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DESIGN AND DEVELOPMENT OF A TABLE MOUNTED MANUAL SEED CRACKING MACHINE FOR A HARD SEED (DEOCLA REFLEXA HOOK F)

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Abstract: Dioclea reflexa seed is a non-conventional seed widely used in the south-eastern Nigeria for culinary and herbal purposes. In using it for these purposes, cracking of the seed to expose the cotyledon is a necessity. However, the seed is seen as one of the hard seeds difficult to crack manually. This work hereby presents the conceptual solution and the fabricated prototype of the manually operated machine to efficiently and safely crack the seed. The design concept involved pushing the seed into a converging passageway with the attendant reaction of the narrowing space-seed interface developing a force that will eventually crack the seed. The machine developed, which also serves as a proof of the concept was fabricated from mild steel using established methods of metal fabrication. The machine prototype was evaluated for seed cracking efficiency as well as the perceived ease of use by operators. Results shows that the machine achieved 96% cracking efficiency and the average response of the test subjects invited to operate the machine was that it is easy to operate.

Keywords: *Dioclea reflexa seed, seed cracking machine, Agbaarin, Ukpo, cracking force, seed deformation rupture*

1. INTRODUCTION

Dioclea reflexa seed is known by several vernacular names across the globe. Some of them are Marble vine, Sea purse, Agbaarin (Yoruba language), Ufor or Ukpo (Igbo), and Bonkele (Lingala) (Olukayode, Alade & Oyelami, 2022), (Ajatta et al., 2019), (Ajayi, 2014). Its full botanical name is Dioclea reflexa Hook F. The seed's natural habitat is the tropical region of the Caribbean, South America, and the West Africa. Researches related to the seed had demonstrated its pharmaceutical, industrial, and dietary usefulness (Ajatta et al., 2019), (Ajayi, 2014), (Mbah et al., 2022). The seeds are widely used in the southeast of Nigeria for culinary purposes as food thickener and as a raw material for traditional herbal medicine (Ajatta, et al., 2019), (Ajayi, 2014), (Mbah et al., 2022). It is regarded as a hard seed to crack. Processing the seeds for domestic use usually involved the need to crack the seed in order to access the cotyledon. The common method of doing this is to manually crush the seed in between two stones. This is tiring and dangerous, hence the need to have a seed cracking machine purposely design for cracking the seed in a safe and less tasking manner.

2. ENGINEERING PROPERTIES OF DIOCLEA REFLEXA SEED

Designing the seed cracking machine involved the determination of some physical and mechanical properties of the seed. The physical properties of interest for the seed in this design are seed linear dimensions (length, width, and thickness), sphericity value ϕ, and geometric mean diameter Dg. The required mechanical properties are seed cracking force, deformation of seed up to cracking point, as well as the coefficient of friction between the seed and the machine processing surfaces. The linear dimensions of the seed are as depicted in *Figure 1*. Mean values of L, W, T, Dg, and ϕ had been reported by (Olukayode, Alade & Oyelami, 2022) and are as reproduced in *Table 1*.

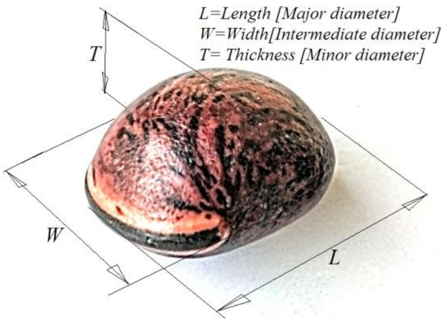


Figure 1. *Dioclea reflexa seed and it's linear dimensions*

Table 1
Physical properties of Dioclea reflexa seeds†
(Olukayode, Alade & Oyelami, 2022)

Physical properties	**Moisture content (% wet bases)γ**			
	4.8	7.2	9.5	12.1
Length, mm	31.01 (1.45)*	31.45 (1.34)	31.77 (1.54)	32.11 (2.17)
Width, mm	26.64 (1.24)	26.85 (0.83)	27.68 (1.36)	27.74(1.93)
Thickness, mm	21.75 (0.89)	21.7 (1.07)	21.395 (1.13)	21.21 (1.30)
Geometric mean diameter, mm	26.18(0.88)	26.36(0.80)	26.58(1.01)	26.62(1.45)
Sphericity, %	84.41(2.10)	83.93(2.69)	84.01 (3.14)	83.11(2.13)

† Measurement was made with 20 replicates. *Numbers in parenthesis are standard deviations.
γ Representing the percentage by weight of water content of the seed.

Table 2

Value of cracking forces and deformation to rupture for the three orientations on the universal testing machine

Seed No.	1	2	3	4	5	6	7	8	9	10	Mean
Axis along L											
Cracking force (kN)	1.25	1.50	1.45	1.60	1.55	1.26	1.55	1.60	1.15	1.15	1.41
Deformation (mm)	2.4	2.6	3.2	3.1	3.5	3.0	3.1	3.0	2.8	3.5	3.0
Length L, (mm)	31.0	30.2	31.1	29.1	31.4	30.0	33.2	33.8	29.1	29.4	30.8
Axis along W											
Cracking force (kN)	1.35	0.85	1.33	0.70	0.80	1.24	1.15	0.90	0.55	0.95	0.98
Deformation (mm)	1.5	1.5	1.5	0.7	1	1.5	3.5	0.8	0.7	2	1.5
Width W (mm)	26.1	26.7	26.8	26.6	29.5	27.1	25.6	29.0	25.5	24.2	26.7
Axis along T											
Cracking force (kN)	0.80	1.00	1.40	1.20	0.95	0.80	0.90	0.45	1.20	0.70	0.94
Deformation (mm)	0.7	0.7	1.0	0.8	0.8	0.9	1.1	1.1	1.3	0.8	0.9
Thickness T (mm)	19.5	19.4	22.3	22.6	19.9	20.4	19.3	20.3	18.4	19.2	20.1

Though (Olukayode, Alade & Oyelami, 2022) also investigated the rupture (cracking) force of the seed under various moisture contents, seed deformation up to rupture point was not reported. Also, there is no information on the coefficient of friction between the seed and metal surfaces of interest in their work or elsewhere in literature. Hence, there is a need to find the values for these parameters. The material chosen for the fabrication of the manual seed cracking machine was mild steel. Coefficient of friction (μ) between Dioclea reflexa seed and mild steel surface was determined using method described by (Fayed, El-Shal M. S. & Omar, 2020). The experiment was repeated five times and the mean value of μ was found to be 0.360. To determine the cracking force and deformation up to seed rupture, the method described by Olukayode, Alade & Oyelami (2022) was used for 10 seeds at 5.6% moisture content (wet basis) for each axis of compression along the length (L), width (T), and thickness (T) axes. Before compression, the seed linear dimension in the orientation of interest was measured using a digital vernier calliper and recorded. The results obtained are detailed in *Table 2*.

3. Design concept

The seed cracking machine was designed using the general procedure for machine design as outlined by Kayode, Adeleke & Alade (2020). The cracker was conceived as consisting of a solid smaller cylinder (A) with centre a and radius Ra rotating inside a hollow bigger cylinder (B) with centre b and radius Rb. The centres are non-centric *(Figure 2a)* and are referenced to a fixed outside point O. The solid smaller cylinder has a vane parallel to its axis. The seed, modelled as a sphere (C) with diameter d, is first put in the bigger space between the cylinders and then nudged towards the narrower space between the two cylinders by the vane when cylinder A is rotated in the anti-clockwise direction. The two cylinders are assumed to be non-deformable (rigid) and only the seed is deformable. The space separating the two cylinders constituted the machine's cracking chamber.

As the seed is pushed deeper by the vane into the narrowing space under force (Pn) due to torque (T), forces of reaction between the seed and the two adjacent cylindrical surfaces continue to build up until it reaches the cracking force value for the seed. At this point, the seed will no longer be able to sustain deformity in order to conform to the narrowing space and cracking of its shell will ensue. Necessity required that there must be an exit point for the seed to leave the chamber once it is cracked, and there must be an entry point to allow fresh seed to enter the chamber.

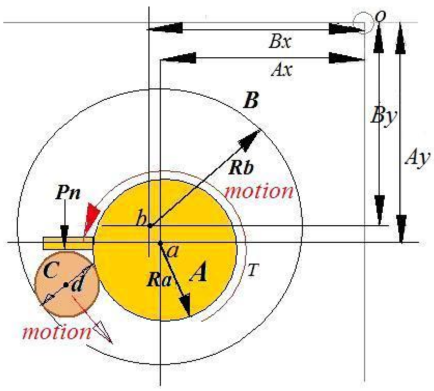


Figure 2a. *Initial design concept*

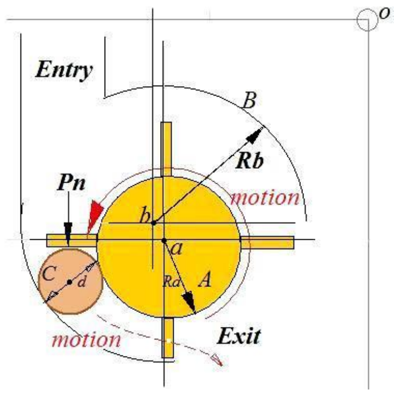


Figure 2b. *Final design concept*

Moreover, a single vane will not be efficient to continuously feed in fresh seeds and expel the cracked ones; hence multiple vanes are to be incorporated to the smaller cylinder. The vanes are spaced in such a way that each space between a vane and the next will only accommodate a single seed. The final conceptual configuration for the seed cracking machine is as depicted in *(Figure 2b)*. Modelling the seed as a sphere is justified due to the high degree of sphericity of Dioclea reflexa seeds at average value of 84% (0.84) *(Table 1)*. Sphericity is the measure of the degree of roundness of the seed. The shape with the maximum value of sphericity is the sphere with a sphericity value of 1.

4. DESIGN ANALYSIS

Referring to *Figure 3*, the forces acting on the seed are as depicted. The geometry of the cylinders and vane arrangements are such that at the beginning of cracking process, the seed will have three points of contact among the two cylinders surfaces and the vane, with the vane in horizontal position at the beginning of the cracking process. From the diagram *(Figure 3)*, line /ns1/and /ms1/ are tangential lines through points of contacts between the sphere (the seed), the inner cylinder (A) and the outer cylinder (B) curved surfaces respectively. Resolving forces parallel and normal to bisecting line /S1S2/ of angle (2y) formed by the two tangential lines, Pn is the normal force exerted by the vane (D) on the sphere C, Fc is the force of the outer cylinder on the sphere and FE is the force of the inner cylinder on the sphere. fuc and fue are frictional forces between the sphere and the cylinders.

For parallel resolution of forces with reference to line /S1S2/:

$$Pn\ CosB - Fc\ Cos\ a - FE\ Cos\ a - fuc\ Cos\ y - fue\ Cos\ y = 0 \tag{1}$$

(Equilibrium condition)

But fuc = μFc and fue = μFE, μ is the coefficient of friction.

$$Pn\ CosB - \ Cos\ a(F_C + F_E) - \mu Cos\ y(F_C + F_E) = 0 \tag{2}$$

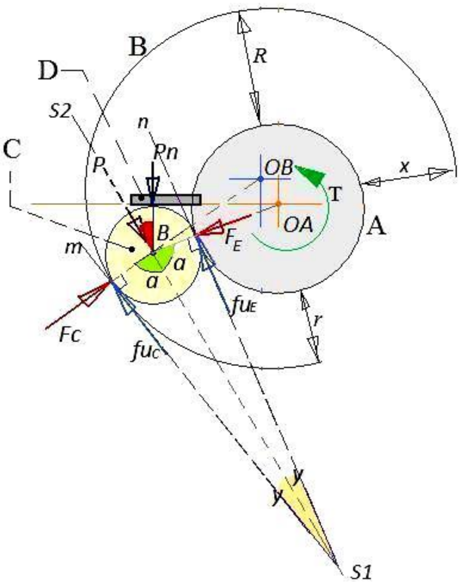


Figure 3. *Force Diagram*

$$Pn\ CosB = (F_C + F_E)(Cosa + \mu Cos\ y) \tag{3}$$

Note that $Pn\ CosB$ = P, the component force of Pn forcing the sphere further into the narrowing space.

For normal resolution of forces with reference to line /S1-S2/:

$$Pn\ SinB + F_E\ Sin\ a - Fc\ Sin\ a + fuc\ Sin\ y - fue\ Siny = 0 \tag{4}$$
(Equilibrium condition)

$$Pn\ SinB - Sin\ a\ (F_C - F_E)\ + \mu\ Sin\ y(F_C - F_E) = 0 \tag{5}$$

$$Pn\ SinB = (F_C - F_E)(Sina - \mu Sin\ y) \tag{6}$$

Divide (6) by (3):

$$\left(\frac{F_C + F_E}{F_C - F_E}\right) = \left(\frac{(Sina - \mu Sin\ y)}{(Cosa + \mu Cos\ y)}\right)\left(\frac{1}{Tan\ B}\right) \tag{7}$$

Referring to *Figure 3* again, R (the widest distance between the two cylinders) is defined by the expression:

$$L<R<2T \tag{8}$$

where L and T are the seed's length and thickness respectively as previously defined. This will allow the cracking chamber to accommodate the seed along its longest dimension, while also preventing two seeds form lying side-by-side in order not to choke the chamber. x is to be greater than d (the diameter of the sphere). This ensure the seed exited the chamber uncracked when the vanes are turned in the opposite direction of the recommended motion for cracking (i.e., anti-clockwise). r is defined by the expression:

$$r = T - \delta \tag{9}$$

where T is the seed's minimum thickness (18.4 mm from *Table 2*) and δ is the seed's maximum deformation up to cracking point (3.5 mm from *Table 2*). Finally, still referencing *Figure 3*, OA and OB are the centres of the smaller (A) and bigger (B) cylinders respectively.

Constructing *Figure 3* to scale and using pre-determined dimensions of 37 mm for diameter of cylinder A, 76 mm for cylinder B, 26 mm for sphere C (from geometric mean diameter on *Table 1*) and (50 mm, 50 mm) for coordinate of centre OA and (56 mm, 46 mm) for coordinates of centre OB with reference to O (see Figure 2 a), the values of angles a, B, and y was measured as 82o, 25o, and 7o respectively. Also taking Fc as 2.0 kN (design value for cracking force greater than the maximum of 1.6 kN as displayed in *Table 2*), FE and Pn were calculated as 1.21 kN and 1.76 kN respectively using Equations 6 and 7.

It should be noted that the spherical shape of the seed is only valid at the onset of cracking process, as the seed squeezed further into the narrowing space, it starts to deform to oblate form till it eventually cracked. Moreover, taking Fc as equal to cracking force at the beginning of the push by the vane of the seed is necessary to estimate the torque that must be supply via the machine crank arm by the operator in order to crush the seed. In reality, compression force progresses from zero until it

reaches a maximum value at the point where the seed cracked and the seed can no longer be assumed to be spherical. However, for sake of simplicity in estimating the torque required, the above analysis gives a reasonable approximation.
The torque T required is given by:

$$T = (Pn).(\gamma) \tag{10}$$

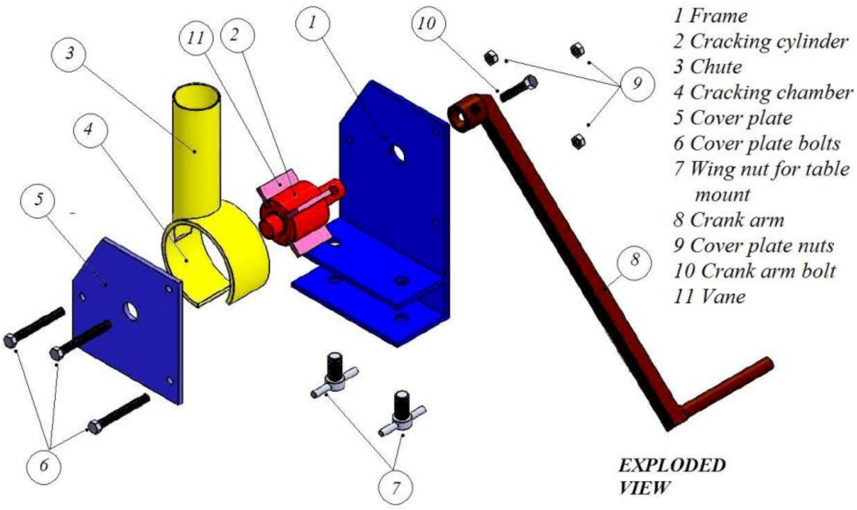
where γ is the perpendicular distance from centre OA of the smaller cylinder (A) to the point of action of force Pn in *Figure 3*. From the accurate geometric construction of *Figure 3* using aforementioned values, γ was 24 mm thus the minimum torque required to fracture the seed via cranking was 42.24 kNmm.

5. DESIGN AND DESCRIPTION OF THE SEED CRACKING MACHINE COMPONENTS

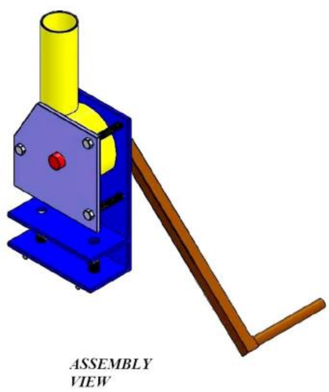
The SolidWorks rendering as well as picture of the seed cracker developed based on the previous discussion are as presented in *Figure 4*. The manual seed cracking machine components are:

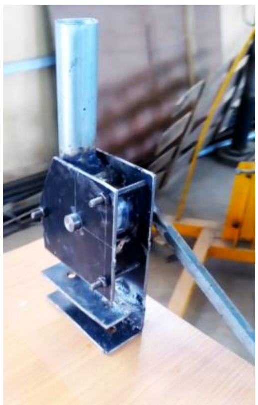
- *The Chute*, made from mild steel, is a hollow cylinder of internal diameter 35 mm, thickness 1 mm and length 154 mm positioned to supply seeds to the chamber at a tangent. The seeds are stacked one above the order in the chute and fed into the cracking chamber under gravity. The chute length allowed for up to a maximum of 10 seeds to be loaded at a time for continuous cracking. Internal diameter 35 mm was chosen to exceed the maximum seed dimension (*Tables 1* and *2*) and to allow for free movement of seeds, but not big enough to hold two seeds side-by-side which may leads to chocking of the chute.
- *Cracking chamber* is formed by a hollow cylinder of internal diameter 76 mm with cylinder thickness 3.5 mm and width 37 mm. A portion of the cylinder curve was removed to provide exit for the cracked seed while the chute interface with it at a tangent as depicted in *Figure 4a*. One end of the cylinder was welded at the rim to the frame in order to close it while the other end was sealed by a cover plate. Cracking chamber is equivalent to circle B in *Figures 2* and *3*.
- *The Frame* is as depicted in *Figure 4a*. It is fabricated from mild steel plate of thickness 4 mm. It was provisioned with hole of diameter 15 mm to carry one end of the cracking cylinder shaft. It also provided surface for attaching cracking chamber by welding and has holes for securing cover plate to cracking chamber via 3 pairs of bolts and nuts. Finally, it has provision for attaching the seed cracking machine to the table.
- *Cover Plate* seals the other open end of the cracking chamber cylinder. Hole of diameter 15 mm was drilled through it. The hole serves as the support for the other end of the cracking cylinder shaft. Additionally, three holes were drilled into it at specific positions to accommodate M8 bolts and nuts which secured it to the frame. The cover plate was made from a 4 mm thick mild steel plate.

– *Cracking Cylinder* is equivalent to circle A in *Figures 2* and *3*. It is to be produce from mild steel and it was designed to carry four vanes on its peripheral inserted into groves parallel to the cylinder axis. The cracking cylinder, being the active part of the machine can be failed by the shearing of the shaft from the cylinder body due to twisting *(Figure 5b)* or by the shearing of the shaft from the cylinder body due to bending force induced by the seed reaction force on the cylinder and the attendant reactions at the shaft supports *(Figure 5c)*.



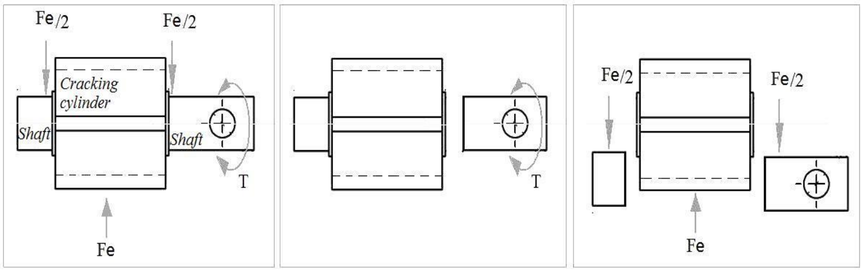
(a)





(b) *(c)*

Figure 4. *SolidWorks rendering of (a) the exploded view showing the components, (b) when assembled and (c) pictorial view of the completed machine*



(a) *(b)* *(c)*

Figure 5. *Modes of failure of Cracking cylinder*
(a) Forces and torque acting on Cracking cylinder,
(b) Shearing of shaft due to twisting,
(c) Shearing of shaft due to bending

(i.) Shearing of shaft due to twisting: the shear stress (τ) on the shaft due to twisting is given by the expression (Khurmi & Gupta, 2005);

$$\tau_t = \frac{16T}{\pi {d_s}^3} \tag{11}$$

the diameter (ds) of the shaft had been pre-determined to be 15 mm, and torque T expected from the crank is 45.76 kNmm, hence the value of τ_t is 0.064 kN/mm^2 (64 MPa) This is a very small value compared to the maximum shear strength for mild still of value 345-525 MPa (Designing Buildings, 2023). Thus, with the assumed value of shaft diameter, failure due to twisting forces had been eliminated.

(ii.) Shearing of shaft due to bending; considering *Figure 5c*, the maximum shear force on the shaft cylinder interface is Fe/2 (Fe is equivalent to F_E in *Figure 3*) which equals the reaction at the support. The shaft is in double shear. The shear stress induced is given by the expression (Khurmi & Gupta, 2005):

$$\tau_n = \frac{2Fe}{\pi {d_s}^2} \tag{12}$$

where d_s is the shaft diameter. Substituting the values of 1.21 kN for Fe and 15 mm for d_s, shear force due to bending is 0.0034 kN/mm^2 (3.4 MPa) this value is small compared to the maximum shear strength for mild still with value 345–525 MPa (Designing Buildings, 2023). Thus, with the assumed value of shaft diameter, failure due to bending forces had been eliminated.

– *The Vane* is a mild steel rectangular prism inserted, by employing interference fit, into the slots on the Cracking cylinder. The vane dimensions as fixed by the designers due to space constraint in the chamber are as shown in *Figure 6*. The failure mode for vane is by bending force induced on it by the resistance of the seed to being push into narrowing space of the cracking chamber. Referring to *Figure 6*, the bending stress on the vane due to force Fn is given by (13) (Khurmi & Gupta, 2005).

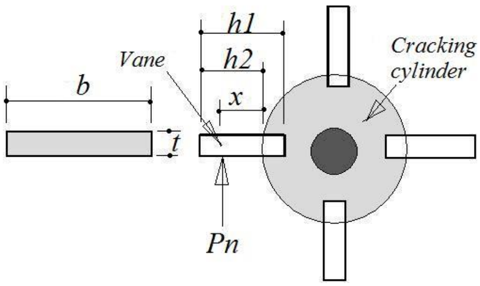


Figure 6. *Force acting on the vane*

$$\sigma = \frac{My}{I} \tag{13}$$

where M is the bending moment, y is the distance to the neutral axis equal to t/2, and I is the area moment of inertia given by (14) (Khurmi & Gupta, 2005).

$$I = \frac{bt^3}{12} \tag{14}$$

where b is the breadth (fixed at 34 mm), h_1 (fixed at 18 mm) is the overall width and, h_2 (fixed at 14 mm) is the width of the vane jutting out of the cracking cylinder curved surface and t is the thickness of the vane (fixed at 4 mm). The bending moment was calculated thus:

$$M = Pn.x \tag{15}$$

x was taken as 5 mm, thus substituting the values into Equations 13–15, σ is 0.095 kN/mm^2 (95 MPa). This value is lower than the allowable normal stress for mild steel which is 155–165 MPa in bending (Bengtsson & Whitaker, 1986).

– *The Crank Arm*: its primary purpose is to supply torque (T) as depicted in *Figure 3*. The length l of the crank was found using the relationship:

$$T = fe.l \tag{16}$$

where fe is the manual effort (in N) supplied by the seed cracking machine operator. The typical value recommended for human effort was taken as 100 N (Engineering Toolbox, 2023). Thus, putting the value of T and fe, the length of l was derived to be 420 mm (460 mm was used in the crank fabrication). The dimensions for the lever square cross-sectional area, the crank handle length and diameter were fixed based on the previous practical experience of the authors with similar design.

6. FABRICATION OF THE PROTOTYPE

The working drawings used in the fabrication of the seed cracking machine prototype which also served as a demonstration of the proof of concept are provided in *Figures 7–11*. Pictorial view of the fabricated seed cracking machine with cover plate removed to show the interior is as shown in *Figure 13*. The exploded isometric view showing how the components are to be assembled is shown in *Figure 14*. The bill of materials is contained in *Table 3*.

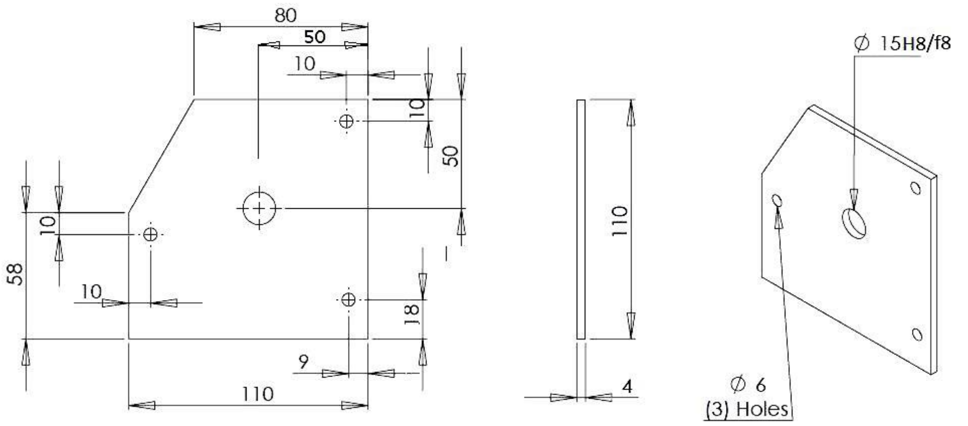


Figure 7. *Cover plate*

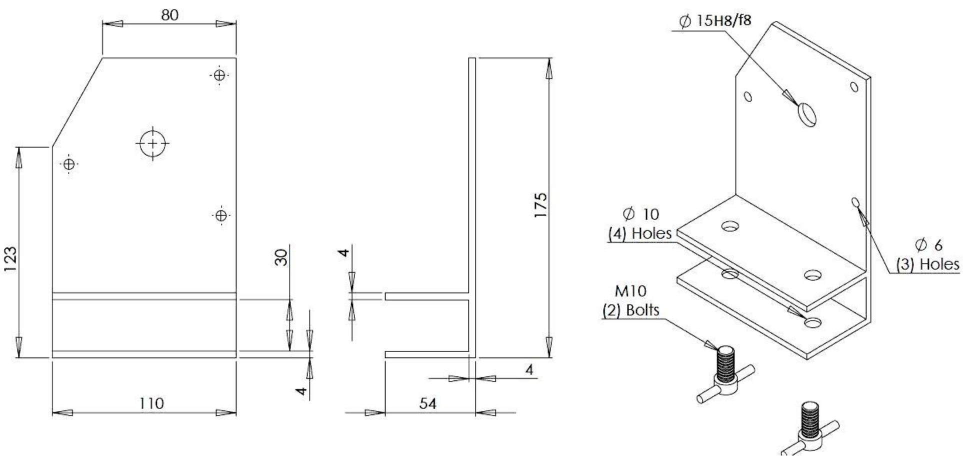


Figure 8. *The Frame*

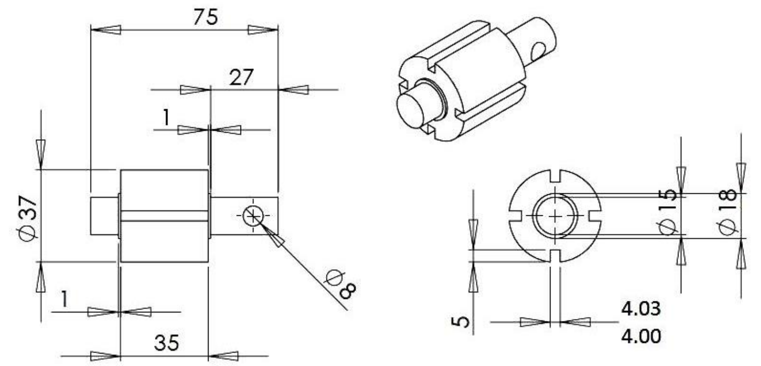
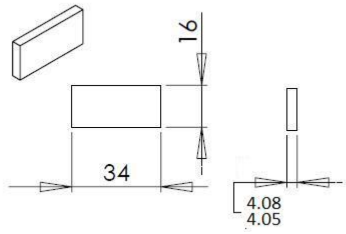


Figure 9. *Cracking cylinder*



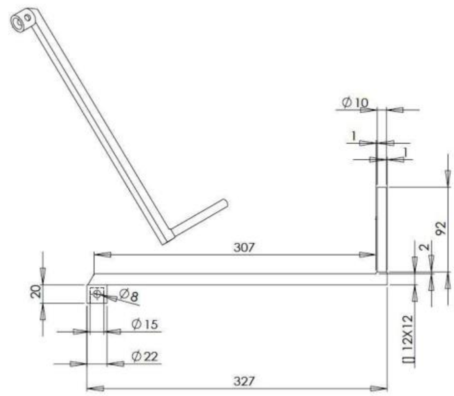
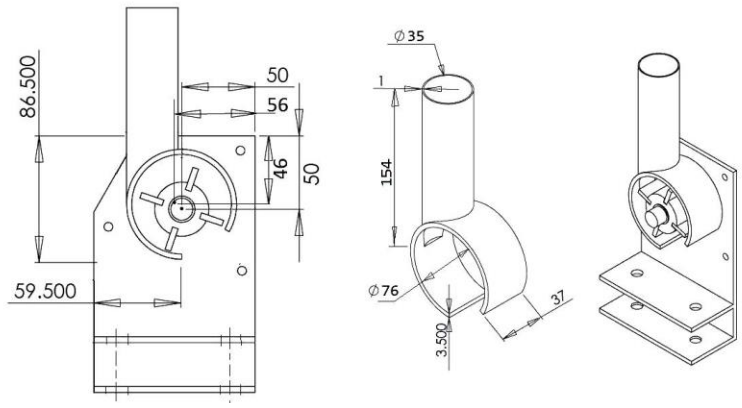


Figure 10. *The Vane* ***Figure 11.*** *The Crank*



(b) *(c)*

Figure 12. *Positioning of Cracking cylinder, Cracking chamber on Frame (a), isometric view of Chute and Cracking chamber as a single piece (b), and isometric view of (a)*

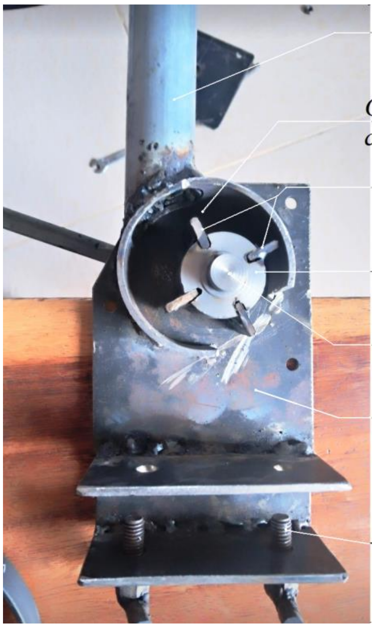


Figure 13. *Pictorial views of the fabricated seed cracking machine with Cover plate removed to show the Cracking chamber and Cracking cylinder*

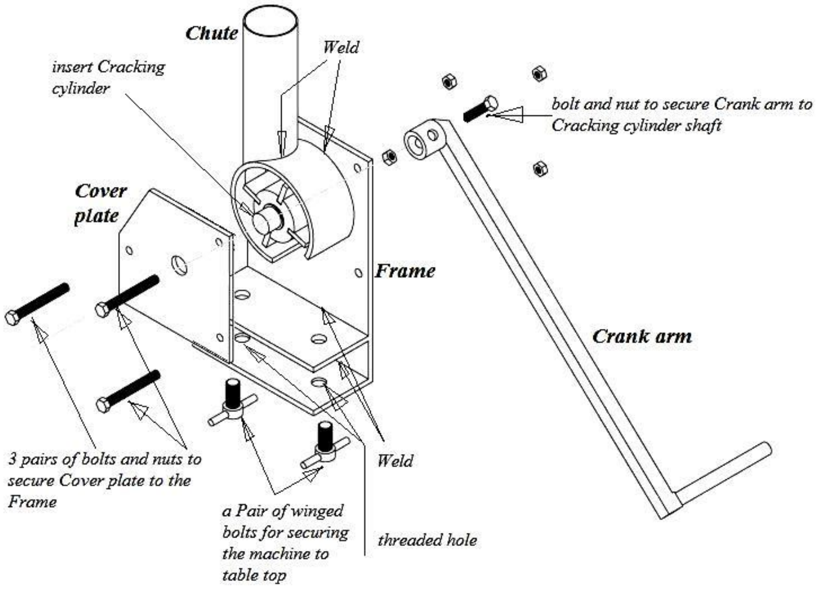


Figure 14. *Isometric view showing how the components are to be assembled*

Table 3
The Bill of materials

SN	Component	Quantity	Material
1	Chute	1	Galvanised Steel pipe
2	Cracking chamber Barrel	1	Mild steel
3	Cracking Cylinder	1	Mild steel
4	Vanes	4	Mild steel
5	Cover plate	1	Mild steel
6	Crank arm	1	Mild steel
7	Bolts and nuts	3 (pairs)	Hex head. M8 Grade 8.8 (ISO 4014)
8	Bolt and nut	1 (pair)	Hex head. M10 Grade 8.8 (ISO 4014)
9	Wing bolt	2	M10 Grade 8.8 (ISO 4014)

7. Evaluation of the prototype

The machine was evaluated based on (i) its seed cracking efficiency, and (ii) perceived ease of use by the user. The seed cracking efficiency (ηc) was defined as:

$$\eta c = \frac{Number\ of\ cracked\ seeds\ outputed\ from\ the\ machine}{Number\ of\ whole\ seed\ fed\ into\ the\ machine} \tag{17}$$

Ten seeds were fed to the chute at the beginning of each test run, the machine was then cranked. After the cracking process for the whole batch is completed, the output was visually inspected to identify the uncracked ones. Equation (17) was used to calculate the cracking efficiency for the trial run. The process was repeated for five separate seed batches. Average cracking efficiency for the five test runs was found to be 96%. Of the total of 50 seeds cracked, two exited the chamber uncracked. Checking their linear dimensions revealed that their thickness were 14.8 and 14.8 mm respectively. This is below the minimum of 15 mm which was the base value used for r *(Figure 3)* in the design. This explains the reason why they escaped cracking. *Figure 15* shows a seed sample before cracking and after cracking.

For the perceived ease of use, ten adults with age range 18 to 45 years, not familiar with where the machine was fabricated or who the designers are, were invited to operate the machine. Each was allowed three trial runs with three seed batches containing ten mature seeds each. At the end of the operations each participant was asked to judge the ease of operation of the machine based on Very Difficult to use (1 point), Difficult to use (2 points), Easy to use (3 points) and Very Easy to use (4 points). This method was based on 4-point Likert Scale. The even number Likert scale was deliberately employed to encourage the participants to make a decision after actually using the machine and to discourage indifference. Since the machine fabricated is the prototype, critical appraisal of its performance will be crucial for future improvement. From the analysis of the participants’ responses, the average of their point-based choices was found to be 3.1. This indicated that averagely, the participants find the machine Easy to use.

(a) *(b)*

Figure 15. *Machine with whole Deocla reflexa seed sample (a) Machine with the cracked product derived from the sample(b).*

8. SUMMARY

A hard seed (Dioclea reflexa Hook f.) cracking machine was conceived and developed based on the concept of forcing the seed though a narrowing rigid passageway until sufficient reactive force at the passage-seed interface cracks the seed. The concept was both graphically and mathematically analysed taking into consideration the seed's engineering properties. From the results of the analysis, a prototype of the machine was fabricated as a proof of concept and was evaluated for seed cracking efficiency and perceived ease of use by the users. Results indicated that the machine developed achieved 96% cracking efficiency and test subjects invited to operate the machine reported on the average that the machine was easy to use.

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