, 2018) and Basreng (Ripitani *et al.*, 2022) etc. A decorticating machine for *Delonix regia* was developed to advance the course for research into the huge nutritional and medicinal benefits of the seed (Ojolo *et al.*, 2019). Preliminary studies revealed that the force required to break the pod was 1360 N. The power rating was 6 kW, and the seed recovery efficiency was 98.4 %, while the throughput capacity was obtained as 56.4 kg/hr. An almond kernel extraction machine was designed, and a compression test machine was used to determine the force required to crack the seed (Marey *et al.*, 2017). The compressive force measured, was instrumental to the design of the cracker as it gave the maximum permissible load.

Oduma *et al.* (2016) designed a hand-fed motorized machine for slicing oil beans. Some of the factors considered were the physical and mechanical properties of the seed; mechanical properties of the construction materials; machinability of construction materials, availability of materials and cost. A shelling machine was developed for groundnut (Alonge *et al.*, 2016; Alonge *et al.*, 2017). The incorporation of a separation unit into the system increased the efficiency of the machine.

Hussain *et al.* (2018) developed a cracking machine for walnuts. Relevant equations were used to design the frame, hopper, shaft, belt length, safe stress of the belt, and power required by the machine for operation. A cracking machine for cashew nuts was developed (Ojolo and Ogunsina, 2007). The percentage of whole kernels produced and the capacity of the machine were estimated as 66.60 % and 18.3 kg/hr respectively. A shelling machine was designed and developed for cashew nuts (Ojolo *et al.*, 2009). The throughput capacity, shelling efficiency and whole kernel recovery were obtained as 15.57 kg/hr, 95 % and 70 % respectively.

A review of shelling, threshing, dehulling and decortication machines for Agricultural products was done to highlight new frontiers in the development of processing machines (Aremu and Fadele, 2018). A *Thevetia* Nutcracker was developed and the optimum cracking efficiency and throughput capacity were evaluated as 96.65 % and 8.5 kg/hr (Odewole and Ajibade, 2015).

Sharifian *et al.* (2008) developed a walnut cracking machine based on some information from the mechanical properties of the fruit. The maximum cracking force and power required were 797 N and 1.99 Watts respectively. In designing the cracker, they reported that the cracking efficiency of the machine is a function of the moisture content of the nut. A similar trend was reported for a Palm Kernel Briquetting Machine (Onyenwoke and Simonyan, 2013). Properties influencing the cracking and separation of palm nuts were studied (Olaoye and Adekande, 2018). Moisture content had a significant effect on the performance of the machine.

A dual-purpose palm nutcracker was developed and tested for performance at various moisture levels (Bamboye and Sadiku, 2003). The machine gave output capacities of 90.4 kg/hr for motorized and 19.8 kg/hr for the manually operated cracker. Ibrahim *et al.* (2016) in examining the performance of a shea nut sheller observed that the feed rate of the machine reportedly varied with the moisture content. This agrees with the assertion by some authors that the moisture content of the product affects the performance of machines meant for processing (Aremu *et al.*, 2015; Sanusi *et al.*, 2019; Busari *et al.*, 2019; Ndukwu *et al.*, 2019). Khairy *et al.* (2015) highlighted the need to have fair knowledge of the moisture content of an agricultural product before designing its processing machine.

Fadele and Aremu (2016) developed a shelling machine for *Moringa oliefera* seed. They reported that as the moisture level of the seed increased from 8.43 to 34.59 % (wet basis), the maximum machine capacity and efficiency of shelling and overall efficiency were obtained as 5.39 kg/hr, 86% and 57.98 % respectively. The selection of materials for construction for most of the machines was based on durability, suitability, strength, availability, and cost. The development

of a suitable technology is key to addressing challenges limiting the efficient post-harvest processing of Agricultural products (Ritanti *et al.*, 2022). Moisture also plays a critical role in the post-harvest processing of the seed since it is usually soaked in warm water for days as shown in Figure 1, before it could be manually cracked.

This study aimed to put a novel idea into the works by developing a machine for the cracking of Mucuna bean seed, evaluating its performance, and investigating the effect of moisture content on the cracking of the seed.



Figure 1: Mucuna bean seed soaked in water for manual cracking

2. Materials and Methods

2.1 Design Considerations

Some physical and mechanical properties of the seed were considered in designing the hopper and discharge chute of the machine. The force required to crack the seed under static load was obtained through a compression test using a Universal Testing Machine (UTM – Instron 3382, 100 KN Floor Model) at the Central Engineering Workshop of Akwa Ibom State University, Nigeria. The force required to break the seed on its major and minor axes were 1,500 and 250 N respectively. The cracker was fabricated using locally available materials to promote the possibility of replacing damaged parts with locally available ones in the market. The total cost of producing the machine was one hundred and fifty thousand naira, equivalent of \$ 200.

2.2 Description of the Machine

The cracker was made of two rotating drums, sprockets, a belt, a pulley, and a gear mechanism. The gear mechanism served as an intermediary between the power transmission system and the drive mechanism. One of the drums was attached to a shaft and was rotational, while the other was stationary. The rotating drum had splines attached around its surface. Fifty per cent of the major diameter of the seed was used as the thickness of each spline. The drums were mounted in such a way that enabled them to rub against each other when rotating. The essence of employing the gear mechanism was to ensure control of the speed of the rotating drum, and to limit impact when the two drums come in contact, thus mitigating against opportunity for increased damage to the seeds. Power was transmitted from the electric motor to the gear mechanism by a v-belt arrangement. The transmission between the gear train and the rotating shaft was aided by a chain drive. The main frame was made of mild steel. Exploded and orthographic views of the machine are shown in *Figures 1, 2 and 3*.

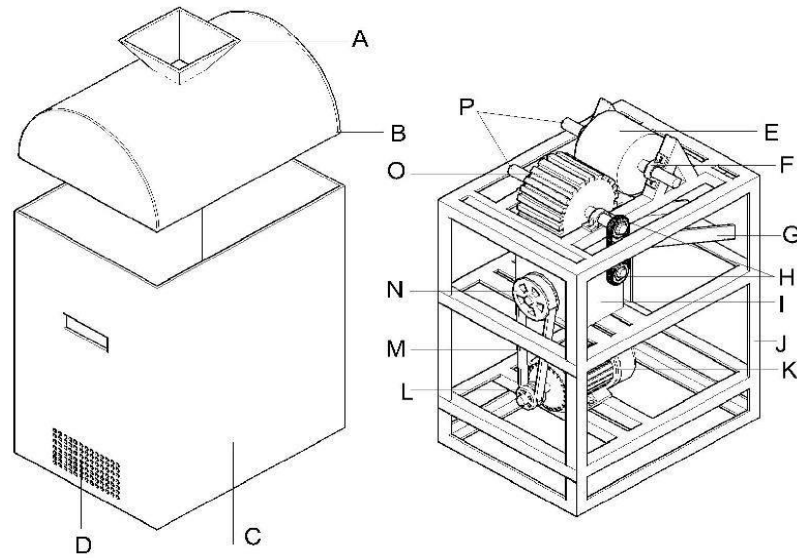


Figure 1: Exploded view of the machine

Legend:

- | | | | |
|---|---------------------|---|----------------|
| A | Hopper | I | Gear |
| B | Rotating Drum Cover | J | Ankle Bar |
| C | Metal Sheet | K | Electric Motor |
| D | Air Duct | L | Driving Pulley |
| E | Stationary Drum | M | Belt |
| F | Coupling Flange | N | Driven Pulley |
| G | Discharge Outlet | O | Driving Drum |
| H | Sprocket | P | Shaft |

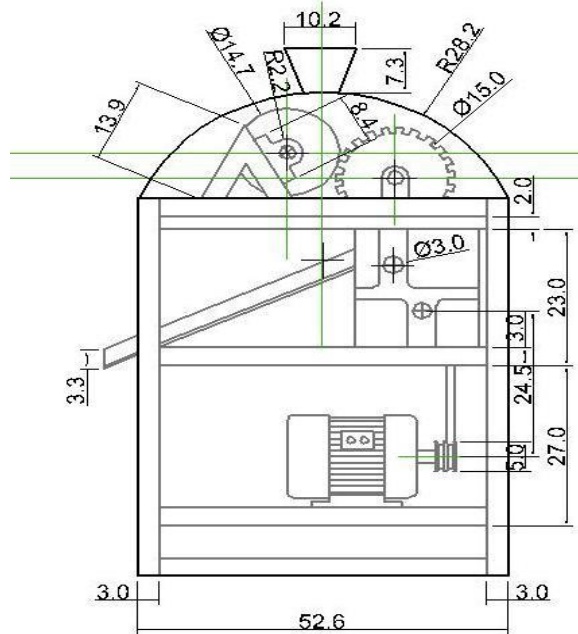


Figure 2: Side view of the machine (from 1st angle)

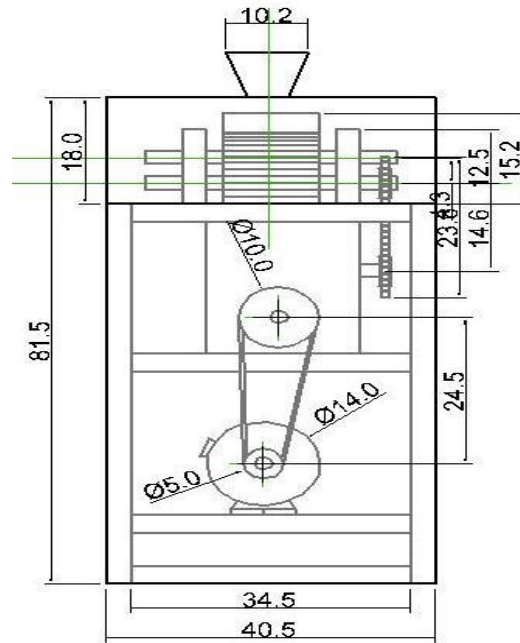


Figure 3: Side view of the machine (from 3rd angle)

2.3 Design Analysis

2.3.1 Shaft Design

Torque transmitted by the shaft (T) and the diameter (d) of the drive shaft were obtained using the equations (1) and (2) respectively as developed by Khurmi and Gupta (2018):

$$T = \frac{60P}{2\pi N} \quad (1)$$

$$d^3 = \left(\frac{16T}{\pi\tau}\right) \quad (2)$$

The maximum permissible stress shear stress (τ) was taken as 42 Mpa (Mega Pascal). The diameter of the shaft (d) was obtained as 15 mm (Millimetre) and $\pi = 3.142$.

2.3.2 Belt Design

The length of the belt

$$L = \frac{\pi(D_1 + D_2)}{2} + 2x + \frac{(D_1 - D_2)^2}{4x} \quad (3)$$

D_1 is the diameter of the bigger pulley, given as 80 mm, while D_2 is the diameter of the smaller pulley, given as 76 mm, while x is the centre distance between the two pulleys (270 mm). The length of the belt was obtained as 786 mm.

The angle of contact of the belt and pulley was derived from the equation below (Khurmi and Gupta, 2018).

$$\theta = (180 - 2\alpha) \frac{\pi}{180} \text{ rad} \quad (4)$$

$$\text{Where, } \sin\alpha = \frac{r_1 - r_2}{x} \quad (5)$$

The angle was obtained as 3.13 rad.

Tensions on the tight side (T_1) and slack side (T_2) of the belt T_1 were obtained by use of the equation 6 (Khurmi and Gupta, 2018).

$$P = (T_1 - T_2)v \quad (6)$$

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu\theta \quad (7)$$

where, v = velocity of the belt (m/s), θ = Angle of wrap ($^\circ$) and μ = coefficient of friction between belt and pulley.

2.3.3 Chain Design

The rotation speed of the smaller sprocket (N_s) was determined using equation 8:

$$\frac{N_b}{N_s} = \frac{D_B}{D_s} = G.R. \quad (8)$$

N_b was the rotation speed of the smaller sprocket (1400 rpm) and the gear ratio was taken as 3:1. The rotation speed of the larger sprocket (N_s) was obtained as 491.3 rpm. The velocity ratio was obtained as 3. Computing the larger sprocket teeth number was done using equation 9:

$$T_2 = T_1 \left(\frac{N_b}{N_s}\right) = G.R. (\text{Gear Ratio}) \quad (9)$$

The number of teeth (T_1) for a velocity ratio of 3 for a roller chain was as specified is 25 (Khurmi and Gupta, 2018). A value of 75 was obtained as the number of teeth of the larger sprocket. The design power (P_d) was obtained from the relation below (Khurmi and Gupta, 2018).

$$P_d = \text{Rated Power}, P \times \text{Service Factor}, K_s \quad (10)$$

The service factor was computed as the production of various factors (K_1 , K_2 and K_3). Where K_1 was the load factor, taken as 1.25 because the expected load was with mild shock; K_2 = lubrication factor, taken as 1, because of routine lubrication of the chain mechanism. K_3 = Rating factor, taken as 1, because the machine was assumed to be used for a maximum of eight hours per day.

$$K_s = K_1 \times K_2 \times K_3 = 1.25 \times 1 \times 1 = 1.25$$

The design power was obtained as 1.87 kW.

The choice of the chain was made with reference to the standard table established by the AMSE code for chain drives. The speed of the bigger sprocket (1400 mm) was constant with a No. 6 chain at 2.73 kW (relatively higher than the design power given as 1.875 kW). Thus a No. 6 chain with strands was used to transmit the required power.

The pitch of the chain, P_1 was obtained as 9.525 mm with reference to the standard table (Khurmi and Gupta, 2018). The roller diameter, d , was given as 6.35 mm. The minimum width of the roller, w , was obtained as 5.72 mm. The pitch diameter of the smaller sprocket, d , was obtained from equation 11 and 12.

$$d_1 = p \operatorname{cosec} \left(\frac{180}{T_1} \right) \quad (11)$$

$$d_2 = p \operatorname{cosec} \left(\frac{180}{T_2} \right) \quad (12)$$

Where T_1 and T_2 are number of teeth on the smaller and bigger sprocket respectively.

The pitch line velocity of the smaller sprocket, v_1 , was obtained from the expression below.

$$V = \frac{nD_1N_1}{60} \quad (13)$$

The pitch line velocity was obtained as 5.87 m/s

The load on the chain was obtained using equation 14.

$$W = \frac{\text{RatedPower}}{\text{Pitchlinevelocity}} \quad (14)$$

The load on the chain was obtained as 226.58 N.

The factor of safety was obtained using equation 15.

$$F_s = \frac{W_b}{W} \quad (15)$$

The value obtained for the safety factor (39) was more than the value specified for a 1400 rpm driven roller chain (Khurmi and Gupta, 2018). The minimum centre distance between the smaller and bigger sprockets was assumed to be 30 times the pitch. The centre distance between the sprockets was obtained as 285 mm. To accommodate the initial slag, the value of the centre distance was reduced by 5 mm. The number of chain links was obtained from the equation 16 (Khurmi and Gupta, 2018):

$$K = \frac{(T_1 + T_2)}{2} + \frac{2x}{P} + \frac{(T_2 - T_1)^2}{2\pi} \times \frac{p}{x} \quad (16)$$

The number of chain links was obtained as 54.7.

The length of the chain was computed using equation 17:

$$L = KP \quad (17)$$

Where, k , was the chain linkage and p , was the pitch diameter. The length was obtained as 58.7 mm.

2.4 Moisture Content (M.C.) of the product used for evaluating the performance of the machine:

The moisture content (% dry basis) of the seed used for performance evaluation of the machine was obtained using equation 18.

$$\text{MoistureContent}(M.C.) = \frac{(w_1 - w_2)}{w_2} (\% \text{ dry basis}) \quad (18)$$

W_1 was the initial weight of the seed and W_2 was the final weight of the seed after drying.

2.5 Performance Evaluation of the Machine

The feed rate of the product to the machine, throughput capacity of the machine, cracking efficiency and percentage of seed breakage were evaluated using equations 19, 20, 21 and 22 respectively.

2.5.1 Feed Rate:

The feed rate of the seed in the machine was calculated using equation 19.

$$F_r = \frac{W_t}{T_c} \text{ (kg/hr)} \quad (19)$$

W_t was the Weight of the seed that filled the hopper (kg) and T_c was the time taken to empty the whole seed into the cracking chamber (hr)

2.5.2 Throughput capacity:

Throughput capacity of the machine was calculated used equation 20.

$$C_t = \frac{W_t}{T_d} \text{ (kg/hr)} \quad (20)$$

T_d was the total time taken by the cracked mixture to level the discharge outlet (hr).

2.5.3 Efficiency of Cracking:

The efficiency of cracking was determined using equation 21.

$$E_c = \left(\frac{W_t - W_n}{W_t} \right) \times 100\% \quad (21)$$

W_n was the weight of partially cracked and un-cracked Mucuna seeds (kg)

2.5.4 Percentage of seed breakage (P_{bk}):

The percentage of seed breakage was calculated using equation 22.

$$P_{bk} = \left(\frac{C_d}{C_d + C_u} \right) \times 100\% \quad (22)$$

C_d was the weight of Cracked and damaged seed (kg) and C_u weight of cracked and undamaged seed (kg)

3.0 Results and Discussion

3.1 Performance Testing

The machine was tested at various moisture levels and the results obtained are presented in Table 1.

Table 1: Performance evaluation of the machine

Moisture content dry basis (%)	Feed rate (kg/hr)	Throughput capacity (kg/hr)	Efficiency of cracking (%)	Percentage of seed breakage (%)
5.31	8.01	12.02	56.60	60.34
9.14	7.52	11.29	60.19	63.33
11.52	7.26	10.89	61.80	64.20
14.53	7.01	10.51	62.76	66.82
16.31	6.67	10.00	64.1	67.4
18.38	6.59	9.88	66.1	69.60

From the results obtained, the feed rate of the machine decreased as the moisture content of the seed increased. At the various moisture levels, a decrease of 17.31 % was recorded as the feed rate of the machine decreased from 8.01 to 6.59 kg/hr. This was responsible for the easy flow of the seed when loaded on the hopper. A mathematical relationship linking the two variables was established in Equation 23.

$$F_r = 8.561 - 0.11m \text{ (} R^2 = 0.987 \text{)} \quad (23)$$

The throughput capacity also decreased with increasing moisture levels. At a moisture level 5.31 % (dry basis), the throughput capacity of the machine was obtained as 12.02 kg/hr, while between 9.14 to 11.52 % (dry basis), it decreased by 3.5 %. The throughput capacity decreased from 10.51 to 9.88 kg/hr as moisture content increased from 14.53 to 18.31 % (dry basis). The efficiency of cracking of the seed increased with increasing moisture content. The result obtained ranged from 56.6 to 66.1 % as moisture level increased from 5.13 to 18.38 %. The range of value was slightly less than what was obtained for a cashew nutcracker (Ojolo et al., 2009) and a Walnut cracker (Antia et al., 2014). It was however higher than what was obtained (Alonge et al., 2016) for a Bambara groundnut sheller (7.5 kg/hr). It was observed that the seeds tend to crack more efficiently when dried than wet owing to loss of moisture. The increased amount of moisture toughens the seed initially, though it gets softened after a minimum of two days. A relationship between moisture content and throughput capacity was obtained as in Figure 4. The high coefficient of correlation obtained in Equation 24, shows a strong relationship between moisture content and the throughput capacity.

$$C_{th} = - 0.166m + 12.85 (R^2 = 0.988) \tag{24}$$

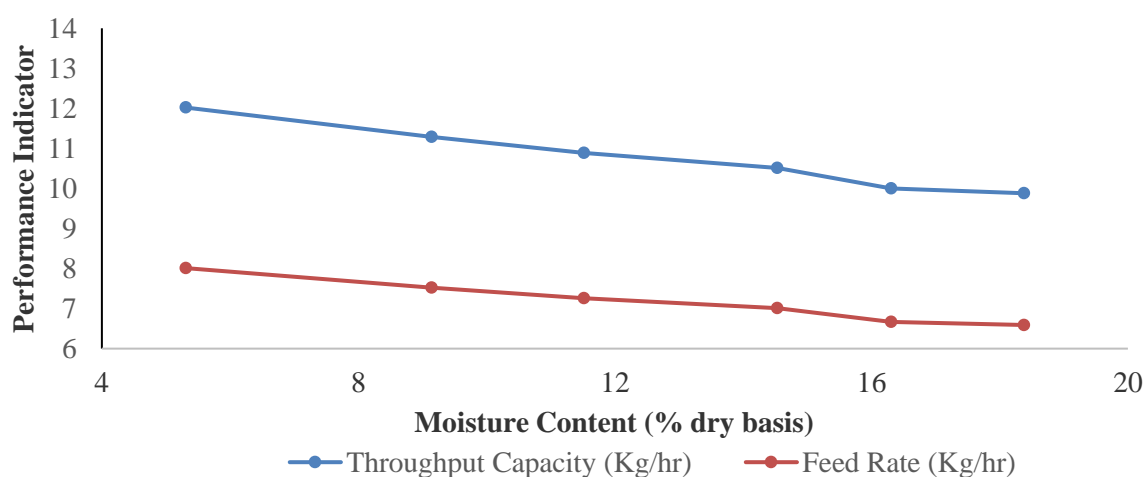


Figure 4: Relationship between moisture content and throughput capacity and feed rate

The percentage of seed breakage showed a positive correlation with moisture level. This was evident in the high R^2 value obtained from a mathematical relationship established for the two factors as presented in Equation 25. Some cracked samples of the seeds and pods are shown in Figure 4.

$$E_{sbr} = 0.680m + 56.75 (R^2 = 0.982) \tag{25}$$



Plate 2: Cracked Mucuna bean seeds with pods

The percentage of seed breakage increased with moisture content. At the various moisture levels tested, a variation of 13.3 % was recorded. The efficiency of the machine to crack the

seed was higher as the product moisture level increased. The values ranged from 56.6 to 66.1 % as captured in Figure 5. A mathematical relationship linking the moisture level of the seed and the cracking efficiency of the machine was established in Equation 26.

$$E_c = 0.672m + 53.49 \quad (R^2 = 0.976) \quad (26)$$

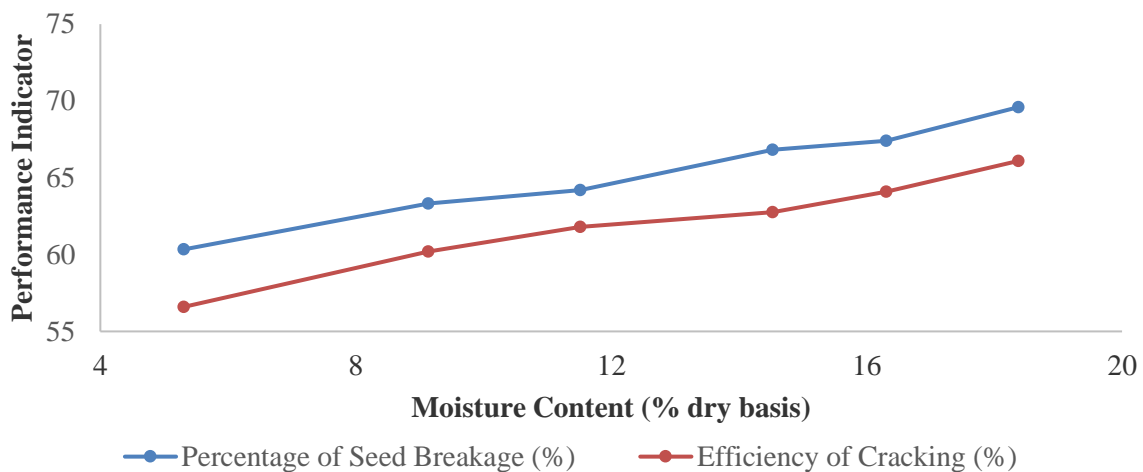


Figure 5: Relationship between moisture content and percentage of seed breakage and cracking efficiency

The range of values obtained was lower than what was obtained for a cashew nutcracker (Ojolo and Ogunsina, 2007), but higher than what was reported for a shelling machine of *Moringa oleifera* seed (Fadele and Aremu, 2016). The seeds were observed to have cracked more efficiently when moisture was reduced. An average of 500 seeds were cracked within an hour, as against a minimum of 48 hours that would have been spent on the same quantity if the seeds were to be soaked in warm water and cracked manually as confirmed by local food processors in the study area.

4. Conclusion

The economic potential of *Mucuna* bean seed is enormous and the development of machines for its processing is of huge significance. This research was an attempt to develop a cracking machine that would limit the time taken to manually crack the seed. The machine was tested for efficiency at various moisture levels of the seed ranging from 5.31% to 18.38% (dry basis). The efficiency was highest (66.10%) at a moisture content of 18.38%, indicating the seed will crack more efficiently if its moisture content is increased (dry basis). The feed rate and throughput capacity of the machine decreased as the moisture level of the seed increased. The percentage of seed breakage increased from 60.34 to 69.60 % within the tested moisture levels. The cracker is recommended for low-income farmers, who need available technology to enable easy processing of the seed, against the conventional manual method which involves soaking in water for days. Further development and optimization of the bean cracker should be considered to cover a range of speed (rpm) and other factors, to improve the capacity and efficiency of the machine.

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Conflict of Interest

The author wishes to state that there is no competing interest associated with the publication of the findings from the study.

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